



VISION and STRATEGY

for the Development and Deployment of Advanced Reactors

FOREWORD

There has been increasing interest in advanced reactors, and for good reason. Advanced non-light water reactors can provide reliable, safe, clean energy as part of a mix with current technology nuclear, new large reactors and new small modular reactors. Multiple nuclear energy generating options will be needed as older plants are decommissioned and an expanded economy creates additional energy demand. This document provides a Vision and Strategy to support the development and deployment of advanced reactors as viable sources for future nuclear energy generation.

The U.S. Department of Energy (DOE), with stakeholder input, has developed a vision and goal for supporting the development and ultimate deployment of advanced reactor technology as part of a broader federal commitment to energy security, economic prosperity, and national security. The vision is that by 2050, advanced reactors will provide a significant and growing component of the nuclear energy mix both domestically and globally. In support, a goal has been established that by the early 2030s, at least two non-light water advanced reactor concepts will have reached technical maturity, demonstrated safety and economic benefits, and completed licensing reviews sufficient to allow construction to go forward.

To achieve this vision and goal, DOE's strategy for accelerating the development and deployment of advanced reactors includes six strategic objectives: making DOE capabilities more accessible to support nuclear innovation through the Gateway for Accelerated Innovation in Nuclear (GAIN), reducing technical risks, developing fuel cycle options, supporting licensing approaches, maximizing the effectiveness of public and private sector investments and developing the workforce.

This document describes our vision and strategy for supporting the development and ultimate deployment of advanced nuclear reactor technology. For more information and continuing updates on Department of Energy plans, programs, and activities, please visit our Web site, <http://www.nuclear.energy.gov>.

Office of Nuclear Energy
U.S. Department of Energy
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Vision and Strategy for the Development and Deployment of Advanced Reactors

EXECUTIVE SUMMARY

Increasing energy demand requires greater use of reliable energy sources in the United States and elsewhere. In particular, significant deployment of new energy sources will be needed by mid-century to meet expected energy demand of an expanding national and world economy. Nuclear energy currently provides about twenty percent of U.S. electricity, and approximately sixty percent of its zero-carbon electricity. The safe and secure use of nuclear energy could play an increasingly important role in achieving global energy needs in the coming decades while providing economically competitive, environmentally friendly, continuously available power. Deployment of new nuclear plants will contribute considerably to job growth in an expanding economy.

Given the number of nuclear plant retirements expected over the next few decades, however, sustaining a substantial nuclear presence in the U.S. power mix beyond 2050 will almost certainly require the development and deployment of a new generation

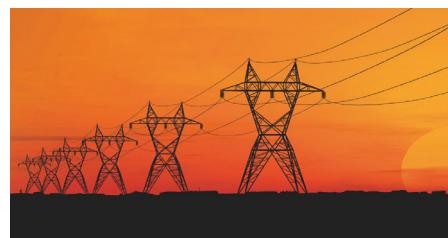
of advanced reactors. Advanced reactor concepts offer significant potential benefits, including possible lower costs, enhanced safety, greater resource utilization, waste minimization, co-production of process heat for industrial operations, improved proliferation resistance, and easier operation. By exercising a leadership role in advanced reactor technology development, the United States can continue to strive to ensure that national security objectives are embodied in new nuclear generation options for global energy needs. The U.S. Department of Energy (DOE), with stakeholder input, has developed a vision and strategy for supporting the development and ultimate deployment of advanced reactor technology as part of a broader federal commitment to energy security, economic prosperity, and national security.

Vision: By 2050, advanced reactors will provide a significant and growing component of the nuclear energy mix both domestically and globally, due to their advantages in terms of

improved safety, cost, performance, sustainability, and reduced proliferation risks.

Recognizing that the deployment of new nuclear technologies can take 15–20 years, DOE intends to place significantly increased emphasis on supporting private sector initiatives to advance a new generation of reactor concepts.

Goal: By the early 2030s, at least two non-light water advanced reactor concepts will have reached technical maturity, demonstrated safety and economic benefits, and completed licensing reviews by the U.S. Nuclear Regulatory Commission (NRC) sufficient to allow construction to go forward.



To achieve this vision and goal, DOE's strategy for accelerating the development and deployment of advanced reactors includes six strategic objectives:

1. Enhance the innovation infrastructure for nuclear technologies and vastly improve private sector access to DOE expertise and capabilities through the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative.

GAIN provides the nuclear community with access to technical, regulatory, and financial support with the aim of greatly accelerating the progress of new or advanced reactor designs from concept to commercialization. Specifically, GAIN provides a single point of contact for accessing critical experimental resources, computational capabilities and engineering expertise. GAIN was launched in collaboration with the DOE Office of Technology Transition's Clean Energy Investment Center, which is helping catalyze private sector investments into the energy sector.

2. Demonstrate performance, reduce costs, and retire technical risks for advanced reactors.

DOE will establish new mechanisms to work with private-sector partners to identify priority technology needs and fund research and development (R&D) efforts—both generic and design-specific—that are aimed at reducing technical risk, enhancing safety and security, accelerating development, and improving the economic competitiveness of advanced reactors.

3. Support the development of fuel cycle pathways for advanced reactors.

Working with industry to develop improved and advanced nuclear fuels is a major objective, both for existing light water reactors and for the entire spectrum of advanced nuclear energy systems. DOE's efforts in this area will focus both on ensuring that sustainable fuel cycle options that are consistent with U.S. nonproliferation objectives are available in the future, and on developing the technologies and capabilities needed to enable the safe and secure

storage, transportation, and disposal of used nuclear fuel and wastes from existing and future nuclear fuel cycles.

4. Support the establishment of an efficient and reliable regulatory framework for advanced reactors.

Industry experts consistently point to the need for an appropriate, efficient and predictable regulatory framework as a high priority for commercializing advanced reactor technologies. DOE and its stakeholders will work with the NRC as the NRC develops new regulatory processes, including efforts to develop design criteria for advanced reactors, staged licensing processes, and preapplication licensability review processes.

5. Maximize the effectiveness of public and private sector investments and explore policy incentives to aid the private sector in accelerating advanced reactor deployment.

Specifically, DOE would explore the use of public-private partnerships and technology-specific working groups to identify opportunities for potential government investment that could help advance multiple reactor concepts. In addition, DOE may explore the use of other appropriate incentives to support advanced reactor deployment in collaboration with the Department's Clean Energy Investment Center.

6. Address human capital and workforce development needs.

DOE plans to continue funding nuclear-related research projects, infrastructure improvements, and educational support through its Nuclear Energy University Program (NEUP).

The vision and strategy outlined in this document provide a guide to DOE's expected future programmatic efforts to support the development and deployment of advanced reactor concepts.¹



INL Human System Simulation Laboratory

¹This document articulates DOE's vision and strategy for accelerating the deployment of advanced reactors. However, nothing in this document represents or should be construed to represent a binding commitment or decision of DOE, nor should this document be construed as proposing legislation or funding in support of any of the activities, objectives, goals, or initiatives it describes.

Accelerating the Development and Deployment of Advanced Reactors

1. Introduction

Increasing energy demand requires greater use of reliable and environmentally friendly energy sources in the United States and elsewhere. In particular, significant deployment of new energy sources will be needed by mid-century to meet expected energy demand of expanding national and international economies. Nuclear energy, which currently accounts for about twenty percent of electricity production in the United States and approximately sixty percent of its zero-carbon electricity, could play a substantial and beneficial role on the scale necessary to support energy security needs by providing economically competitive, continuously available power. Deployment of new nuclear plants will contribute considerably to job growth in an expanding economy.

Given the number of nuclear plant retirements expected over the next few decades the nuclear energy industry faces substantial challenges. Due to current market conditions driven largely by record low natural gas prices, flat or declining energy demand, increasing nuclear operating costs, and other market forces, a number of nuclear plants have either already shut down or are at risk of early retirement, especially in restructured energy markets. Furthermore, based on current operating licenses, U.S. nuclear capacity will begin declining rapidly after 2030, even without early retirements. Further license extensions, together with deployment of new light water reactors (LWRs) and small modular reactors (SMRs) could potentially offset some of

this decline, but sustaining a substantial nuclear presence beyond 2050 will almost certainly require the successful development and deployment of a new generation of advanced reactors. These reactors, known as advanced reactors or Generation IV reactors² could offer significant potential benefits including possible lower costs, enhanced safety, greater resource utilization³, waste minimization, co-production of process heat for industrial operations, improved proliferation resistance, and easier operation.

Because various combinations of these attributes could make Generation IV reactors attractive for markets in the United States and internationally, advanced reactor technologies are already attracting interest, not only from the government sector, but also from the financial and commercial energy sectors. However, unlike LWR technology, which is largely proven, Generation IV reactors still need further demonstration of their performance characteristics and validation of their “value proposition” before broader deployment can occur.



²The evolution of nuclear energy technology is often described in generations. Most commercial reactors that are now in operation are considered Generation II technology. The new LWR plants that have been proposed or are currently under construction, including units at Vogtle and V.C. Summer, are considered Generation III+ technology. For further discussion of the differences between reactor technologies see “Nuclear Reactors: Generation to Generation” published by the American Academy of Arts and Sciences (<http://www.amacad.org/pdfs/nuclearreactors.pdf>).

³Resource utilization in this case refers to the efficient use of available nuclear materials to safely maximize energy output while reducing waste streams.

