August 22, 2012

The Honorable Rodney Frelinghuysen
Chairman, Subcommittee on Energy
and Water Development
Committee on Appropriations
United States House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

On behalf of the Commission, I am pleased to submit the enclosed U.S. Nuclear Regulatory Commission (NRC) report addressing advanced reactor licensing, as required by the House Committee Report on the Energy and Water Development Appropriations Act, 2012, of the Consolidated Appropriations Act, 2012 (P.L. 112-74).

This staff report addresses the NRC's overall strategy for, and approach to, preparing for the licensing of advanced reactors. The report addresses licensing applications anticipated over the next two decades, as well as potential licensing activity beyond that time. The report focuses on the licensing of nuclear reactor facilities for commercial use and illustrates regulatory challenges that may occur if various advanced reactor initiatives evolve into licensing applications.

The NRC will continue to effectively and efficiently plan for the anticipated advanced reactor licensing workload, consistent with its mission and goals, and with no compromise to the continued safety of the operating reactor fleet.

Should you have any questions, please contact me or Ms. Rebecca L. Schmidt, Director of the Office of Congressional Affairs at email: Rebecca.Schmidt@nrc.gov.

Sincerely,

/RA/

Allison M. Macfarlane

Enclosure:
Report to Congress on Advanced
Reactor Licensing

cc: Representative Peter J. Visclosky

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

Report to Congress: Advanced Reactor Licensing

August 2012

CONTENTS

EXECUTIVE SUMMARY

There is significant and growing interest in deploying advanced reactor* systems for a variety of purposes in this country. Recent and ongoing initiatives related to advanced nuclear technologies by the U.S. private sector and within the international community could lead to commercial licensing applications before the U.S. Nuclear Regulatory Commission (NRC or the Commission) both in the near term and over the next 1 to 2 decades. Such applications would involve reactor technologies other than the light-water-reactor (LWR) technology employed in the current U.S. commercial nuclear reactor fleet.

The Consolidated Appropriations Act, 2012 (P.L. 112-74), contains, as one of its subdivisions, the Energy and Water Development Appropriations Act, 2012 (the Act), which sets forth the fiscal year 2012 appropriations for the NRC. To address a provision identified in the House Committee Report on the Act, the NRC has prepared this report to address, at a minimum: (1) the anticipated advanced reactor licensing scope over the next 1 to 2 decades, (2) the overall research and development activities that should be conducted to support NRC reviews in anticipation of the advanced reactor licensing scope, including updating and extending national consensus standards, (3) the projected resource requirements for both experienced personnel and development facilities to support the NRC given the anticipated scope of advanced reactor licensing, and (4) the overall plan for using and sharing the limited resources between industry and the Government, including use of the facilities and personnel at the national laboratories and elsewhere within Government and industry.

This report, prepared in response to the Congressional request and follow-on discussions with Congressional staff**, addresses the NRC's overall strategy for and approach to preparing for the licensing of advanced reactors. The report addresses licensing applications anticipated over the next 1 to 2 decades, as well as the potential licensing beyond twenty years. The report focuses on the licensing of nuclear reactor facilities for commercial use. Also, the report reflects the possibility that some number of the advanced reactor initiatives will evolve into licensing applications in order to illustrate potential regulatory challenges. However, it is important to recognize that the NRC, as an independent regulator focused on the health and safety of the public and common defense and security, does not promote any particular technology or design or the use of nuclear energy and; moreover, the content of this report is not intended to reflect any correlation with the NRC's planning and budgeting for 2014 and beyond.

In discussing advanced reactor technologies, it is important to note that the characteristics of advanced reactors have evolved over past decades, and this evolution is expected to continue. However, the NRC's regulatory expectations regarding advanced reactors remain clear. The Commission's Policy Statement on the Regulation of Advanced Reactors states the following:

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* As used in this report, advanced reactors refers to those designs of commercial reactors, employing either light-water-reactor (LWR) or non-LWR technology, which incorporate the Commission's expectations set forth in the Policy Statement on the Regulation of Advanced Reactors, 73 Federal Register, 60612 (October 14, 2008).

**Telephone conversations between NRC staff and Congressional staff resulted in expanding the report scope to address licensing in the timeframe beyond 20 years and the report due date of August 30, 2012.

> Regarding advanced reactors, the Commission expects, as a minimum, at least the same degree of protection of the environment and public health and safety and the common defense and security that is required for current generation light-water reactors [i.e., those licensed before 1997]. Furthermore, the Commission expects that advanced reactors will provide enhanced margins of safety and/or use simplified, inherent, passive, or other innovative means to accomplish their safety and security functions.[1]

This policy was carried forward for applicability to the Generation III+ reactor designs (i.e., LWR designs such as the AP1000 and the economic simplified boiling-water reactor (ESBWR)) and is communicated to all potential licensing applicants and stakeholders.

The NRC is conducting new reactor licensing activities, refining the processes for overseeing new reactor construction activities, and addressing the significant policy and technical issues related to the licensing of advanced reactor designs. The focus in 2012 and beyond is on completing the licensing activities for the design certifications and combined license applications now before the agency, expanding implementation of the construction inspection program to oversee construction as the combined licenses are issued, and beginning the review of applications for advanced reactor designs.

To facilitate the review of designs that differ from the large LWR facilities, the NRC is developing a regulatory approach that supports the unique aspects of advanced designs. This includes identifying and resolving policy, technical, and licensing issues; developing the regulatory strategies to support efficient and timely reviews; engaging the Department of Energy (DOE), designers, and potential applicants in meaningful preapplication interactions; and coordinating activities with internal and external stakeholders. One initiative NRC has undertaken to streamline its review of new applications involves integrating the use of risk insights to create design-specific review plans and standards for light-water small modular reactor (SMR) designs and the development, over the longer term, of a new risk-informed, performance-based regulatory structure for non-LWR advanced reactor designs. For awareness and insights regarding advanced reactor licensing in other countries, the NRC continues to be involved in the international nuclear community, as exemplified by the agency working closely with the International Atomic Energy Agency (IAEA) and regulators in other countries participating in the Multinational Design Evaluation Program (MDEP) and the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) Committee on Nuclear Regulatory Activities (CNRA) Working Group on the Regulation of New Reactors (WGRNR).

Chapter 2 of this report details the anticipated licensing-related activities for the next twenty years and beyond and the planning assumptions – and, importantly, also details the rationale and information that provide the basis for the assumptions. To discuss the expectations, assumptions, and planning associated with advanced reactor technologies anticipated for licensing, this report is structured in terms of the following broad timeframes: near term (within 5 years), longer term (within 10 years), horizon (10–20 years), and beyond the horizon (20+ years). In summary:

- Within the near term, in addition to current and planned Generation III+ licensing activities, the NRC anticipates licensing activities focused on integral pressurized-water reactor designs.

- Within the longer term, the NRC anticipates continuation of the near-term activities and expanded activities pertaining to liquid-metal cooled reactor designs.

- Within the horizon timeframe, licensing activities, in addition to continuation of those from the prior timeframes, may include one or more advanced reactor concepts currently identified for research by the Generation IV International Forum and supported by DOE.

- For the beyond-the-horizon timeframe, NRC licensing activities would correlate with (1) the DOE's Nuclear Energy Research and Development Roadmap—Report to Congress, issued April 2010, (2) recommendations of the Blue Ribbon Commission on America's Nuclear Future—Report to the Secretary of Energy, issued January 2012, and (3) U.S. national policy regarding the nuclear fuel cycle.