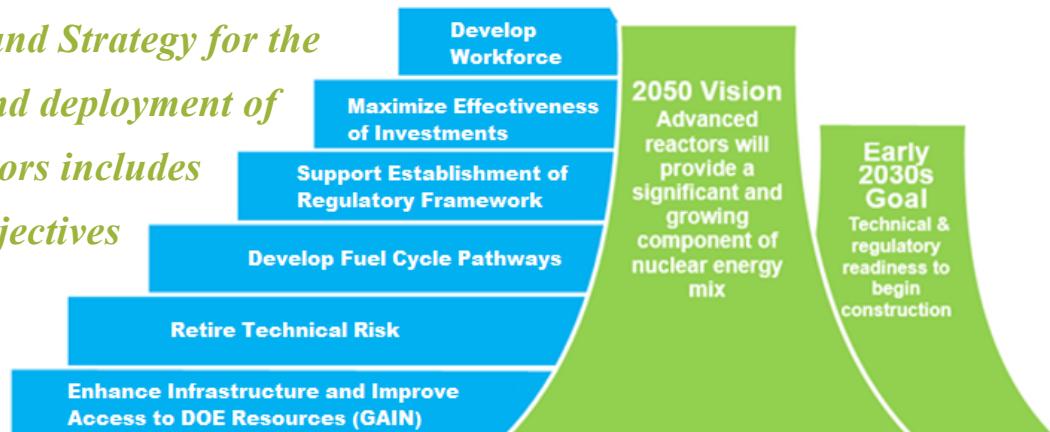
This document outlines the U.S. Department of Energy's (DOE's) vision and strategy for supporting the development and ultimate deployment of advanced reactor technology as part of a broader federal commitment to support deployment of nuclear technology as a viable energy option for the future by (1) supporting the safe, economic, and reliable operation of the current fleet of nuclear reactors; (2) pursuing the construction and operation of new large Generation III+ light water reactor designs; (3) supporting the development, licensing, and deployment of small modular reactors; and (4) implementing a strategy for the development and deployment of advanced, Generation IV reactor technology. This document and the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative are intended to be elements of DOE's efforts to communicate with industry, utilities, universities, nuclear organizations and stakeholders on DOE's actions to support development and deployment of advanced reactors as options to meet the country's energy generation needs.

This Vision and Strategy supports the DOE Office of Nuclear

Energy mission to advance nuclear power as a resource capable of meeting the nation's energy, environmental, and national security needs.

This document is organized as follows: Section 2 reviews the larger policy context for federal investment in a new generation of nuclear reactor technology. Section 3 provides status and prospects for large LWRs and SMRs. Section 4 reviews the goals and objectives of DOE's advanced reactor strategy and describes specific action DOE is taking or may consider to enhance and improve access to its nuclear innovation capabilities, demonstrate performance and retire technical risk for advanced reactor concepts, develop associated fuel cycle pathways, support the NRC in addressing regulatory challenges, maximize the effectiveness of public/private-sector resources and capabilities, and provide for human capital and workforce needs.

DOE's Vision and Strategy for the development and deployment of advanced reactors includes six strategic objectives



2. Policy Context for DOE's Advanced Reactor Technology Strategy

To understand the importance of nuclear energy and the need for continued investment in the development and deployment of improved nuclear technologies, it is useful to examine nuclear energy's place in America's overall energy portfolio, today and into the future. Nuclear energy safely, reliably and economically contributes about 20% of U.S. electricity production. The nation's current fleet of 99 commercial reactor units has a combined capacity of 100 gigawatts (GW) and operates at an average capacity factor of 91%. Nuclear power remains the single largest source of carbon-free energy in the United States at present, accounting for approximately 60% of non-greenhouse-gas-emitting electric power generation nationwide.

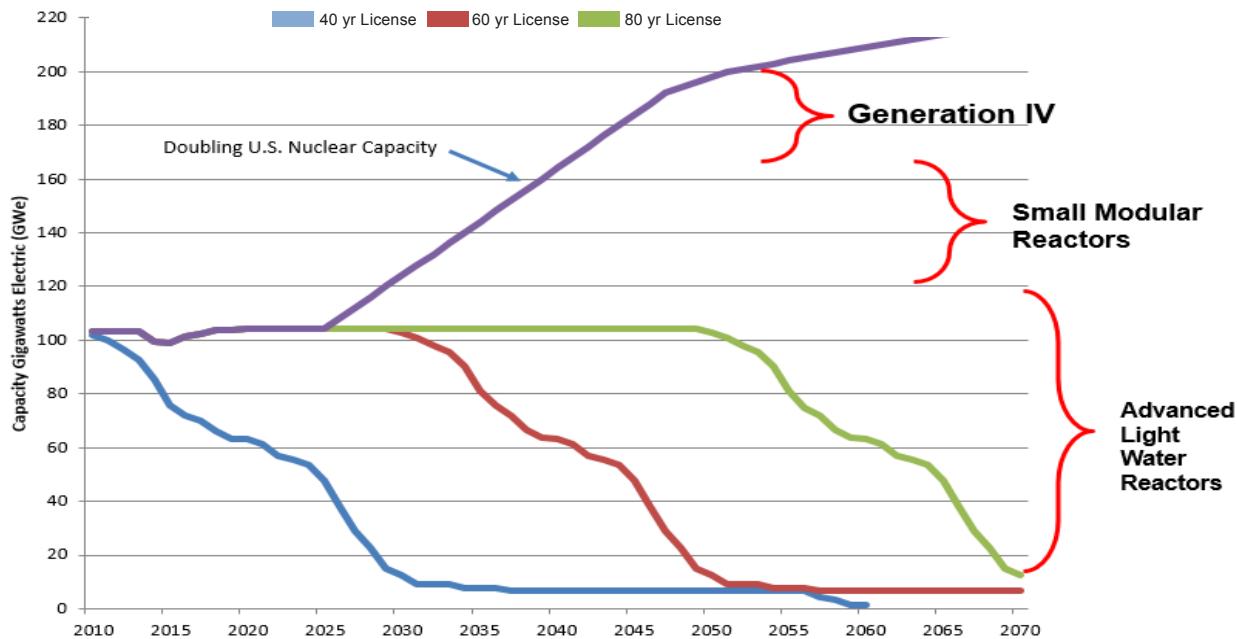
How much nuclear energy might be needed in 2050 and beyond will depend on a number of factors. By way of providing a benchmark, it is useful to consider how much new reactor capacity would be needed to simply maintain nuclear energy's current 20% share of overall U.S. electricity production in light of expected electricity demand growth over the next several decades. Given that overall U.S. demand for electrical energy is expected to grow by about 24% from 2013 to 2040⁴, nuclear generating capacity would need to total at least 125 GW to maintain nuclear energy's current share of electricity production. If meeting the nation's energy needs were to require the replacement of a significant fraction of retiring aging fossil-fuel plants with nuclear generation options, then another 50 to 100 GW of nuclear energy might be needed in the coming decades. Furthermore, efforts to electrify the transportation sector

⁴ DOE Energy Information Administration, Annual Energy Outlook 2015, page 24.

could lead to significantly higher demand for electricity in general and nuclear energy in particular⁵. Finally, the introduction of nuclear energy for non-electric applications such as desalination or industrial process heat would dictate the need for even more nuclear energy. Therefore, a projection of at least 200 GW of nuclear capacity by mid-century would seem to be a reasonable target for the United States in light of expected demand growth.

Most of the currently operating Generation II nuclear power plants received license extensions for a total of 60 years of operation per plant. Some fraction of these plants will apply for and receive a subsequent license renewal for an additional 20 years of operation. At the same time, however, market forces, such as low natural gas prices, may cause other units to shut down prematurely. Without further license renewals or an aggressive new build program, overall nuclear capacity in the United States can be expected to decline rapidly beginning in 2030. Further license renewals could potentially delay this decline until 2050, but at some point the current fleet of reactors will have to be retired. A rapid decline in nuclear power in the United States could jeopardize our ability to extend U.S. objectives related to safety, security, and nonproliferation to the international community.

Figure 1. Possible U.S. Nuclear Capacity for Different Scenarios



⁵ A 2015 report by the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC), titled Environmental Assessment of a Full Electric Transportation Portfolio, examines the potential impact of using electricity to meet a large share of future transportation energy needs—both in terms of greenhouse-gas emissions and in terms of air quality. The report assumes that by 2050 electricity replaces traditional fuels for approximately half of light- and medium-duty transportation and a significant portion of non-road equipment.

How best to replace the 100 GW of existing U.S. nuclear capacity by mid-century and beyond and how best to fill the potential need for 100 GW of additional capacity are important questions for policymakers, technology developers, and power producers today because the time scales needed to deploy advanced nuclear systems are long – perhaps 20 years.

Figure 1 shows possible generating capacity available from the current U.S. nuclear power plant fleet under different scenarios for the maximum license period granted to these plants (i.e., 60 years and potentially up to 80 years). The curve labeled “Doubling U.S. Nuclear Capacity” illustrates an approach to meeting energy needs for the 21st century. The chart assumes that U.S. nuclear capacity would have to double by 2050 to replace retiring units and provide for certain process heat and transportation needs. The capacity additions needed to achieve the “doubling” curve will likely come from a combination of new large LWRs, SMRs, and advanced reactors. Specific capacity amounts are postulated.

There are many good reasons to believe that LWRs will continue to fill a significant fraction of overall demand for nuclear energy in the United States. LWR technology is mature, and the recently completed DOE Nuclear Power

2010 Program led to Design Certification and several Early Site Permits and Construction and Operating Licenses. Currently several new builds of Generation III+ reactors are underway. Uncertainties associated with cost, schedule, and licensing should diminish in a few years. Further, recent progress toward certifying and licensing designs for SMRs, supported by the DOE SMR Licensing Technical Support (LTS) program, can be expected to provide power producers with another viable nuclear generating option by the mid-2020s. Hence, DOE currently expects that several new LWR plants, both large and small, will be built in the coming decades accounting for a significant portion of the needed capacity. Noting the progress made by the Nuclear Power 2010 and SMR LTS programs, DOE seeks to incorporate certain elements of those efforts into the development and deployment of advanced reactors. With the retirement of the current fleet over time and other market uncertainties, it is reasonable to expect that an expanded economy could drive demand for a substantial contribution from advanced reactors, even accounting for the deployment of a new generation of large LWRs and SMRs. In the context of a 200 GW estimate for new nuclear capacity needed in the 2050 timeframe, a contribution of some 30–50 GW from advanced reactors is not out of the question.

Given the scale of expected global energy needs, there is widespread interest in advanced reactor technologies that could offer significant contributions to the future nuclear energy mix. At various forums in 2015 and 2016, industry participants expressed interest in developing plans for new, advanced “Generation IV” nuclear plants. This interest in advanced reactor technologies, and that of other stakeholders, including members of the Secretary of Energy Advisory Board, reflects a view that Generation IV systems could deliver expanded opportunities and should be part of the overall power mix. Various combinations of potential attributes – from possible lower costs and enhanced safety to advantageous fuel cycle characteristics, non-electric applications, easier operation, and proliferation resistance – could make such systems attractive for many markets in the United States and internationally. More importantly, U.S. leadership in these efforts would seek to support international national security objectives with respect to global safety, security, and nonproliferation of nuclear energy technologies.

For all of these reasons, DOE anticipates that a mix of existing LWRs, new Generation III+ large LWRs, SMRs, and Generation IV advanced reactors could provide for nuclear energy generation into the middle of the twenty-first century. Thereafter, the latter three types of nuclear systems (large Generation III+, SMR, and Generation IV) could be expected to meet a significant portion of America’s clean energy needs.

The next section of this document provides contextual information on LWRs and SMRs. Section 4 describes DOE’s vision and strategy for advanced reactors. It outlines ambitious development and deployment goals and describes specific actions the Department is taking or considering to achieve these goals.

3. Status and Prospects for Light Water Reactor Technology

This section discusses the current status of light water reactor technology, covering the spectrum from Generation II reactors (the current fleet) to Generation III+ reactors (current new builds) to small modular reactors (under development). This section also reviews future prospects for each of these technologies and summarizes DOE’s efforts to address critical issues.

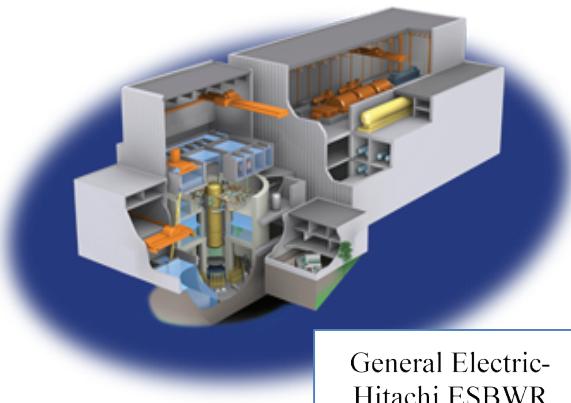
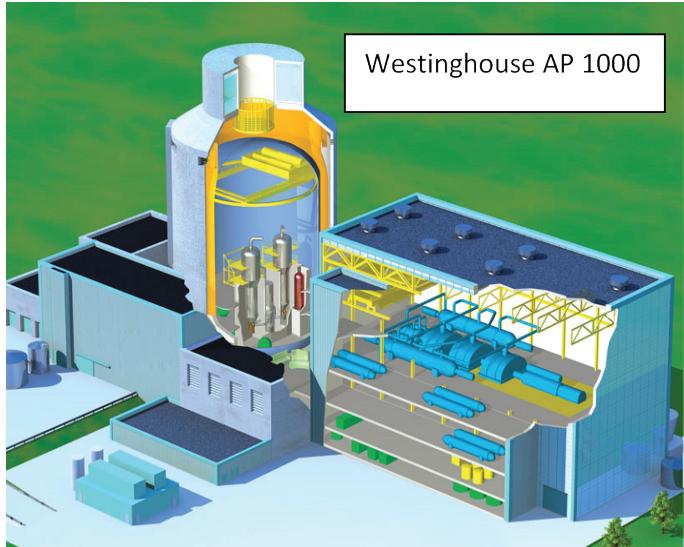
3.1 Status and Prospects for Generation II Reactors

Between now and 2050, most of the nuclear power plants that are still in operation in the United States will begin to reach the end of their licensing period. Most of the plants have license extension to allow operation for 60 years and some will pursue subsequent license approval for operation to 80 years. At present, nuclear utilities, Dominion Energy and Exelon, have stated their intentions to seek further license extensions that will enable operation of the Surry Station and Peach Bottom plant to 80 years. Additional nuclear utilities are expected to announce their intentions in the near term. Apart from license expirations, economic pressures have already resulted in the closure of six nuclear reactors and, without policy and/or market solutions, could result in premature closure of more of the existing nuclear fleet, particularly in merchant electricity markets. Decisions about early closure or extending the operation of a particular plant are ultimately driven by economic factors; however, the economics may be improved through technical advancements, as well as through financial or policy incentives.

DOE, through its Light Water Reactor Sustainability Program, has partnered with the Electric Power Research Institute to develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors. Specifically, DOE is engaged in (1) managing the aging of plant systems, structures, and components so that nuclear power plant lifetimes can be extended and existing plants can continue to operate safely; (2) providing science-based technology solutions in support of economic and efficient plant operation; and (3) developing accident tolerant fuels to improve safety performance through innovations such as advanced cladding materials for application in the current large light water reactor fleet.

3.2 Status and Prospects for Large Generation III+ Nuclear Plants

The DOE Nuclear Power 2010 program addressed technological and regulatory uncertainties associated with the deployment of new, passively safe, large advanced light water reactors, termed Generation III+ reactors. These passively safe reactor designs offered a step increase in the overall safety of reactor technology by reducing the need for human intervention. DOE partnered with two reactor vendors in public-private cost-shared projects to develop engineering designs and obtain NRC certification of two advanced light water reactors: the Westinghouse AP1000 and the General Electric-Hitachi Economic Simplified Boiling Water Reactor or ESBWR.



In addition, DOE and its industry partners shared the cost of demonstrating regulatory procedures for obtaining early site permits (ESPs) and combined construction and operating licenses (COLs) for these reactors from the NRC. These efforts led to the NRC's issuance of COLs for Vogtle Units 3 and 4, Summer Units 3 and 4, Fermi Unit 3, and South Texas Units 3 and 4.

DOE issued a loan guarantee that is helping to finance Vogtle Units 3 and 4; in addition, the Internal Revenue Service has implemented rules allowing production tax credits for new nuclear unit operations. These incentives have helped spur the construction of the new AP1000 units at Vogtle and V.C. Summer. Construction on these units is progressing in support of scheduled commercial operation in 2020.

DOE and the U.S. Department of Commerce continue to look for opportunities to work with industry to support the further deployment of U.S.-designed Generation III+ reactors in the United States and abroad, through the Commerce/Team USA initiative or by advocating for U.S. companies in international commercial solicitations.



Vogtle Progress – Left: Placement of Unit 3 CA01 module; Right: arrival of Unit 4 make up tank (Courtesy of Georgia Power/Southern Company)

3.3 Status and Prospects for Light Water Small Modular Reactors (SMRs)



NuScale Power
SMR Module

In 2012, DOE initiated the SMR LTS program to support the development, licensing, and eventual commercial deployment of SMRs as another clean, affordable electricity generation option. DOE's program is focused on the front end of the SMR development cycle: specifically the early design, certification, and licensing of the most promising domestic SMR technologies. With financial support from DOE over the past several years, efforts to advance and license NuScale Power's SMR design have been making excellent progress.

DOE awarded cost-shared agreements with two siting partners (Tennessee Valley Authority and Utah Associated Municipal Power Systems / NuScale Power) to perform activities leading to site permits and licenses for SMRs. The SMR LTS program will conclude in 2017, and as such, DOE is currently exploring additional opportunities for accelerating the commercialization of SMR technology, through policy mechanisms such as investment tax credits and additional loan guarantees.

4. DOE's Advanced Reactor Strategy

As noted in the previous section, growing demand for clean and reliable energy coupled with the potential benefits of advanced reactor designs, which operate at higher temperatures and offer inherent safety features, are driving current interest in a new generation of nuclear power systems. Some systems are designed to produce electricity at higher efficiencies and provide process heat for industrial applications such as for the production of hydrogen and synthetic transportation fuels. Liquid metal cooled fast reactors have inherent safety features and could make a substantial contribution to meeting future electricity energy needs while also minimizing waste and enhancing resource utilization. A further advantage of advanced reactors is that they could be built in large numbers in factory settings, much like SMRs. When combined with advanced energy conversion technologies, these reactors could offer a safe and economically attractive source of clean power after 2035. As an additional benefit, development of advanced reactors allows the United States to exercise technology leadership to influence and leverage the deployment of energy options internationally. This creates business opportunities for the United States and supports establishment of high standards for safety and nonproliferation.

Figure 2 depicts a notional schedule for implementing key strategic steps toward advanced reactor deployment.

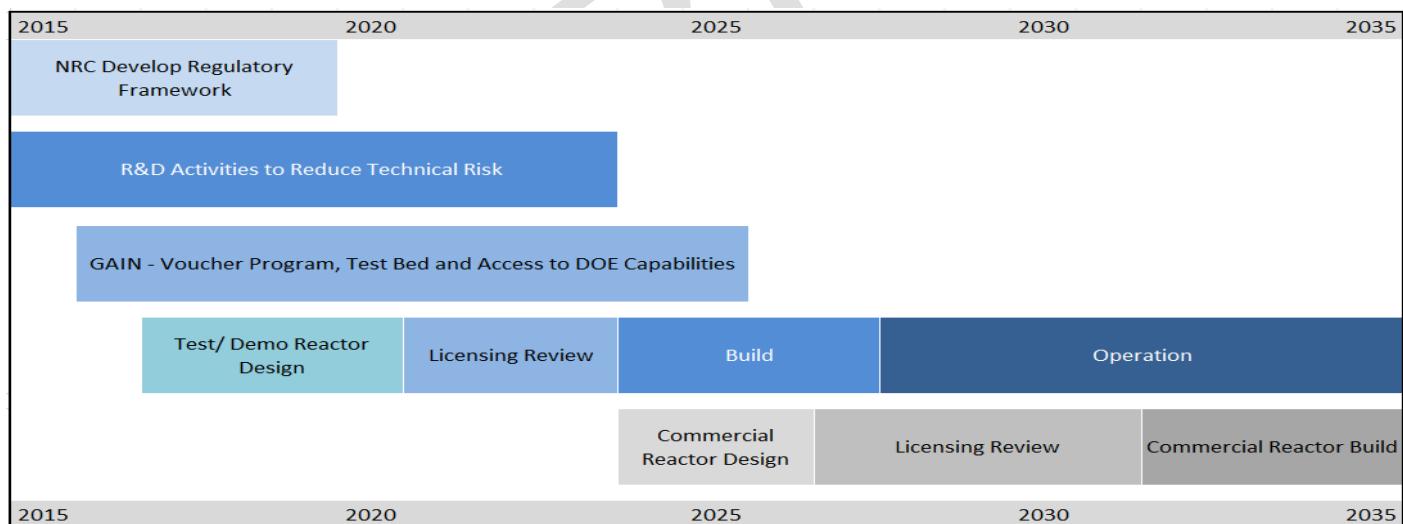


Figure 2. Notional Timeline for Advanced Reactor Development and Deployment

These steps are aimed at achieving DOE's over arching vision for the development of advanced (Generation IV) reactor technology.

Vision: *By 2050, advanced reactors will provide a significant and growing component of the nuclear energy mix both domestically and globally, due to their advantages in terms of improved safety, cost, performance, sustainability, and reduced proliferation risks.*

Recognizing that the deployment of new nuclear technologies can take 15–20 years, DOE has identified a specific goal for the development and deployment of advanced reactors.