Crucial to licensing for any advanced reactor technology is the consideration of review and oversight of new nuclear fuel designs and their production. Any advanced reactor design that uses fuel that differs significantly from the current type (zirconium-clad, low-enriched uranium dioxide) will require the evaluation of technical and regulatory approaches to the licensing of fuel fabrication, transportation, storage, and waste disposal operations.

Chapter 3 describes the types of analysis tools, and supporting data and experiments that would be needed to efficiently and effectively license the advanced reactor technologies described in Chapter 2. The research base to support NRC licensing of advanced reactor technologies, as compared to that for LWR technology, is much more limited and, for some beyond-the-horizon design concepts, almost nonexistent. For this reason, significant research efforts must be undertaken to support the NRC's advanced reactor licensing decisions for designs that differ significantly from LWR technology. Such research must be conducted so that the analysis methods and supporting experimental data can support an independent safety finding by the NRC. Since some advanced reactor technologies are currently, or will be, in use in other countries, the NRC plans on significant bi-lateral and multi-lateral cooperative efforts with the regulatory authorities of those countries.

Chapter 4 addresses the human resource and facility requirements to support advanced reactor licensing. The evolution of advanced reactor technologies requires the aforementioned investment in research and, correspondingly, use of resources—both personnel and facilities (e.g., laboratory, testing, experimental, and training). It requires an appreciable cadre of scientists and engineers familiar with the technology, licensing and operation requirements, and the underlying research and databases needed to support the development and licensing. The resource needs are similar for both NRC and the industry and include a workforce with the necessary knowledge and skill sets, as well as access to research capabilities and test facilities that can provide data and analyses to support the design and the NRC's licensing review. Varied experimental and test facilities are needed to support both developmental and confirmatory research. Within the nuclear community, a number of such facilities currently exist, ranging from some with multipurpose research capabilities to those with unique capabilities.

In planning for the future, recognition of the NRC's current international reputation is vital. The international nuclear community has characterized the NRC's regulatory structure and its programs, processes, and practices as the "gold standard." This recognition was earned over decades of reactor regulation, with a focus on LWR technology. However, other nations have moved forward with non-LWR advanced reactor technologies and the NRC intends to take full advantage of their experience and expertise. The NRC envisions having a key role in future international regulatory initiatives.

The NRC's plans for including international activities in its efforts derives from the recognition that a number of nations, both developed and developing, are striving to commercialize advanced reactor technologies. Collaboration and harmonization of regulatory requirements, processes, and technical guidance at the international level is important to the safe and efficient evolution and eventual deployment of such technologies.

The NRC's plans involve initiatives and efforts that are national and international in nature, and it anticipates significant interaction with stakeholders including DOE, national laboratories, the commercial industry, and academia. The plan also anticipates significant involvement of the international nuclear community. The plan has three major components: (1) regulatory structure, (2) research efforts, and (3) human resource development. The components are closely intertwined.

The regulatory structure component is predicated on the expansion of the MDEP approach for advanced reactor technologies, either directly through an expansion of MDEP, formation of MDEP-like structures through the IAEA, or through bilateral or multilateral international agreements with countries currently operating or actively interested in licensing specific advanced reactor technologies. The plan would seek to expand significantly these international interactions, first through MDEP-like activities and then through the spectrum of international activities that could benefit the NRC's efforts to be ready to license advanced reactor technologies. In pursuing international engagements, the NRC would maintain interaction with DOE and the domestic industry to ensure broad stakeholder input regarding the technologies, licensing and operating experience, and overall safety philosophy.

To address research efforts, NRC envisions working closely with DOE, the Electric Power Research Institute, the Nuclear Energy Agency, IAEA, and the nuclear industry to motivate, manage, and cofund the research efforts, including unique facility development needed to support development and licensing of advanced reactor technologies. Based on specific research needs such as those summarized in Chapter 3, the NRC would work with the key national and international stakeholders to develop cooperative research activities to address those needs. The NRC will remain mindful of the need for clear independence in the regulatory aspects of these research endeavors by ensuring development of a clear and defensible set of research results to support regulatory decisions.

Regarding human resource requirements, NRC envisions coordinating its efforts with DOE, the domestic nuclear industry, and academia, to support national programs of classroom, laboratory, and field experience, funded in part by the NRC Educational Grants Program, that would support development, licensing, construction, and operation of nuclear power plants and the associated fuel fabrication facilities. To the extent that interaction with international programs would facilitate the NRC's mission to protect public health and safety and the common defense and security in the licensing and oversight of new reactor technologies and fuel facilities, our plans would include those interactions. For advanced technologies, the NRC expects that coordinated programs led by DOE and the industry would support the NRC's skill needs for advanced reactor technologies.

Correlated with advanced reactor technology research needs, NRC envisions continued and expanded national and international support for experimental and test facilities, such as those addressed in Chapter 4. The NRC expects that DOE would lead U.S. programs for such support. In addition, the NRC anticipates continued efforts by reactor vendors to develop the separate test facilities necessary to develop data to support their licensing applications.

The NRC's plans parallel the recommendations of the Blue Ribbon Commission on America's Nuclear Future (BRC) (**http://www.brc.gov/**). The BRC recommended additional research, development, and the deployment of advanced reactor and fuel cycle technologies, as well as stable funding to support a long-term research program. The BRC also recommended that adequate Federal funding be provided to the NRC to support a robust effort to develop a regulatory framework for advanced nuclear energy systems.

It is important to remember, however, that NRC assumes the submission of commercial advanced reactor design certification and licensing applications, as discussed in this report, solely for the purpose of providing the information Congress has requested. The discussion is not intended to promote the use of nuclear energy or any particular design or technology, and does not reflect any correlation with the NRC's planning or budgeting for 2014 or beyond. Such matters are outside NRC's statutory authority to promote or implement, but could be addressed by Congress as part of an integrated, national-level nuclear strategy. The NRC will continue to plan in a manner designed to effectively and efficiently accomplish the agency's anticipated advanced reactor licensing workload consistent with its mission and goals and with no compromise to the continued safety of the operating reactor fleet. ■

CHAPTER 1
INTRODUCTION

1.1 THE REPORT

The Consolidated Appropriations Act, 2012 (P.L. 112-74), contains, as one of its subdivisions, the Energy and Water Development Appropriations Act, 2012 (the Act), which sets forth the fiscal year (FY) 2012 appropriations for the U.S. Nuclear Regulatory Commission (NRC or the Commission).[2] The House Committee Report on the Act requested that the NRC provide a report that addresses, at a minimum, the following:

1. The anticipated advanced reactor licensing scope over the next 1 to 2 decades

2. The overall research and development (R&D) activities that should be conducted to support NRC reviews in anticipation of the advanced reactor licensing scope, including updating and extending national consensus standards

3. The projected resource requirements for both experienced personnel and development facilities to support the NRC given the anticipated scope of advanced reactor licensing

4. The overall plan for using and sharing the limited resources between industry and the Government, including use of the facilities and personnel at the national laboratories and elsewhere within Government and industry[3]

In response to the aforementioned Congressional request and follow-on NRC discussions with Congressional staff, the NRC has prepared this comprehensive report addressing the NRC's overall strategy for and approach to preparing for the licensing of advanced reactors. The report addresses licensing applications anticipated over the next 1 to 2 decades, as well as potential licensing beyond twenty years. The report focuses on the commercial application of advanced reactors (i.e., NRC licensing of nuclear reactor facilities for commercial and industrial use).