Goal: *By the early 2030s, at least two non-light water advanced reactor concepts will have reached technical maturity, demonstrated safety and economic benefits, and completed licensing reviews by the U.S. Nuclear Regulatory Commission (NRC) sufficient to allow construction to go forward.*

If this goal is met, then utilities can consider advanced reactors as part of their long-range acquisition plans. To that end, DOE has identified several strategic objectives:

- 1) Enhance the innovation infrastructure for nuclear technologies, and vastly improve access to DOE expertise and capabilities for advanced reactor development through the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative.
- 2) Demonstrate performance, reduce costs, and retire technical risks for advanced reactors.
- 3) Support industry in the development of fuel cycle pathways for advanced reactors.
- 4) Support the establishment of an efficient and reliable regulatory framework for advanced reactors.
- 5) Maximize the effectiveness of private and public sector investments to aid the private sector in accelerating advanced reactor deployment.
- 6) Address human capital and workforce development needs.

While DOE's advanced reactor strategy focuses on U.S. activities, DOE would also continue to engage internationally to leverage mutual capabilities in support of research and development (R&D) and to address specific needs.

4.1 Strategic Objective 1: Enhance the innovation infrastructure for nuclear technologies and vastly improve access to DOE expertise and capabilities through the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative.

Activities to be undertaken in pursuit of this strategic objective encompass three areas: (1) enhancing DOE's innovation infrastructure, specifically including DOE's advanced reactor testing capabilities; (2) implementing GAIN; and (3) improving modelling and simulation tools for advanced reactors. Key benefits of GAIN are to incubate/nurture industry technology development, and to assist in commercializing DOE-developed nuclear energy technologies, while providing streamlined access to necessary capabilities.

DOE's Nuclear Innovation Infrastructure: Currently DOE has two operating thermal high flux spectrum test reactors, the High Flux Isotope Reactor (HFIR) and the Advanced Test Reactor (ATR). HFIR is used to study advanced materials, perform neutron scattering analyses, and produce isotopes for industry and medicine. The ATR is the only U.S. research reactor capable of providing large-volume, high-flux neutron thermal spectrum irradiation in a prototypic environment for thermal irradiation, thereby enabling researchers to study the effects of neutron and gamma radiation on reactor materials and fuels. Testing at ATR supports research to develop future reactor designs and to test new types of nuclear fuels that reduce waste generation and proliferation risks. The ATR also supports future development programs for the Navy Nuclear Propulsion Program, as well as commercial isotope production.

While DOE has thermal neutron capabilities, DOE currently lacks the fast neutron test capability that could be used to support the development of innovative advanced reactor concepts and to conduct research on advanced nuclear fuel, materials, components, and safety designs. In the past, two facilities provided this capability: the Fast Flux Test Facility (FFTF) and Experimental Breeder Reactor II (EBR II). Both of these reactors were shut down more than 20 years ago.

DOE is currently returning the Transient Reactor Test Facility (TREAT) to operations in order to support resumed transient testing in FY 2018. Transient testing involves placing fuel into the core of a nuclear reactor and subjecting it to short bursts of intense neutron radiation. After the test, the fuel is analyzed at a post-irradiation examination facility to determine the effects of the radiation. This capability will be instrumental in proving the safety of advanced reactor designs and facilitating the licensing process.

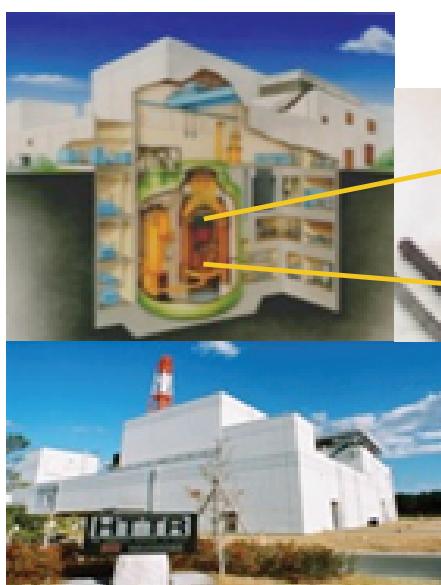
DOE also manages a considerable number of post irradiation facilities that can be used to conduct experiments and testing in support of advanced reactor development, including activities that involve nuclear fuel and material irradiations, safety experiments, and post irradiation examination capabilities. These experimental facilities and testing capabilities are



Advanced Test Reactor at Idaho National Laboratory



Transient Reactor Test Facility at Idaho National Laboratory



Fuel element for the Japan High Temperature Test Reactor (HTTR). The United States and other countries such as Japan are collaborating to develop advanced reactors.

essential elements of an R&D test bed for advancing innovative reactor concepts.

In 2016, DOE completed a planning study to identify test/demonstration reactor options that would be needed to satisfy the materials and fuels irradiation testing and demonstration needs of the national laboratories, industry, and other relevant stakeholders, including NRC licensing requirements. The study examined current capabilities and needs in the context of a national policy to support innovation in nuclear energy.

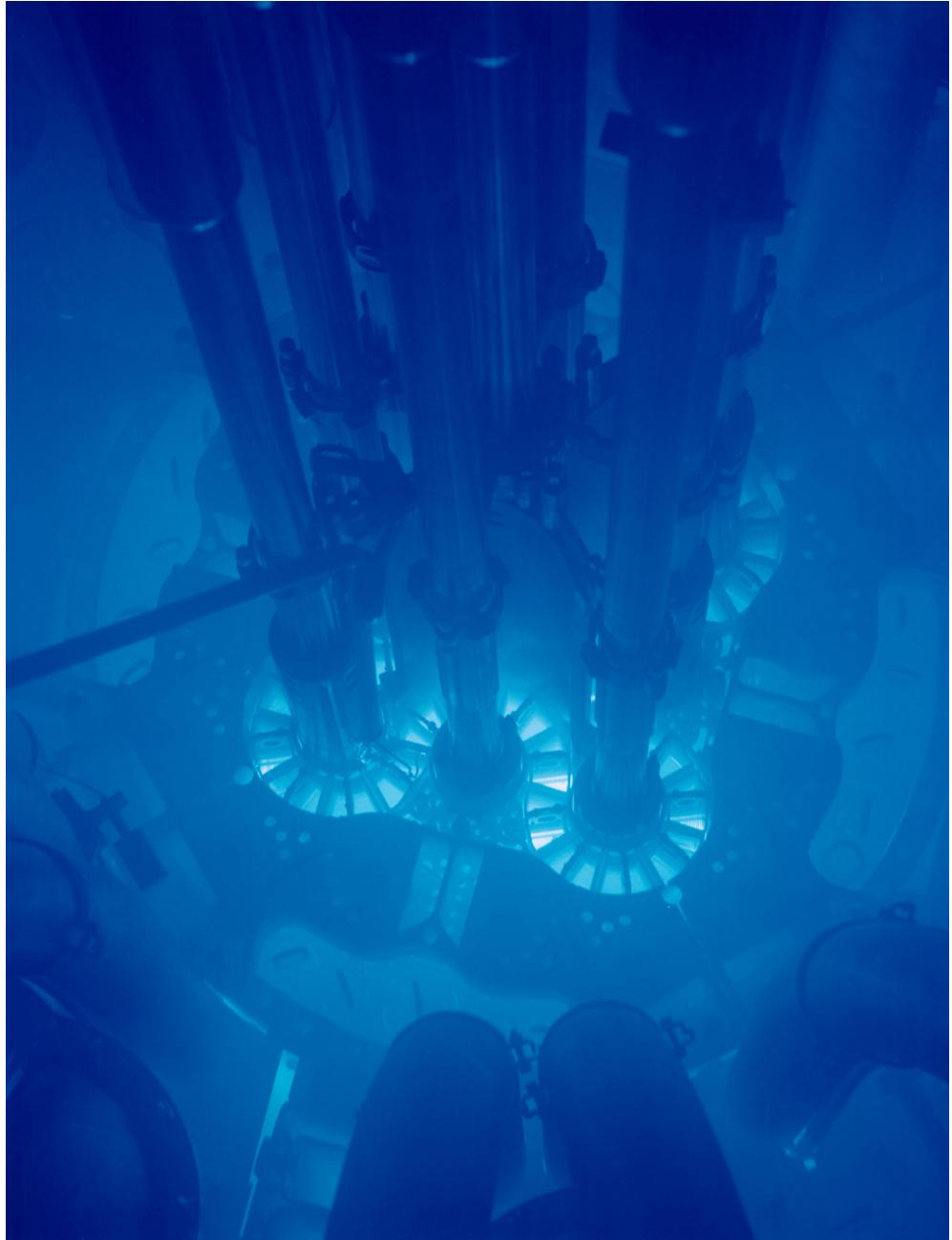
Subsequent to completion of the planning study DOE requested the Nuclear Energy Advisory Committee (NEAC) to determine whether, in their expert judgement, there is sufficient

projected demand from the community of potential users (e.g. DOE, other government agencies, universities, industry and international entities) that cannot be filled using existing, readily accessible capabilities, to warrant DOE launching an effort that could lead to construction of a new test reactor. NEAC will provide a report to inform a decision by the government on whether to proceed with a test reactor design effort; this effort could be U.S.-only, or could be multi-national.

With regard to test reactor needs, DOE has been working with nuclear innovators to assist them in obtaining access to capabilities, including overseas. However, in the long term,

adding new capabilities such as a U.S.-based test reactor may be beneficial. While a new test reactor would not be available in time to have a major impact on achieving the demonstration goal for the early 2030s, innovation will not stop with the initial demonstration of advanced reactor concepts. Efforts to improve fuels and materials will continue beyond 2030, and a new test reactor could augment the capabilities DOE and the laboratories can offer to those looking to improve on initial advanced reactor designs.

Finally, because several countries are working to deploy advanced reactor technologies, DOE engages in several bilateral and multilateral cooperative efforts with international partners in this area. To meet global energy needs, it is essential to continue to effectively leverage nuclear capabilities, infrastructure, resources, and technical expertise for the mutual benefit of the international community.



Advanced Test Reactor

Gateway for Accelerated Innovation in Nuclear (GAIN):

GAIN was established in collaboration with the DOE's Office of Technology Transition's new Clean Energy Investment Center to provide the nuclear community with access to the technical, regulatory, and financial support needed to move new or advanced reactor designs toward commercialization while simultaneously ensuring the continued safe, reliable, and economic operation of the existing nuclear fleet.