The NRC has monitored an increasing number of initiatives in recent years related to advanced reactor designs and technologies by an array of private and government entities that could lead to commercial licensing applications. This report reflects the possibility that this trend will continue and that some of the initiatives will evolve into licensing applications, in order to illustrate some potential regulatory challenges. However, it is important to recognize that the NRC, as an independent regulator, focused on the health and safety of the public and common defense and security, does not promote any particular technology or design or the use of nuclear energy. In the event that these initiatives develop to the extent they would be expected to result in licensing activities, the NRC would request appropriate resources through the agency's planning and budgeting process.

1.2 COMMISSION POLICY—ADVANCED REACTORS

The NRC's policy with respect to regulating nuclear power reactors, consistent with its legislative mandate, is to ensure adequate protection of public health and safety, the common defense and security and the environment. From the NRC's regulatory perspective, the characteristics of "advanced reactors" have evolved over past decades, and this evolution is expected to continue. On July 8, 1986, the Commission published a policy statement on the regulation of advanced reactors to address the then-anticipated advances beyond the then-current large, light-water-reactor (LWR) designs of the operating fleet.[4] The policy included three primary objectives:

1. to maintain the earliest possible interaction of applicants, vendors, and Government agencies with the NRC
2. to provide all interested parties, including the public, with the Commission's views concerning the desired characteristics of advanced reactor designs
3. to express the NRC's intent to issue timely comment on the implications of such designs for safety and the regulatory process

On July 12, 1994, the Commission updated and confirmed the 1986 policy statement on the regulation of advanced reactors.[5] On October 14, 2008, the Commission issued its current policy statement regarding advanced reactors and included items to be considered during the design of such reactors.[6] The Commission's 2008 Policy Statement on the Regulation of Advanced Reactors reinforced and updated the policy statements regarding advanced reactors previously published in 1986 and 1994. In part, the 2008 update to the policy states the following:

> Regarding advanced reactors, the Commission expects, as a minimum, at least the same degree of protection of the environment and public health and safety and the common defense and security that is required for current generation light-water reactors [i.e., those licensed before 1997]. Furthermore, the Commission expects that advanced reactors will provide enhanced margins of safety and/or use simplified, inherent, passive, or other innovative means to accomplish their safety and security functions.[7]

The "Generation III+" LWR designs, recently certified or currently undergoing NRC design certification reviews, incorporate, as practicable, the Commission's expectations for advanced reactors. License applications for the integral pressurized water reactor (iPWR) designs (i.e., small modular reactor (SMR) designs using LWR technology) are expected to be submitted in the near term. The NRC anticipates that these designs will incorporate to a greater extent the Commission's expectations for advanced reactors. Additionally, licensing applications for reactor designs using non-LWR technology may be submitted over the longer term and these designs may further incorporate the Commission's expectations.

1.3 NRC REACTOR REGULATIONS

The NRC regulations contained in Title 10 of the Code of Federal Regulations (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities,"[8] are applicable to all nuclear power reactors. The regulations were developed to ensure the safe operation of large LWR facilities and the current regulations incorporate experience gained over the past 50 years based on the design and operation of the current fleet of large LWR facilities. While the safety philosophy inherent in these regulations applies to all reactor technologies, the specific and prescriptive aspects of these regulations clearly focus on the current fleet of large LWR facilities.

NRC's regulations, which have undergone periodic revisions and updates, provide the licensing bases for the current fleet of LWR-design operating reactors and the Generation III+ LWR designs. In addition, these regulations provide the licensing bases for a limited number of commercial non-LWR designs and several designs of research and test reactors. They also provide the NRC with the regulatory framework for the agency's interactions with DOE regarding R&D programs for non-LWR designs (e.g., the sodium liquid-metal advanced fast reactor (1991), the modular high-temperature gas-cooled reactor (1996), the power reactor innovative small module liquid-metal reactor (1994), and the Next Generation Nuclear Plant (high-temperature, gas-cooled design) project identified in the Energy Policy Act of 2005[9]). The provisions of 10 CFR 50.12, "Specific Exemptions," identify a noteworthy flexibility that is applicable to advanced reactor designs independent of specific technology. This regulation permits the NRC to grant specific exemptions to the regulations in 10 CFR Part 50 under certain circumstances.

The NRC's nuclear power reactor regulations are workable and effective, as demonstrated by the agency's completion of application reviews and issuance of construction permits and operating licenses (under 10 CFR Part 50) and design certifications, combined licenses (COLs), and early site permits (under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants"[10]). With modifications, these regulations would provide the regulatory framework for licensing advanced reactor designs in the future.

Not surprisingly, the NRC's documented guidance for compliance with the regulations is similarly focused on the current LWR facilities. As a result, the NRC revised NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," issued March 2007,[11] and other regulatory guidance to reflect the Generation III+ LWR designs (e.g., AP1000, the economic simplified boiling-water reactor (ESBWR)). In addition, as discussed later in this report, the NRC is currently preparing regulatory guidance to address iPWR designs.

1.4 NRC STRATEGIC PLAN

The mission of the NRC is to license and regulate the Nation's civilian use of nuclear materials to ensure the adequate protection of public health and safety, promote the common defense and security, and protect the environment. The NRC's overarching planning aspect for mission success is the continued update and implementation of the NRC's Strategic Plan,[12] which defines the agency's strategic goals and identifies the programs, processes, skills, technologies, and resources used to achieve the stated goals.

Among the multiple challenges addressed in the current Strategic Plan is the review of licensing applications to construct and operate new nuclear power plants while continuing to ensure the safe and secure operation of the existing operating fleet. The NRC identified this ongoing multifaceted challenge years ago and anticipates that this challenge will continue for a number of years. Amplifying the challenge at the present time is the need to address appropriate lessons learned from the events at Fukushima in March 2011. While the future licensing of advanced reactor technologies, which is the focus of this report, may present variations of this challenge, the NRC is confident that it has in place adequate strategies to continue to carry out its mission and effectively perform its mandated functions now and in the future. The NRC's plan for moving forward is a continuation, modified as appropriate, of current agency programs, practices, and processes, along with the collaborative interrelationships with national and international agencies and ongoing interactions with licensees, applicants, industry, and other external stakeholders.

1.5 OVERVIEW—NRC NEW AND ADVANCED REACTORS

The NRC staff is conducting new reactor licensing review activities, refining the processes for overseeing new reactor construction, and addressing the significant policy and technical issues related to the licensing of advanced reactor designs. Figure 1.1 in the Appendix of Figures illustrates the schedule for new reactor licensing activities. Significant new reactor licensing milestones were achieved in December 2011 and in early 2012, when the Commission voted to approve a rule certifying an amended version of Westinghouse's AP1000 reactor design for use in the U.S. and then voted to approve issuance of COLs for the lead applications that reference the amended AP1000 design. These include Vogtle Electric Generating Plant, Units 3 and 4, under construction in Georgia, and Virgil C. Summer Nuclear Station, Units 2 and 3, under construction in South Carolina. It is expected that COLs will be issued for additional applications that reference the amended AP1000 design and other designs currently undergoing design certification reviews.

The NRC staff is preparing for a changing workload, which will shift in coming years from licensing large LWRs toward overseeing construction of these reactors and the licensing of advanced reactor designs. The focus in 2012 and beyond is on completing the licensing activities for the design certifications and COL applications now before the agency, expanding implementation of the construction inspection program to oversee construction activities as the COLs are issued, and beginning the review of applications for advanced reactor designs.

The NRC is aware that reactor designers are currently developing a number of small LWR and non-LWR designs that apply innovative solutions to technical nuclear issues. In addition to the traditional role of providing base load electricity, these advanced reactor designs could be used for generating electricity in isolated areas or for producing high-temperature process heat for industrial purposes. To facilitate the licensing review of new designs that differ from the large LWR facilities, the NRC is actively seeking to develop a regulatory infrastructure that uniquely supports the advanced reactor designs. The staff is intensifying its efforts to prepare the agency to review applications related to the design, construction, and operation of advanced reactors. This includes identifying and resolving policy, technical, and licensing issues related to advanced reactors; developing the regulatory framework to support efficient and timely licensing reviews;

engaging DOE, designers, and potential applicants in meaningful preapplication interactions; and coordinating activities with internal and external stakeholders.

With the development of new reactor designs and technologies, the NRC is working closely with the international community (e.g., the International Atomic Energy Agency (IAEA) and regulators in other countries who are interested in participating in the Multinational Design Evaluation Program (MDEP)). MDEP is a program where regulatory organizations jointly cooperate in sharing information about the review of specific new reactor designs. These next-generation designs require detailed evaluation of their safety, as well as development of inspections, tests, analyses, and acceptance criteria for their construction. Construction, startup, and operation of several first-of-a-kind nuclear power plants designed in the U.S. will likely occur in the U.S. and other countries as well. A significant percentage of the major components for these plants will be manufactured outside this country. To meet this challenge, the NRC is closely engaged with its counterpart regulatory authorities worldwide to enhance the sharing of relevant information, experience, and expertise.

1.6 NRC ADVANCED REACTOR PROGRAM

The NRC's advanced reactor program is focused on preparing the agency for reviews of applications related to the design, construction, and operation of advanced reactors. These efforts include the following:

- Identify and resolve significant policy, technical, and licensing issues.
- Develop the regulatory framework to support efficient and timely licensing reviews.
- Engage in research focused on key areas to support licensing reviews.
- Engage reactor designers, potential applicants, industry, and DOE in meaningful preapplication interactions and coordinate with internal and external stakeholders.
- Establish an advanced reactors training curriculum for the NRC staff.
- Remain cognizant of international developments and programs.

NRC policy encourages early discussion (i.e., before submission of a license application) between agency staff and potential applicants. This can often lead to the staff clarifying licensing guidance, as well as identifying and addressing potential regulatory and technical issues much earlier in the licensing process. Because some issues have the potential to influence design decisions, leaving such matters unaddressed before receipt of the applications could significantly complicate the licensing process, reduce the efficiency of the staff, and likely extend the review schedules.

In 2010, for example, with the goal of identifying any regulatory issues that could impact licensing reviews not previously identified, the NRC staff initiated the Issues Identification and Ranking Program (IIRP). This initiative included designated staff and a structured process to identify and prioritize potential issues. IIRPs were completed in six topical areas related to potential issues: (1) emergency preparedness, (2) control room staffing, (3) source term, (4) security, (5) environmental, and (6) cross-organizational.[13]

The NRC staff continues to interact with stakeholders, both internal (e.g., the Advisory Committee on Reactor Safeguards) and external (e.g., the nuclear industry, potential applicants, technical societies, DOE, IAEA, the public) as it moves towards resolving regulatory issues applicable to advanced reactors. For example, the staff has ongoing public regulatory workshops with the Nuclear Energy Institute (NEI) to discuss staff and industry positions on issues of interest.

To appropriately and safely license advanced reactors, the NRC is integrating the use of risk insights more fully into preapplication activities and the review of applications, focusing on iPWR designs in the near term. The agency's objective is to focus the review and staff resources on risk-significant structures, systems, components (SSCs) and other aspects of the design that contribute the most to safety. The approach includes: (1) use a more risk-informed and integrated review framework for staff preapplication and application review activities pertaining to iPWR design applications; and, (2) develop, over the longer term, a new risk-informed, performance-based regulatory structure for licensing non-LWR advanced reactor designs (e.g., high-temperature, gas-cooled reactors (HTGRs) and liquid-metal reactors (LMRs)).

1.7 BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE

The Blue Ribbon Commission on America's Nuclear Future (BRC)[14] (http://www.brc.gov/) recommended additional research, development, and deployment of advanced reactor and fuel cycle technologies, as well as stable funding to support a long-term research program. The BRC also recommended that adequate Federal funding be provided to the NRC to support a robust effort to develop a regulatory framework for advanced nuclear energy systems.

The NRC agrees that the potential exists for innovation in nuclear power technologies. The NRC also agrees that the development of a regulatory framework for advanced nuclear energy systems (reactors, fuel cycle, waste management) could provide confidence and stability in the regulatory process for advanced systems. ■

CHAPTER 2
REACTOR LICENSING

2.1 OVERVIEW

Ensuring readiness to carry out its responsibilities relating to reactor licensing applications that may be submitted in the future presents a challenge that the NRC has ably addressed in anticipation of applications for diverse reactor designs and technologies in the past. The NRC's current licensing requirements and processes set forth in 10 CFR Part 50 and 10 CFR Part 52 can be used for licensing future reactor designs and technologies. However, enhancements to the regulatory framework to address potential policy, licensing, and technical issues presented by advanced reactor designs, including both designs employing LWR technology and designs involving non-LWR technology, could contribute to improvements in the effectiveness and efficiency of future licensing. The NRC has steadfastly pursued such regulatory enhancements in the past and continues to do so.

For example, in early 2001, in anticipation of then-identified future industry applications related to the AP1000, the pebble bed modular reactor (PBMR), the International Reactor Innovative and Secure (IRIS), and other reactor designs, the Commission directed the staff to assess its readiness and the existing regulatory infrastructure and to identify appropriate enhancements. In response, the staff performed a comprehensive assessment and identified areas in which additional foresight was needed, including regulatory infrastructure changes, research activities,[15] and critical skills and resource challenges. The staff initiated multiple activities to address the identified needs, including increased interactions with industry. The staff encouraged industry to be as specific as possible with its plans and schedules for submitting new applications, in order to assist the NRC in planning for advanced reactor activities without impacting its responsibilities for licensed reactors and applications under review.

Furthermore, during the early-to-mid 2000s, multiple changes in industry plans regarding advanced reactor licensing applications mandated that the NRC revise its advanced reactor readiness activities. For instance, vendors cancelled the PBMR preapplication review and delayed and subsequently cancelled the anticipated IRIS application, while the NRC staff initiated the ESBWR preapplication review and initiated interactions with DOE for the Next Generation Nuclear Plant (NGNP) project.

Additionally, in 2006, in preparation for anticipated multiple licensing applications related to the AP1000, the advanced boiling-water reactor (ABWR), ESBWR, U.S. Evolutionary Power Reactor (EPR), and other reactor designs, the NRC adopted a new regulatory strategy that involved the standardization of licensing applications with the intent of optimizing application review activities, staff resources, and review schedules. Simultaneously, the NRC began using a formal process to gather advance information and notice of the industry's plans by issuing an annual Regulatory

Issue Summary (RIS), which asks the industry to voluntarily provide information on its plans and schedules for submitting design and licensing applications. These requests have proved successful, as they provide the industry an opportunity to voluntarily provide NRC with valuable information that assists the NRC's efforts to prepare for the anticipated applications. The NRC issued the most recent RIS request in December 2011[16]and the industry responses provide valuable information for NRC's planning for the next several years.