Undertaking the R&D activities required to commercialize new or advanced reactor technologies is very expensive and requires special equipment and facilities that are, in many cases, unique to DOE. By helping researchers and developers match their needs to DOE facilities and expertise, GAIN will greatly accelerate the normal development cycle for translating ideas to products.

Gateway for Accelerated Innovation in Nuclear

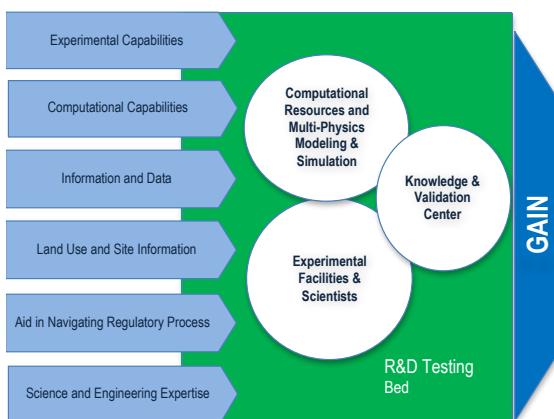


Figure 3. Gateway for Accelerated Innovation in Nuclear (GAIN) Framework



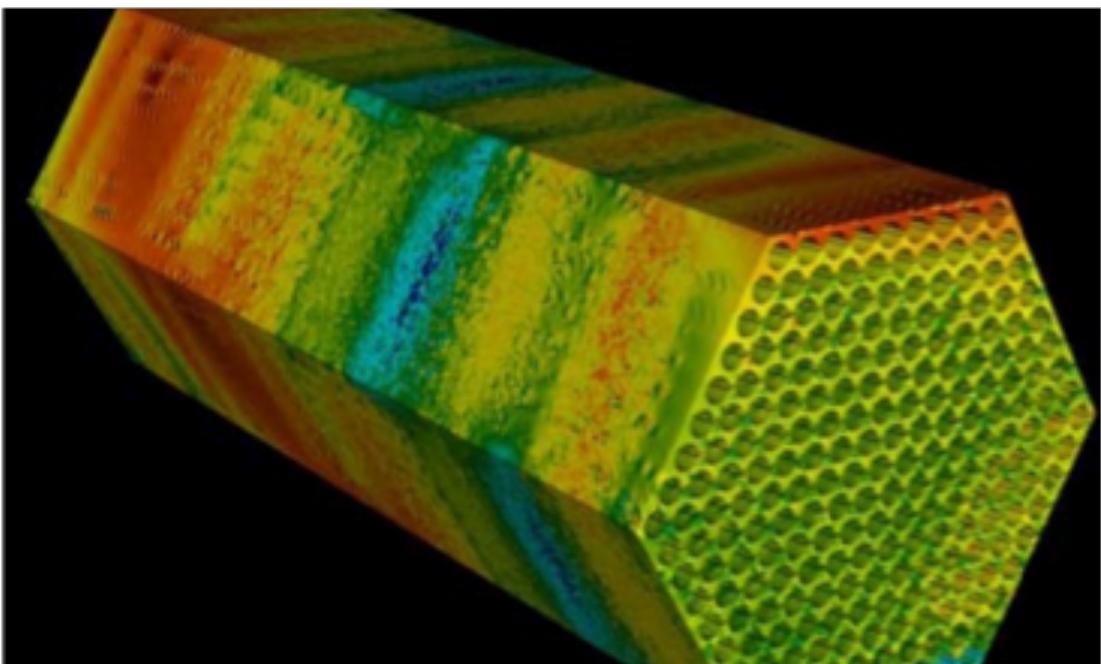
Several different kinds of resources and capabilities are accessible through GAIN:

- Experimental capabilities. The primary emphasis is on nuclear and radiological facilities but GAIN also provides access to other testing capabilities (e.g. thermal-fluid test loops, control systems testing, etc.).
- Computational capabilities along with state-of-the art modeling and simulation tools.
- Information and data through the Knowledge and Validation Center.
- Land use and site information for demonstration facilities.
- Assistance with navigating the regulatory process.
- Science and engineering expertise and experience

GAIN, through the Nuclear Science User Facilities (NSUF) program, provides a single point of contact for university, national laboratory, and industry researchers interested in a wide range of nuclear energy related capabilities and expertise. GAIN also includes a voucher system designed to provide financial support for accessing national laboratory capabilities and expertise. The voucher system supports small business participation through cost-shared projects at various facilities. Access to information and data will be provided through the Knowledge and Validation Center. The Idaho National Laboratory (INL) serves as the GAIN integrator, coordinating access to nuclear energy-related capabilities across the DOE complex (Figure 3). DOE is also looking to leverage GAIN internationally.

Advanced Modeling and Simulation: Modeling and simulation is another way to accelerate the development of advanced nuclear technologies, while also reducing R&D costs. Designing advanced reactors and verifying their safety and performance characteristics requires improved tools for modeling and simulating diverse phenomena including neutronics, thermal fluid dynamics, and structural mechanics. Improved modeling and simulation capabilities increase the fidelity and accuracy of reactor design and safety calculations. To develop these capabilities, DOE plans to exploit modern computational hardware and enabling tools for scientific computing, including tools for meshing complex geometries and visualization tools that can aid researchers' understanding of calculated reactor behavior.

These improved capabilities would make reactor simulation more predictive (reducing the need to rely on calibration and conservative margins to compensate for potential inaccuracies) and improve researchers' ability to characterize prediction uncertainty. Improved accuracy and better integration of capabilities also facilitates design optimization to achieve the best balance between cost and performance. Development of appropriate methods, data, and codes also supports regulatory review of advanced reactors to ensure their safety.



Simulation of coolant flow relative temperatures around a sodium-cooled fast reactor fuel bundle performed under DOE's Nuclear Energy Advanced Modeling Simulation (NEAMS) Program

Enhancing Nuclear Innovation Infrastructure and Vastly Improving Access

To enhance the nation's nuclear innovation infrastructure, DOE plans to improve its experimental, testing, and simulation capabilities. DOE also plans to vastly improve access to DOE expertise and capabilities. Key activities include implementing the Gateway for Accelerated Innovation in Nuclear (GAIN) and completing the planned return of the Transient Reactor Test Facility (TREAT) to operation to support the resumption of testing. DOE will consider the results of an advanced test/demonstration reactor planning study to identify new test and/or demonstration reactor needs to support the development of advanced reactor technologies. As part of its advanced reactor strategy, DOE will also pursue the further development of nuclear and non-nuclear experimental test bed capabilities and modeling and simulation capabilities. GAIN aims to provide greater access to experimental, testing, and modeling and simulation capabilities; facilitate use of the DOE nuclear technology database; and promote broader engagement with industry to understand technical needs. GAIN includes a voucher system and access to information and data to support moving reactor designs toward commercialization. Finally, DOE will explore options for adding an element of international collaboration to GAIN and the Nuclear Science User Facilities (NSUF) program.

4.2 Strategic Objective 2: Demonstrate performance and retire technical risks for advanced reactors

The nuclear energy industry is both the technology provider and customer for advanced reactor technologies. For the last few years, DOE has been interacting with private-sector partners to align its R&D investment decisions with the industry's most pressing needs. These interactions have helped DOE identify, through a technical review panel process, technology needs that (1) are being addressed by additional R&D investment and (2) would accelerate the retirement of technical risk. Several industry-led R&D efforts were funded through this process. In addition DOE has embarked on efforts to fund two advanced reactor concepts to accelerate their maturation.

DOE also performs targeted research at its national laboratories (generic and design-specific, as informed by industry needs) to solve technical issues that reduce technical risk, enhance safety and security, accelerate development, and improve the economic competitiveness of advanced reactors. This research to address technical risk reduces technical uncertainty concerning innovative aspects of new designs and assists multiple companies. Current research is focused on high-temperature reactors (HTRs), liquid metal cooled

fast reactors (LMFRs), and salt cooled reactors. HTR research is focused on developing innovative fuel forms and advanced high-temperature materials. Gas Fast Reactor (GFR) research is centered on silicon carbide materials research. LMFR research is focused on concept development and establishing component-testing capability. Research on salt cooled reactor concepts includes university-led work on fluoride high temperature (FHR) reactors and laboratory-based plans to examine molten salt reactor (MSR) technology. DOE also conducts crosscutting R&D on advanced reactor modeling and simulation code development and validation, advanced instrumentation, and development of advanced manufacturing capabilities based on identified needs. Other DOE work examines approaches for using nuclear energy as part of an increasingly diverse electricity generation mix.

In sum, DOE's strategy for reducing technical risk and improving the economics of advanced reactor concepts includes continued R&D, support for industry cost-shared R&D, and assessment of future test and/or demonstration reactor needs to inform the Department's future investment decisions.

DOE's other near-term efforts to engage industry partners include work with the Electric Power Research Institute

(EPRI) to identify utilities' research, development, demonstration and deployment needs related to advancing the commercialization of advanced reactors. DOE also participates in activities to strategically support advanced reactors with the American Society of Mechanical Engineers, the American Nuclear Society, the U.S. Nuclear Infrastructure Council, and the Nuclear Energy Institute's Advanced Reactor Working Group, which includes reactor vendors, suppliers, and utilities interested in supporting the development of advanced reactors.

In addition to engaging internationally to leverage infrastructure capabilities, DOE will continue to pursue bilateral and multilateral collaborations aimed at retiring technical risks associated with the deployment of advanced reactors.