In recent years, the NRC has embarked upon and continues to pursue a variety of readiness activities to prepare for anticipated applications for several SMR designs that employ advanced technologies. To identify those issues that need to be addressed to support licensing reviews, the NRC staff has thoroughly reviewed and evaluated past advanced reactor experience and interacted with a variety of stakeholders. Currently, the NRC is focused on iPWR designs because several such applications are expected in the near term (i.e., within 5 years).

DOE has recently taken actions that increase the likelihood that licensing applications for SMR designs employing advanced technologies will be submitted to the NRC in the near term. In March 2012, DOE issued a funding opportunity announcement (FOA) to establish cost-shared agreements with private industry to support the design and licensing of SMRs.[17] The funding announcement supports first-of-a-kind engineering, design certification, and licensing through a cost-shared partnership and provides funding for up to two SMR designs. Congress directed DOE to consider applications utilizing any technology that can be expeditiously deployed. Accordingly, the FOA is focused on designs that can be expeditiously licensed and meet a commercial operation date on a domestic site by 2022.

To discuss the expectations, assumptions, and planning associated with advanced reactor technologies anticipated for future licensing, this report is structured in terms of the following broad timeframes pertaining to the potential submittal dates of advanced reactor applications: near term (within 5 years), longer term (within 10 years), horizon (10–20 years), and beyond the horizon (20+ years). The following sections address the anticipated licensing-related activities for these timeframes and the planning assumptions and bases for the assumptions. There is, of course, a greater degree of certainty for the near term than the other timeframes.

2.2 NEAR TERM (5 YEARS)

2.2.1 Integral Pressurized-Water Reactors The NRC is aware of a number of iPWR designs being considered and developed by industry both in the U.S. and other countries. These designs employ LWR technology with current design fuel and secondary loop steam generators, but also incorporate a number of advanced features and characteristics. The specific design features, power level, plant configuration, and operating characteristics vary among the vendors.

In the near term, based on information provided by the nuclear industry and direct communications with reactor designers and vendors and various business entities, the NRC expects the submittal of licensing applications for several iPWR designs. Applications are anticipated for both design certifications and COLs under 10 CFR Part 52 and construction permits and operating licenses under 10 CFR Part 50. The NRC believes that all of the iPWR designs will incorporate simplified, inherent, passive, or other innovative means to ensure that safety and security functions are consistent with the Commission's expectations for advanced reactors.[18]

2.2.2 Integral Pressurized-Water Reactor Preapplication Activities The NRC is currently engaged in preapplication interactions with several iPWR designers and vendors (i.e., potential applicants). At the present time, no application has been submitted and no design is undergoing formal licensing review. The agency anticipates one or more applications to be submitted in calendar year 2013, with additional applications in subsequent years. Figure 2.1 in the Appendix of Figures illustrates the preapplication and licensing application schedule based on information currently available to the NRC.

Below is a summary of the reactor designers and potential applicants with whom the NRC is currently engaged in preapplication activities.

2.2.2.1 BABCOCK & WILCOX NUCLEAR ENERGY, INC. The NRC has been engaged in preapplication activities with Babcock & Wilcox Nuclear Energy, Inc. (B&W NE) since mid-2009, following receipt of the company's letter of intent to submit an application for design certification for the B&W mPower™ advanced light-water reactor. The design is a 180-megawatt-electic (MWe) iPWR that consists of a self-contained module with the reactor core and steam generator located in a common reactor vessel (See Fig 2.2 in the Appendix of Figures). During 2011, the staff engaged B&W NE through multiple public meetings on various aspects of the company's mPower™ design. In February 2012, B&W NE provided a letter to the NRC that detailed its plans to submit approximately 35 topical or technical reports before submitting its design certification application, which is expected in 2013. The NRC staff has reviewed reports on topics such as design description, critical heat flux testing plan, and integrated system testing plan.

2.2.2.2 TENNESSEE VALLEY AUTHORITY In late 2010, the Tennessee Valley Authority (TVA) indicated its interest in building B&W NE mPower™ modules at the Clinch River site in Roane County, TN. TVA indicated that it would request a construction permit under 10 CFR Part 50 and submit a preliminary safety analysis report. TVA is engaged with the NRC staff to develop a licensing and regulatory framework for the construction and operation one or more mPower™ modules at the Clinch River site. Based on information provided by TVA, NRC plans to continue to engage with TVA in pre-application activities through FY 2012, and to receive TVA's construction permit application for the Clinch River site in the 2013–2014 timeframe.

2.2.2.3 NUSCALE POWER The NRC staff has been engaged in preapplication activities with NuScale Power (NuScale) since the company formally communicated its intent to file an application for design certification of the NuScale design and requested prelicensing interactions with the NRC in early 2008. NuScale aims to commercialize a modular, scalable 45-MWe iPWR design (See Figure 2.3 in the Appendix of Figures). The NRC has received topical reports from NuScale for review that cover areas such as quality assurance, human factors engineering, program management, accident analyses, and thermal-hydraulic and neutronics phenomena identification and ranking. NuScale and the NRC are continuing to discuss aspects of the design at public meetings.

2.2.2.4 WESTINGHOUSE ELECTRIC COMPANY Westinghouse Electric Company (WEC) has expressed interest in licensing an SMR design and is planning to submit an application for design certification to the NRC. The SMR is an iPWR design with a thermal power rating of 800 megawatts (MWt) (approximately 225 MWe). The design incorporates multiple passive design features, as well as many of the features incorporated in the AP1000 design (See Figure 2.4 in the Appendix of Figures). To date, the NRC staff has had limited preapplication interaction with WEC. Based on information provided by WEC, NRC anticipates that preapplication review work on the WEC SMR will accelerate later in 2012 and 2013.

2.2.2.5 HOLTEC INTERNATIONAL The Holtec Inherently Safe Modular Underground Reactor (HI-SMUR), also known as SMR-160, is a 160-MWe iPWR that is cooled by natural circulation and features a deep-underground, thick-walled reactor vessel (See Figure 2.5 in the Appendix of Figures). Holtec initially expressed interest in licensing the SMR-160 in late 2010. The NRC staff has had preapplication meetings with Holtec in 2011 and 2012.

2.3 LONGER TERM (10 YEARS)

2.3.1 Non-Light Water Reactors The term "non-LWR" encompasses a broad variety of reactor technologies and design concepts. It includes, for example, fast-spectrum-neutron and thermal-spectrum-neutron designs; solid-fuel and liquid-fuel designs; heavy-water, gas, and liquid-metal coolant designs; accelerator-driven reactors; and other technologies. Multiple non-LWR designs are being considered worldwide, with several undergoing design and development. In some cases, such designs are operational outside the U.S. In this country, several designs of non-LWR plants were constructed and operated for commercial, governmental, or test purposes in prior decades. However, at the present time, no non-LWR plant is in commercial operation in the U.S.

The NRC is aware of several efforts that could lead to the submittal of licensing applications for non-LWR designs within the next decade. A licensing application for the NGNP project, using HTGR technology, may be submitted, but the schedule is uncertain. In addition, one or more licensing applications for LMR designs by designers and vendors that are now under discussion with the NRC may be submitted.

2.3.2 Prior Non-Light Water Reactor Initiatives In the 1980s and 1990s, the NRC conducted preapplication reviews for several non-LWR designs in support of DOE's advanced reactor design initiatives. The NRC reviews were conducted using then-current regulations and guidance and provided insights for revisions necessary to support non-LWR designs. These preapplication activities, which included interactions with DOE, national laboratories, reactor designers and vendors, and stakeholders, addressed varied policy, technical, and licensing topics. The activities did not result in the certification of any design or licensing of any plant.

2.3.2.1 MODULAR HIGH-TEMPERATURE, GAS-COOLED REACTOR The NRC conducted a preapplication review of the conceptual design of the modular high-temperature, gas-cooled reactor (MHTGR) from 1986 to 1996. The staff documented the results of its review in NUREG-1338, "Pre-application Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor."[19],[20] The MHTGR reactor plant design is a small, modular, graphite-moderated, helium-cooled, high-temperature, thermal-power reactor plant design similar to that of the Fort St. Vrain plant which was licensed by the Atomic Energy Commission in the early 1970s and decommissioned in 1989.

The NRC directed its review approach and criteria toward meeting the guidance in the Commission's 1986 and 1994 advanced reactor policy statements. The review consisted of an in-depth analysis of the potential licensing issues associated with MHTGR's design features, potential policy issues, and technical issues, as well as confirmatory R&D programs and plans for prototype testing. In 1996, Congress eliminated funding for the MHTGR program, and the NRC terminated its review activities.

2.3.2.2 SODIUM ADVANCED FAST REACTOR AND POWER REACTOR INNOVATIVE SMALL MODULE In the 1980s, DOE funded studies for conceptual designs of advanced liquid-metal reactor plants through its Advanced Liquid Metal Reactor (ALMR) Program. DOE supported two designs—Rockwell International's Sodium Advanced Fast Reactor (SAFR) and General Electric's Power Reactor Innovative Small Module (PRISM). Both designs incorporated the use of multiple SMRs cooled by liquid sodium and consisted of multiple power units per site, colocated with a spent fuel processing facility. In support of DOE, the NRC began a preapplication review of the preliminary safety information documentation for these two designs in 1986. The NRC staff conducted these reviews in accordance with the Commission's policy on advanced reactors with a focus on policy, licensing, and technical issues.

In the early 1990s, DOE discontinued its development of the SAFR design and concentrated on the PRISM design. However, DOE requested that the NRC staff complete its review of the SAFR design. The NRC published its preapplication safety evaluation report (PSER) for the SAFR design in NUREG-1369, "Preapplication Safety Evaluation Report for the Sodium Advanced Fast Reactor (SAFR) Liquid-Metal Reactor," issued December 1991, and the PRISM PSER in NUREG-1368, "Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor," issued February 1994. DOE canceled the ALMR Program in 1994, and the NRC terminated its PRISM review efforts.

2.3.2.3 PEBBLE BED MODULAR REACTOR Exelon Generation Company (Exelon) began preapplication discussions with the NRC on the licensing of the PBMR in the U.S. in 2001. The PBMR is a pebble-bed, helium-cooled, thermal HTGR design. The preapplication interactions included NRC review of a series of Exelon, prepared white papers on licensing and technical topics. Exelon subsequently ended interactions and the NRC did not prepare a PSER.

PBMR (Pty) Limited, a South Africa-based firm established in 1999 to develop and market small-scale, high-temperature reactors both in South Africa and internationally, conducted preapplication discussions with the NRC regarding the PBMR design in the early 2000s. These discussions included NRC review of a series of white papers from PBMR (Pty) Ltd. Ultimately, PBMR (Pty) Ltd. did not submit a licensing application.

2.3.3 Next Generation Nuclear Plant Project Consistent with the Energy Policy Act of 2005, the NRC actively participates with DOE regarding research and preapplication regulatory activities for DOE's NGNP project—a reactor employing HTGR technology with the design yet to be finalized (See Figure 2.6 in the Appendix of Figures). DOE began the NGNP project in 2006 and determined that it would be conducted in two phases. The first phase calls for an extensive R&D program geared towards selecting and validating HTGR technology. The second phase is a continuation of the R&D activities in Phase 1, which would culminate in an NRC license for construction and operation through a public-private partnership. A joint DOE/NRC working group developed the strategy for licensing the NGNP. The Next Generation Nuclear Plant Licensing Strategy Report to Congress, filed in August 2008, documents this strategy. The report identifies NRC licensing requirements for LWRs that could present a challenge to licensing non-LWR technologies.

On October 17, 2011, the Secretary of Energy forwarded to Congress a report[21] stating the status of Phase 1 activities. The report contained the recommendations of the Nuclear Energy Advisory Committee, which included the following:

> Given current fiscal constraints, competing priorities, projected cost of the prototype, and the inability to reach agreement with industry on cost share, the Department will not proceed with Phase 2 design activities at this time. The Project will continue to focus on high temperature reactor research and development activities, interactions with the Nuclear Regulatory Commission to develop a licensing framework, and establishment of a public-private partnership until conditions warrant a change of direction.

Subsequently, DOE converted Phase 2 of the project into a longer term R&D program of reduced scope. The NRC continues preapplication licensing activities focused on a series of DOE sponsored white papers. The NRC will develop policy issue assessment reports regarding pertinent issues that stem from the white papers.

Recently, the NGNP Industry Alliance (Alliance), a consortium of private sector firms, in response to the NRC's December 2011 Regulatory Issue Summary, informed the agency of planned activities to support the future commercialization of modular HTGR technology. The Alliance announced the selection of the AREVA prismatic core modular HTGR in a steam cycle configuration for initial applications for cogeneration of process heat and electricity and a target date of 2015 for submittal of a construction permit application, in accordance with 10 CFR Part 50. The Alliance stated it is continuing to evaluate licensing options and the site for the facility.

2.3.4 Liquid-Metal Reactors—PRISM, 4S, and Gen4 Module Several private industry reactor designers and vendors have held discussions with the NRC regarding different fast-spectrum-neutron LMR designs. The NRC staff is currently engaged in preliminary preapplication discussions with three firms. At this time, no application has been submitted. Figure 2.1 in the Appendix of Figures illustrates the preapplication and application schedule suggested by the designers based on information currently available to the NRC.

2.3.4.1 PRISM DESIGN GE Hitachi Nuclear Energy (GEH) continues development of the PRISM design, a small, modular, pool-type, liquid-metal (sodium) fast reactor with metallic fuel producing 840 MWt power (See Figure 2.7 in the Appendix of Figures). As previously identified in this report, the NRC staff conducted a preapplication review in the early 1990s that resulted in publication of NUREG-1368. GEH has continued design development work that includes preliminary preapplication discussions with the NRC. In 2010, GEH provided the NRC with a draft licensing strategy for the PRISM design for informal NRC consideration.

In its communications with the NRC, GEH has expressed an interest in submitting a licensing application at an unspecified future date.

2.3.4.2 4S DESIGN The Toshiba Corporation (Toshiba) is developing the Super-Safe, Small and Simple (4S) design, a small, pool-type liquid-metal (sodium) fast reactor with metallic fuel (See Figure 2.8 in the Appendix of Figures). In combination with power generation equipment, the reactor is designed for use as a power source in remote locations and intended to operate for 30 years without refueling. The 4S has a primary electrical output of 10 MWe (30 MWt). The NRC and Toshiba began discussions for the preapplication review in late 2007 and such discussions have continued on a periodic basis. Toshiba has submitted various technical reports pertaining to the 4S design for NRC consideration. The company has informed the NRC that it plans to submit a licensing application at an unspecified future date.