High Temperature Test Facility at Oregon State University
(Scaled Electrically Heated High Temperature Gas Reactor Test Facility)



Mechanisms Engineering (Sodium) Test Loop at ANL

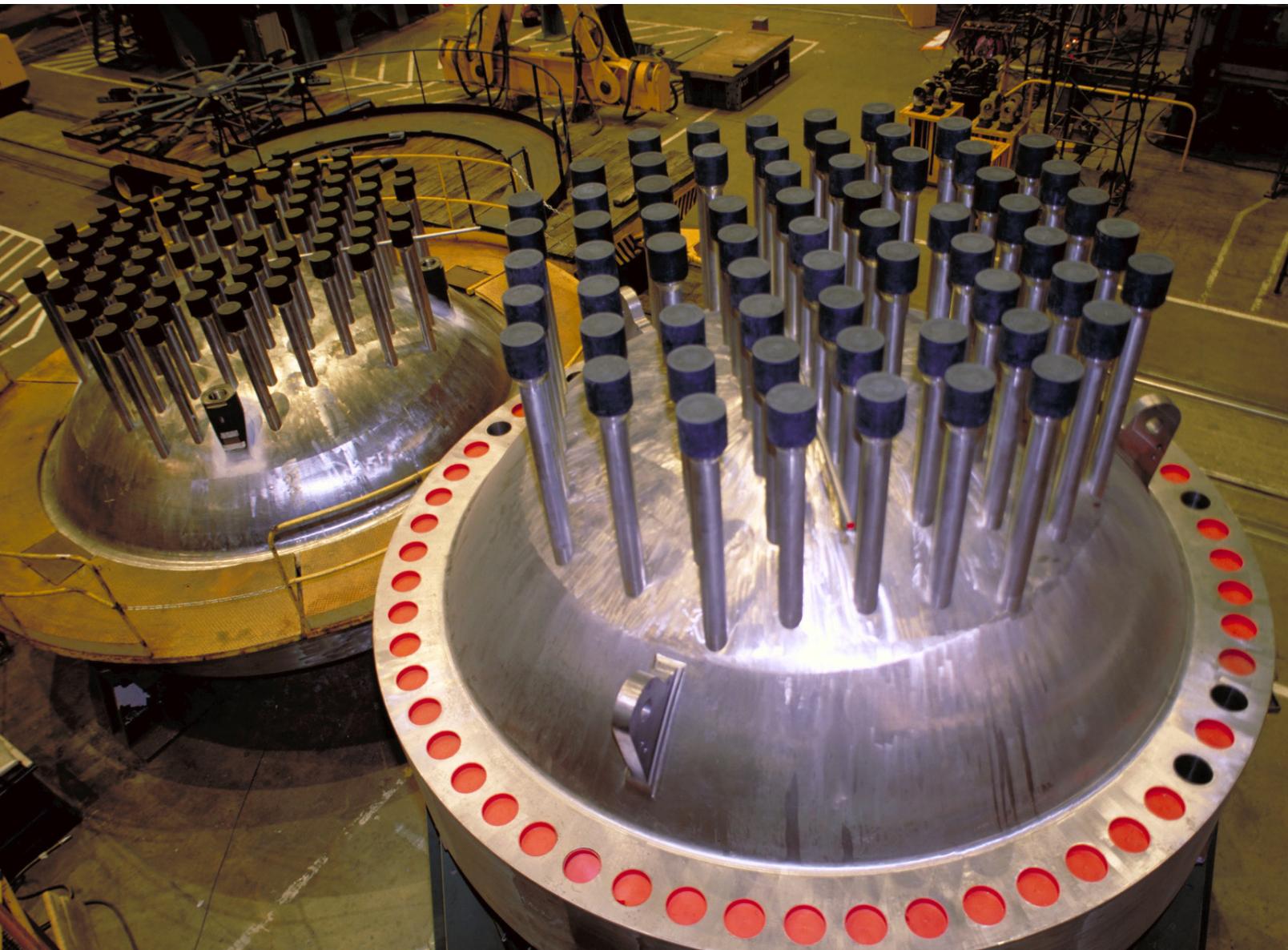


Brayton Cycle Test Loop
Sandia National Laboratories

Retiring Advanced Reactor Technical Risk

DOE will pursue a multifaceted set of efforts to retire technical risks associated with advanced reactors. Specifically, DOE plans to solicit industry input on R&D needs, prioritize plans, and conduct R&D in support of advanced reactor development. These efforts would include traditional laboratory R&D and relevant research projects selected through the Department's Nuclear Energy University Program. DOE would support cost-shared, industry-led R&D for concept-level development and conduct research into high-temperature (HTR) reactor concepts, liquid metal cooled fast reactors (LMFRs), gas fast reactors (GFRs) and molten salt cooled reactors (MSRs). DOE will consider developing a test/demonstration reactor to further enhance its testing capabilities and support the timely deployment of advanced reactors. Finally, DOE will also pursue technical solutions to support the changing role of nuclear energy as part of a diverse electricity generation mix and for non-electric uses.

Reactor Vessel head. A pressurized water reactor head, with the control rods visible on the top



4.3 Strategic Objective 3: Develop fuel cycle pathways for advanced reactors

Working with industry to develop improved and advanced nuclear fuels is a major objective, both for existing LWRs and for the entire spectrum of advanced nuclear energy systems. Developing advanced fuels is also essential to ensuring that sustainable fuel cycle options will be available in the future. Further R&D efforts in this area would focus on working with industry to develop accident tolerant fuels for LWRs and developing new fuels for advanced reactors, including tristructural-isotropic (TRISO) coated particle fuel, metallic fuel and transmutation fuels.

Recent research aimed at developing fuels for non-LWR advanced reactor systems has focused on qualifying TRISO-coated particle fuel and on investigating metallic transmutation fuels. Activities have included irradiation testing, development of fabrication techniques, improvements in material testing capabilities, associated model development, and coordination with the Office of Nuclear Energy's nuclear model and instrument development programs. DOE is also cooperating with universities to support its advanced

fuel development activities through the Nuclear Energy University Program. Focus areas for DOE R&D in advanced, non-LWR nuclear fuels would include:

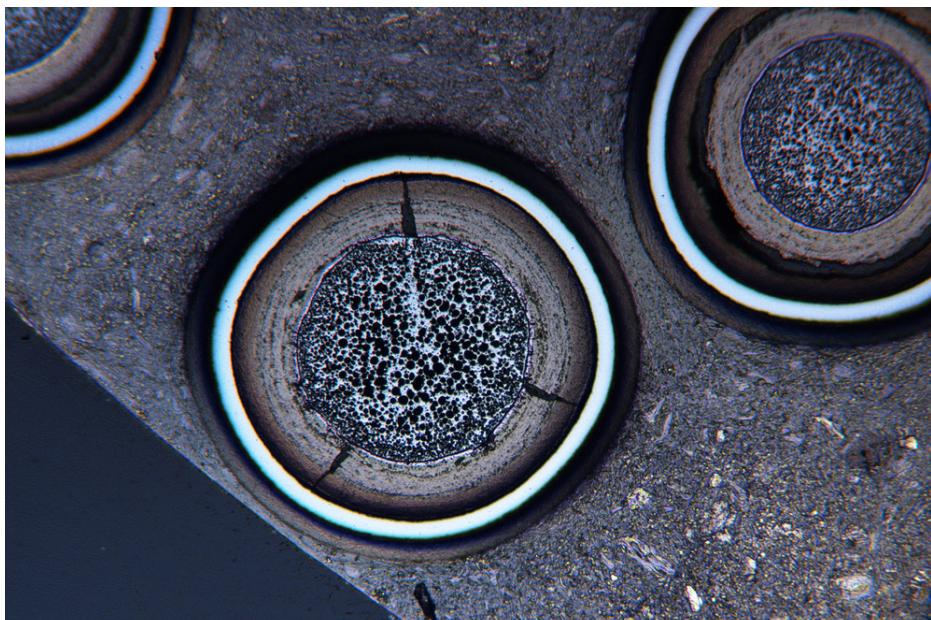
- Supporting advanced metal fuel development including demonstrating higher density, fuel burnup rates, and longer life fuels and fuel fabrication methods.
- Continuing the development of TRISO-coated particle fuel in support of fuel qualification.
- Examining potential liquid fuel options and development issues.
- Facilitating the regulation of advanced reactor fuel.
- Developing a baseline transmutation fuel.
- Advancing multi-scale physics modeling.

DOE's fuel cycle pathway would continue to adhere to proliferation resistance principles. Fuels would not include directly weapons-usable materials. Non-accumulation of weapons-usable materials would be a criteria, diversion potential would be limited and the concept of security-by-design would be an expected element for facilities as well as the overall fuel cycle. In addition to exploring new nuclear fuel options, DOE currently conducts



TRISO coated particle fuel

R&D on the disposition of used nuclear fuel. This work aims to provide a sound technical basis for managing the back end of the nuclear fuel cycle, including the identification and evaluation of safe and secure options for used nuclear fuel storage, resource utilization, transportation, and permanent disposal of radioactive wastes. R&D on storage options currently focuses on closing technical gaps related to the extended storage of used nuclear fuel, including addressing uncertainties related to the performance of cladding for high-burnup used nuclear fuel and long-term canister integrity. Current R&D to address transportation issues is focused on ensuring the transportability of used nuclear fuel following extended storage, addressing data gaps regarding nuclear fuel integrity, assuring the retrievability of used nuclear fuel, and understanding stresses and strains during transportation. In the area of used nuclear fuel disposal, current R&D efforts are focused on identifying multiple viable disposal options and addressing technical challenges for generic disposal concepts in various host media. Overall R&D goals at this stage include reducing generic sources of uncertainty that may impact the viability of disposal concepts, increasing confidence in the robustness of generic disposal concepts, and developing the science and engineering tools needed to select, characterize, and license disposal options.