2.3.4.3 GEN4 MODULE Gen4 Energy, Inc., previously Hyperion Power Generation, Inc., has under development a small, liquid-metal (lead-bismuth eutectic coolant) fast reactor with uranium nitride fuel designed to produce 25 MWe (70 MWt) power (See Figure 2.9 in the Appendix of Figures). The firm is conducting preliminary discussions with the NRC and has expressed its intent to submit a licensing application at an unspecified future date.

2.4 REACTOR DESIGNS AND TECHNOLOGIES ON THE HORIZON (10–20 YEARS)

The NRC anticipates that it could receive commercial licensing applications within the timeframe of 10-20 years based on the agency's awareness of nuclear industry planning, the current state of reactor technologies and designs, and the expected future research and development associated with those technologies. The likelihood of future commercial licensing applications in this time frame, which NRC refers to as "on the horizon," is dependent on many factors outside the statutory or regulatory authority of the NRC, including but not limited to the pace of technology development, economic considerations, public and Congressional support for nuclear power, and other factors that impact the viability of the commercial nuclear industry.

Currently, in addition to those designs discussed above, the NRC is aware of other varied reactor technologies and numerous conceptual designs under development worldwide. The NRC's familiarity with the current status and future expectations for such technologies and designs is based on information acquired from interactions with DOE, IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), the Nuclear Energy Agency (NEA), and MDEP; the staff's participation in varied international conferences and symposia; and other external sources.

In addition to potential applications related to new advanced reactor designs, the NRC anticipates receiving additional COL applications under 10 CFR Part 52 during this timeframe. As discussed previously, based on information potential advanced reactor design and licensing applicants have provided in preapplication discussions, the NRC also expects to continue its work on iPWRs and other advanced reactor designs in the next 10–20 years. Based on information the industry has provided voluntarily in response to NRC's Regulatory Issue Summaries, NRC expects that a large portion of its new reactor licensing work in the next 10–20 years will center on iPWRs and other advanced reactor designs currently undergoing preapplication reviews.

Further, NRC has based its prediction for future commercial licensing applications on an expectation that such applications would likely stem from those technologies currently identified and actively being developed through DOE's funding and research and development activities. In addition, NRC has based its prediction for future commercial licensing applications on Generation IV International Forum (GIF) funding and research and development activities, which are described below. The following paragraphs provide a summary of the technologies currently undergoing research supported by GIF and DOE. These funding, research and development activities could potentially lead to design certification and licensing applications which the NRC would review within the next 10-20 years.

2.4.1 Generation IV International Forum GIF was chartered in 2001 to lead the collaborative efforts of the world's leading nuclear technology nations to develop the next generation of nuclear energy systems. GIF's efforts resulted in the identification of the six most promising reactor concepts for the international research community to investigate. The report titled "A Technology Roadmap for Generation IV Nuclear Energy Systems," issued December 2002, documented this goal. The DOE Nuclear Energy Research Advisory Committee and GIF jointly published the report.[22] As stated in that report, depending on their respective degrees of technical maturity, the Generation IV systems are expected to be introduced commercially between 2015 and 2030 or beyond.

The GIF goals provided the basis for identifying and selecting six nuclear energy systems for further development. The six selected systems employ a variety of reactor, energy conversion, and fuel cycle technologies. Their designs feature thermal and fast neutron spectra and closed and open fuel cycles, as well as a wide range of reactor sizes from very small to very large. GIF selected the following Generation IV systems for further study: gas-cooled fast reactor (GFR), lead-cooled fast reactor (LFR), molten salt reactor (MSR), sodium-cooled fast reactor (SFR), supercritical-water-cooled reactor (SCWR), and very high-temperature reactor (VHTR). See Appendix of Figures (Figures 2.10 - 2.15) and a descriptive summary of these systems below (http://www.gen-4.org/PDFs/GIF_Overview.pdf). In addition, the IAEA's Advanced Reactors Information System (ARIS) (http://aris.iaea.org) database provides comprehensive information on advanced designs and concepts, ranging from evolutionary LWR designs and iPWRs for near-term deployment to innovative concepts still under development.

GAS-COOLED FAST REACTOR -The main characteristics of the gas-cooled fast reactor are fissile self-sufficient cores with fast neutron spectrum, robust refractory fuel, high operating temperature, high efficiency electricity production, energy conversion with a gas turbine and full actinide recycling possibly associated with an integrated on-site fuel reprocessing facility. A technology demonstration reactor needed to qualify key technologies could be put into operation by 2020.

LEAD-COOLED FAST REACTOR -The lead-cooled fast reactor system is characterized by a fast-neutron spectrum and a closed fuel cycle with full actinide recycling, possibly in central or regional fuel cycle facilities. The coolant could be either lead or lead/bismuth eutectic. The LFR can be operated as a breeder; a burner of actinides from spent LWR fuel; or a burner/

breeder using thorium matrices. Two reactor size options are considered: a small transportable system of 50 to 150 MWe with a very long core life and a medium system of 300 to 600 MWe. In the long term, a large system of 1200 MWe could be envisaged. The LFR system may be deployable by 2025.

MOLTEN-SALT REACTOR -The molten-salt reactor system embodies the very special feature of a liquid fuel. MSR concepts, which can be used as efficient burners of transuranic elements (TRU) from spent LWR fuel, have also a breeding capability in any kind of neutron spectrum ranging from thermal (with a thorium based fuel cycle) to fast (with the U-Pu fuel cycle). Whether configured for burning or breeding, MSRs have considerable promise for the minimization of radiotoxic nuclear waste.

SODIUM-COOLED FAST REACTOR -The sodium-cooled fast reactor system uses liquid sodium as the reactor coolant, allowing high power density with low coolant volume fraction. The reactor can be arranged in a pool layout or a compact loop layout. Reactor size options under consideration range from small (50 to 300 MWe) modular reactors to larger reactors (up to 1500 MWe). The two primary fuel recycle technology options are advanced aqueous and pyrometallurgical processing. A variety of fuel options are being considered for the SFR, with mixed oxide preferred for advanced aqueous recycle and mixed metal alloy preferred for pyrometallurgical processing. Owing to the significant past experience accumulated with sodium cooled reactors in several countries, the deployment availability of SFR systems is targeted for 2020.

SUPERCRITICAL-WATER-COOLED REACTOR -Supercritical-water-cooled reactors are a class of high-temperature, high-pressure water-cooled reactors operating with a direct energy conversion cycle and above the thermodynamic critical point of water (374°C, 22.1 MPa). The higher thermodynamic efficiency and plant simplification opportunities afforded by a high-temperature, single-phase coolant translate into improved economics. A wide variety of options are currently considered: both thermal-neutron and fast neutron spectra are envisaged and both pressure vessel and pressure tube configurations are considered. The operation of a 30 to 150 MWe technology demonstration is targeted for 2022.