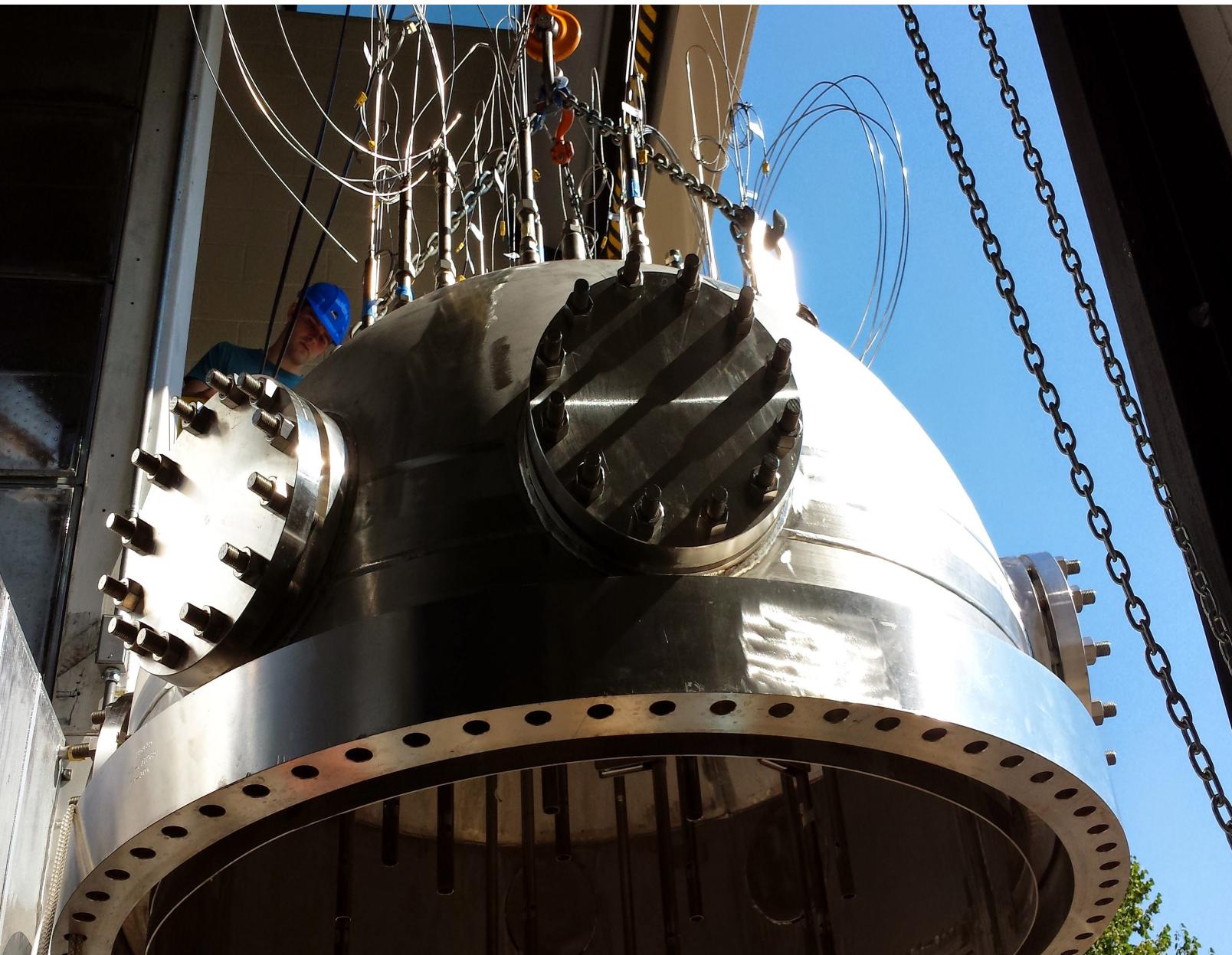


Post irradiation examination of TRISO fuel particles

Supporting the Development of Fuel Cycle Pathways for Advanced Reactors

DOE will pursue R&D to develop improved fuels for existing reactor technologies and suitable fuels for advanced reactors. As informed by industry, these efforts will likely focus on TRISO-coated particle fuel for high temperature reactors, metallic fuel for fast reactors, and transmutation fuels for longer-term applications. DOE will also assess and pursue critical elements for the deployment of advanced fuel cycles, including identifying and characterizing fuels and separations/enrichment technologies. As part of these efforts, DOE would assess the need for and/or provide for the deployment of fuel cycle facilities. To address other aspects of the back end of the nuclear fuel cycle, DOE is pursuing R&D focused on the storage and disposal of used nuclear fuel. The aim of this R&D is to develop the technologies and capabilities needed to enable the safe storage, transportation, and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles, including identifying and addressing technical challenges that may arise from advanced nuclear fuel cycles.

Oregon State University, High Temperature Test Facility



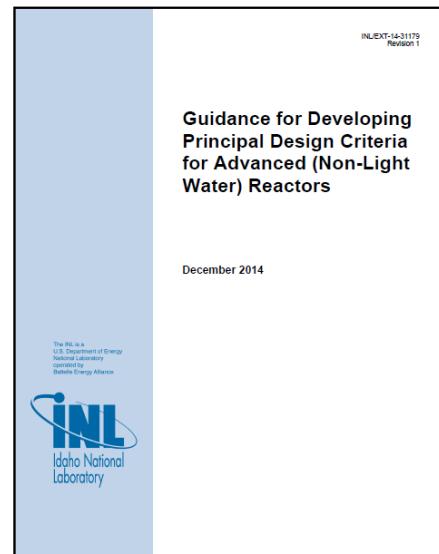
4.4 Strategic Objective 4: **Support the establishment** **of an efficient and reliable** **regulatory framework for** **advanced reactors**

The NRC's framework of regulations, processes, and procedures for regulating the nuclear power industry is based largely on LWR technologies. For the last several years, DOE has been interacting with the nuclear energy industry to better understand its needs and priorities, and, better align DOE's R&D program to address those needs. Industry experts consistently point to the need for an appropriate, efficient and predictable regulatory framework as a high priority. This focus is consistent with Congressional intent as reflected in provisions of the Energy Policy Act of 2005 that pertain to the Next Generation Nuclear Plant (NGNP) project. These provisions direct the NRC and DOE to work together to develop an appropriate licensing strategy to support the deployment of next-generation technology. In a 2012 report to Congress on advanced reactor licensing⁶, the NRC described its overall long-term strategy for licensing advanced reactors and noted the need to better accommodate non-LWR technologies within the regulatory process. While the NRC has stated that the existing LWR-based regulatory framework, with appropriate exemptions, could in fact be utilized, establishing a regulatory framework for advanced reactors could offer significant benefits. Such a framework could more specifically address regulatory requirements for

advanced reactors and make the review process more efficient and predictable. The NRC is in the process of developing a document that describes its overarching approach to preparing for non-LWR regulatory activities. That approach includes three major focus areas: technical preparations, licensing preparations, and outreach. It also includes enhancements to the regulatory framework for non-LWRs such as the development of advanced design criteria, the development of a staged licensing process, and early engagement with design-related policy issues

More recently, the NRC, with DOE's assistance, has begun developing a regulatory framework for advanced reactors. A goal of this effort is for the NRC to issue specific regulatory guidance on general design criteria for non-LWR advanced reactors in 2017.

In September 2015 and June 2016, NRC and DOE held initial workshops in a planned series of workshops to explore more efficient development and licensing processes for advanced reactors. The workshop series aims to explore options for increased efficiency, from both a technical and regulatory perspective, for safely developing and deploying advanced non-light water reactors. The discussions cover both near- and longer-term opportunities to develop new concepts and enhance appropriate regulatory processes and guidance.



DOE and NRC have agreed to continue to address action items identified during the workshops and will provide updates during subsequent meetings. Other ideas to be considered include issuing topical reports to obtain feedback on specific technical or analytical issues for less mature reactor concepts, developing an informal preliminary design review process, and addressing the need for modifications to existing licensing guidance, such as the Standard Review Plan, to address differences associated with advanced reactors.



Supporting the Establishment of a Regulatory Framework for Advanced Reactors

DOE and its stakeholders will collaborate with the NRC as the NRC develops a regulatory framework for advanced reactors. This collaboration could include efforts to provide assistance to the NRC as it develops design criteria for advanced reactors, staged licensing processes, and preliminary licensability review processes. In addition, DOE will assist the NRC in efforts to resolve key policy issues, co-host joint workshops, explore options for new fuel and fuel fabrication facilities, and modify existing guidance (such as the Standard Review Plan) to accommodate advanced non-light water reactor designs.

⁶<http://www.nrc.gov/reading-rm/doc-collections/congress-docs/correspondence/2012/freilinghuysen-08-22-2012.pdf>

4.5 Strategic Objective 5: Maximize the effectiveness of public and private sector investments and explore policy incentives to aid the private sector in accelerating advanced reactor deployment

While industry will lead development and deployment efforts, the high cost of designing a nuclear plant can challenge the ability of reactor vendors to develop new designs and the ability of electric utilities to deploy new reactors. DOE could use public-private partnerships and various financial mechanisms to address cost barriers to advanced reactor development and deployment. Past DOE efforts to support the deployment of new nuclear technologies have included initiatives such as the Nuclear Power 2010 program, which supported site identification and first-of-a-kind engineering for Generation III+ light water reactor designs. It also implemented certain financial incentives, authorized under the Energy Policy Act of 2005, for building new nuclear power plants. The SMR Licensing Technical Support Program also provided support for reactor deployment.

Public-private engagement is an important element in any future deployment strategy for advanced reactors. In addition to interacting with the public through various forums, DOE participates in stakeholder meetings, provides information, and solicits input on issues such as reactor regulation, siting, and used fuel disposition. Mechanisms for accelerating the deployment of advanced reactor technology include public-private partnerships, technology centered working groups, and financial incentives.

Public-private partnerships could be used to develop and commercialize specific elements of advanced

reactor technology as well as to finance the overall design, licensing, and construction of commercial plants. DOE has been funding cost-shared, industry-led R&D for technology development projects, cost-shared programs for developing reactor concepts, and the Small Business Innovation Research program, which provides federal seed money to domestic businesses to engage in research that has the potential for commercialization. In addition, DOE's Office of Technology Transitions (OTT) has launched the statutory Technology Commercialization Fund. This fund provides an additional mechanism for matching private funds with federal funds in support of efforts to commercialize promising energy technologies developed by the DOE national laboratories. Going forward, DOE will explore the use of public-private partnerships—similar to the public-private partnerships utilized in the Nuclear Power 2010 and SMR Licensing Technical Support programs—to address the need for licensing technical support and construction support. These types of partnerships could help to advance non-LWR reactor designs that are relatively mature and support deployment in the early-2030s timeframe. Finally, OTT's new Clean Energy Investment Center provides the capability to bring additional partnering services and access to the investment community in support of future commercialization efforts.

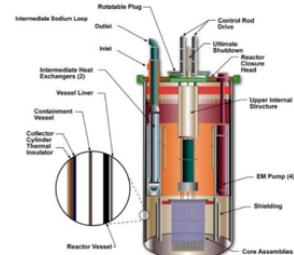
Technology centered working groups can bring together vendors who are working on reactor concepts that have much in common. For instance there are many vendors working on sodium fast reactors, high temperature gas reactors, molten salt cooled reactors, and other advanced reactor concepts. One idea to accelerate development is for these vendors to pool resources as appropriate and work on technical, regulatory, safety,



- PWR
- BWR



- AP1000
- ESBWR
- NuScale
- B&W mPower
- Holtec SMR-160
- Westinghouse SMR



- Sodium Fast Reactor
- High Temperature Gas Reactor
- Lead Fast Reactor
- Gas Fast Reactor
- Molten Salt Reactor



Figure 4. Public-Private Partnerships for Reactor Development

security, and nonproliferation issues in a collaborative manner. DOE is playing a role in helping to organize such groups, consistent with applicable law. Technology centered working groups, in turn, could help DOE identify the government investments that would benefit the greatest number of vendors and utilities. The first round of technology centered working group meetings took place in 2016 and are already showing positive results.

Policy and financial incentives can be used to accelerate private investment in advanced nuclear technologies. Financial incentives can be tailored to encourage investment in technologies that are still in the early, proof-of-concept development phase as well as technologies that have reached the construction or production phase. In 2014, for example, DOE provided \$12.5 billion in federal loan guarantees for the construction of two large new nuclear reactors under the Title 17 loan guarantee program.

Power purchase agreements are another mechanism for addressing cost barriers. Such agreements allow nuclear generators to sell electricity at a fixed price for a specified period of time, thereby guaranteeing a certain level of revenue, reducing market uncertainty, and encouraging further deployment.

Another approach is for the federal government to act as the “first mover” on new reactor projects by partnering with power companies or utilities to enter into negotiated ownership arrangements in which the facility is eventually purchased by the private-sector partner. The nuclear units would be licensed, built and operated by the private-sector partner.



Advanced Test Reactor (No. 3) is used to study the effects of radiation on materials and is also capable of producing rare and valuable medical and industrial isotopes. It is the most versatile test reactor in the world.

Maximizing the Effectiveness of Public/Private-Sector Investments to Accelerate Advanced Reactor Deployment

DOE will explore new ways to work with the private sector to accelerate advanced reactor deployment and support the further development of selected advanced reactor concepts. DOE would also use public-private partnerships and technology-specific working groups to identify opportunities for government investment that could help advance multiple reactor concepts. Finally, DOE and the Administration will explore the use of other appropriate financial incentives to support advanced reactor deployment.

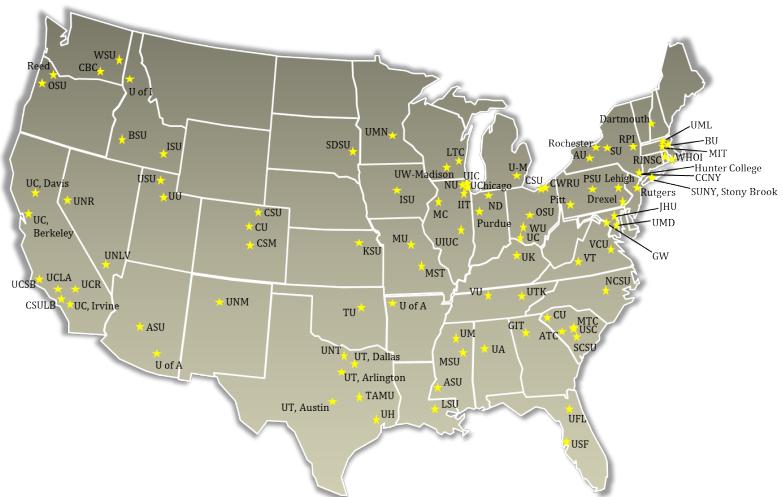
4.6 Strategic Objective 6: Address human capital and workforce development needs

The adequacy of the nuclear energy workforce is a growing concern for the nuclear energy industry and an issue of obvious importance for future efforts to deploy new nuclear technologies. According to recent estimates by the Nuclear Energy Institute, 39% of the U.S. nuclear workforce will be eligible for retirement by 2018. This means that the industry may need to hire 20,000 new workers over the next several years to replace retiring workers. More broadly, investments in a skilled workforce are needed to ensure that the nation can continue to build, maintain, and operate a reliable and efficient energy infrastructure. Historically, a large part of this investment has come through federal funding for education and research.

DOE's Office of Nuclear Energy created the Nuclear Energy University Programs (NEUP) in 2009. NEUP engages U.S. colleges and universities to conduct R&D, enhance infrastructure,

and support student education, thereby helping to sustain a world-class nuclear energy and workforce capability. It has funded research projects in areas that are relevant for the development of components and materials for advanced nuclear systems. This funding not only supports the development of new Nuclear Technologies, it also attracts students to enter nuclear energy and related nuclear science fields.

At the direction of Congress, the Department also supports workforce development by funding annual undergraduate scholarships and graduate-level fellowships in nuclear energy-related fields of study through the Integrated University Program (IUP). Since the awards were initiated in 2009, 98% of students who completed these fellowships subsequently pursued additional education or careers in nuclear energy fields at the Department's national laboratories, government agencies, academic institutions, or private companies.



Since FY09, the Office of Nuclear Energy has awarded over \$400M to more than 100 schools.

Developing the Nuclear Energy Workforce of the Future

DOE plans to continue funding nuclear-related research projects, infrastructure enhancements, and educational support through its Nuclear Energy University Programs. In addition, DOE will promote advanced reactor technology training opportunities through its newly established traineeship program. DOE will also seek opportunities to engage academic institutions, where appropriate, in enhancing research efforts relevant to the development of advanced reactor technologies.

Conclusion

DOE's strategy for the development and deployment of advanced nuclear reactors includes specific objectives for improving experimental and test capabilities and expanding access to facilities and expertise, retiring technical risk, developing fuel cycle pathways, assisting the NRC in efforts to establish an advanced reactor regulatory framework, effectively maximizing private sector resources to accelerate deployment, and addressing human capital and workforce development needs. Implementation of the activities associated with these objectives would need to be coordinated and sequenced to assure that federal efforts produce the desired outcomes. Activities must be prioritized and resources allocated to deliver the right solution, at the right time, to the right customer.

Because the development needs of individual advanced reactor concepts vary considerably, all elements of this strategy may not apply to all concepts. However DOE intends this Vision and Strategy to guide programmatic efforts in support of initiatives for the development and deployment of at least two advanced reactor concepts in the early 2030s.

Improving DOE infrastructure and facilitating access would have benefits for most technologies and concepts. Efforts to reduce technical risk are intended to both address specific technical issues and to advance concept maturity. DOE support for the development of at least two new reactor concepts is not intended to down-select technology areas; rather, it is intended to demonstrate that further funding can advance specific concepts while also showing that advanced reactors are making viable progress toward being able to address the nation's clean energy needs. DOE has not selected any specific technologies to support. DOE expertise and infrastructure would assist the NRC in its efforts to establish a regulatory framework that makes for effective and efficient license submission and subsequent NRC review processes. Fuel cycle work would include developing specific fuels for longer-term concepts and exploring fuel disposition for advanced reactors. Efforts to maximize the effectiveness of public and private sector investments and develop human capital with expertise in non-light water reactor technologies are likewise essential to accelerate advanced reactor deployment and to ensure that the talent needed not only to develop, but also operate these new reactors is available in the future.

While elements of this strategy could support reactor concepts at differing levels of development, DOE has formulated a notional timeline for completing the design process and submitting license applications to the NRC for reactor concepts that could be in a position to reach milestones in the near term (see next page). More time would be needed to address design, fuel, materials or component development challenges for other, less mature reactor concepts. DOE could support certain development needs for some of these longer-term concepts. DOE would also continue to engage in joint efforts with nuclear industry organizations to pursue shared objectives in the development and deployment of advanced reactors.



High Temperature Test Facility - Ceramic Core Block

Timeline for Advanced Reactor Development and Deployment

DOE has initiated a multi-faceted effort to support the design and licensing of at least two commercial advanced reactor concepts by the early 2030s. This effort includes working with the NRC and with DOE's stakeholders and industry partners as the NRC develops a new regulatory framework for advanced reactors. Current plans target the completion of general design criteria for advanced reactors in 2017. The NRC expects early engagement with potential applicants on any policy issues related to licensing so that there is a timely resolution before an application would be submitted. Throughout this period, research and development aimed at retiring technical risks associated with fuels, materials, and components would continue. Through GAIN, DOE expects to enhance the nation's nuclear innovation infrastructure and improve industry's access to DOE capabilities and expertise. The TREAT reactor is scheduled to go on line in 2018. Additionally, DOE's cost-shared support for further development of two advanced reactor concepts, launched in 2015, is expected to continue through 2020. Meanwhile, DOE's test/demonstration reactor study, to be completed in 2016, should provide further options for supporting future reactor commercialization with the expectation that a potential new test or demonstration reactor would be operational by the late 2020s if needed.

Acronyms

ABWR	Advanced Boiling Water Reactor	IPSR	Integral Primary System Reactor
AEC	Atomic Energy Commission	LWR	Light Water Reactor
ALWR	Advanced Light Water Reactor	MWh	Megawatt Hour
ASME	American Society of Mechanical Engineers	MT	Metric Ton
ANS	American Nuclear Society	NDE	Non-destructive Examination
CFD	Computational Fluid Dynamics	NE	Office of Nuclear Energy
CFR	Code of Federal Regulations	NEA	Nuclear Energy Agency
COL	Construction and Operating License	NEI	Nuclear Energy Institute
DAS	Deputy Assistant Secretary	NESCC	Nuclear Energy Standards Coordination Collaborative
DBA	Design Basis Accident	NGNP	Next Generation Nuclear Plant
DOE	U.S. Department of Energy	NIST	National Institute of Standards and Technology
DOE-ID	U.S. Department of Energy-Idaho Office	NP2010	Nuclear Power 2010
EIA	Energy Information Administration	NRC	U.S. Nuclear Regulatory Commission
EOI	Expression of Interest	OECD	Org. for Economic Cooperation and Development
EPRI	Electric Power Research Institute	OTT	Office of Technology Transitions
ESP	Early Site Permit	PIRT	Phenomena Identification and Ranking Table
FY	Fiscal Year	PRA	Probabilistic Risk Assessment
GEN III+	Generation III+	PRDP	Power Reactor Development Program
GHG	Greenhouse Gas	PSA	Probabilistic Safety Assessment
GWe	Gigawatts Electric	R&D	Research and Development
HCSG	Helical Coil Steam Generators	RD&D	Research, Development, and Demonstration
I&C	Instrumentation and Control	SDO	Standards Developing Organization
IAEA	International Atomic Energy Agency	SMR	Small Modular Reactor
IEEE	Institute of Electrical and Electronics Engineers	SSC	Structure, System, and Component
INPO	Institute of Nuclear Power Operations	U.S. NIC	U.S. Nuclear Infrastructure Council
ITAAC	Inspections, Tests, Analyses, and Acceptance Criteria		
INL	Idaho National Laboratory		