VERY-HIGH TEMPERATURE REACTOR -The very-high temperature reactor is a next step in the evolutionary development of high-temperature reactors. The VHTR is a helium gas-cooled, graphite-moderated, thermal neutron spectrum reactor with a core outlet temperature greater than 900oC, and a goal of 1000oC, sufficient to support production of hydrogen by thermo-chemical processes. The reference reactor thermal power is set at a level that allows passive decay heat removal, currently estimated to be about 600 MWt. The VHTR is primarily dedicated to the cogeneration of electricity and hydrogen, as well as to other process heat applications. It can produce hydrogen from water by using thermo-chemical, electrochemical or hybrid processes with reduced emission of CO2 gases. At first, a once-through low-enriched uranium (<20% U-235) fuel cycle will be adopted, but a closed fuel cycle will be assessed, as well as potential symbiotic fuel cycles with other types of reactors (especially light-water reactors) for waste reduction.

2.4.2 U.S. Department of Energy DOE is leading efforts to research and develop nuclear energy technologies to help meet U.S. energy security, proliferation resistance, and climate goals which include developing the next generation of nuclear power technologies. DOE's Office of Nuclear Energy (NE) funds R&D to assure the U.S. has viable nuclear energy options to meet the nation's energy needs and the DOE 2010 Nuclear Energy Research and Development Roadmap,[23] presents a high-level vision and framework for R&D activities both in the near term and in years ahead. NE is conducting varied R&D activities that encompass the technology concepts selected by GIF. For example, NE's Advanced Reactor Concepts program and Small Modular Reactors program fund R&D on SFRs, LFRs, HTGRs, and light-water SMRs.

The U.S. is pursuing the VHTR concept within the NGNP Project, consistent with the *Energy Policy Act of 2005.* The NGNP program includes R&D support for fuels and materials and is intended to contribute to the commercialization of this concept. Further discussion is provided in Chapter 3.

DOE research continues on SFR technologies to support potential future fuel cycle or waste disposal options, although no active SFR demonstration project is underway. DOE also supports SFR international safety and licensing collaboration under a trilateral agreement with France and Japan.

For LFR technology, DOE recently funded the restart of the Lead/Lead Bismuth Loop, to support testing of lead and lead-bismuth coolants, at Los Alamos National Laboratory.

2.5 REACTOR DESIGNS AND TECHNOLOGIES BEYOND THE HORIZON (20+ YEARS)

Predicting the commercial potential of alternative nuclear technologies beyond 20 years involves a high level of uncertainty and complexity. As previously noted, the likelihood of commercial licensing applications depends on many factors beyond the NRC's statutory and regulatory authority. As NRC considers the potential receipt and review of advanced reactor design and license applications, it is feasible that any, or none, of the technologies and designs currently identified and undergoing preliminary or advanced development by national or international private entities, public-private consortia, non-U. S. Government agencies, or other entities may result in future commercial applications.

Based on information NRC has received from the industry, DOE, international organizations, and other stakeholders, NRC anticipates that in the timeframe beyond twenty years from now, NRC's advanced reactor work will focus on continuing its review of commercial licensing applications that reference then-certified reactor designs and new reactor design applications. For example, should DOE's support for SFR and/or VHTR technologies result in one or more commercial license applications within 10-20 years, the NRC would anticipate additional applications referencing those designs in subsequent years.

In addition, the NRC anticipates receiving and reviewing potential commercial licensing applications for those reactor technologies and designs that are currently and actively supported by GIF funding and R&D activities. As an example, GIF has identified the gas-cooled fast reactor, supercritical-water-cooled reactor, lead-cooled fast reactor, and molten salt reactor, for development but DOE does not currently prioritize these technologies for R&D. Depending on GIF's R&D activities concerning these technologies, NRC could potentially receive design certification and/or license applications referencing these designs twenty years from now and beyond. In general, based on NRC's knowledge of R&D activities concerning these technologies, applications for such designs should be considered feasible only in the timeframe of "beyond the horizon."

Additional insight into NRC's potential work on advanced reactors twenty years from now and beyond derives from a recent report by the Reactor and Fuel Cycle Technology Subcommittee of the Blue Ribbon Commission on America's Nuclear Future.[24] The subcommittee was formed to examine issues surrounding the potential of existing and future reactor and fuel cycle technologies and related R&D programs. The subcommittee concluded the following:

> Alternatives to the once-through fuel cycle (as practiced in the United States, Sweden, Canada and elsewhere) or to the modified open fuel cycle (as practiced in France, Japan, and Russia and planned in some other countries) will require decades of RD&D before they are ready for widespread commercial application.

The NRC acknowledges that fast-spectrum reactors are a potential component in the nation's long-term energy solution and a sustainable fuel cycle because such reactors have the ability to burn recycled nuclear fuel. Should Congress determine that fully or partially closing the fuel cycle in part by using advanced reactor technologies is in the national interest, the NRC would expect that it would take approximately 20 years before commercial licensing applications for several fast reactor designs would be received. NRC also notes that should fast-spectrum reactors be used in this manner, NRC's work concerning high-level radioactive waste management will also be impacted, especially if such designs are deployed internationally.

2.6 FUEL FACILITIES, TRANSPORTATION, STORAGE, AND WASTE

Any advanced reactor design that utilizes fuel that differs significantly from the current type (zirconium-clad, low-enriched uranium dioxide (UO_2)) will require the evaluation of technical information and regulatory approaches to the licensing of fuel fabrication, transportation, storage, and waste disposal operations.

2.6.1 New Fuel Fabrication and Transportation The availability of nuclear fuel in commercial quantities may present a significant challenge to operating some designs of advanced reactors. For the iPWR designs that use fuel and fuel assemblies similar to those in the current LWR fleet, the existing fuel fabrication facilities should be able to manufacture such fuel. However, for HTGR and LMR designs that use fuels substantially different from the fuel used in the current LWR fleet, especially fuel designs with greater than 5-percent enrichment, new fuel fabrication facilities, new spent fuel storage designs, and new transportation packages may be needed. As discussed further in Chapter 3, fuel related research is likely necessary to support commercialization of an advanced reactor design, particularly non-LWRs.

Higher uranium-235 (U-235) assay levels are needed for higher burnup fuel. The capacity for producing higher assay fuels at existing uranium enrichment plants is expected to be limited.

Several enrichment plants in the U.S. and Europe are also limited to five weight percent U-235. To accommodate the production of higher assay fuels, licensing of enrichment plants designed for higher assays will be necessary. In addition, uranium hexafluoride (UF_6) transportation cylinders for enriched product will need to be certified for products above five weight percent U-235. The standard transportation cylinder in use today for shipment of enriched UF_6 from enrichment plants to fuel fabrication facilities is the 30B cylinder, which has a maximum net weight of 2.5 tons and is approved for up to five weight percent U-235. The next largest UF_6 cylinder approved for greater than five weight percent U-235 is the 8A cylinder, which has a maximum net weight of 255 pounds and is approved for up to 12.5 weight percent U-235. The smaller 8A cylinder would be less practical for the shipment of commercial quantities of enriched product. Therefore, certification of new UF_6 transportation packages will be necessary if industry seeks to use higher burnup fuels.

NRC licensing of facilities to manufacture non-LWR fuels could be done under the current regulatory scheme. Alternatively, the agency could develop specific regulations for non-LWR fuels for fuel facility licensing. Regardless of the regulatory framework, NRC licensing would require a detailed review of the proposed site, proposed facility, and proposed operations. The review would determine whether the applicant has identified, evaluated, and established controls for potential hazards, particularly hazards that differ substantially from those associated with low-enriched uranium (LEU) fuel facilities where the NRC has regulatory experience. New hazards could result from the nuclear material being processed (plutonium or other actinides rather than uranium) or the chemical form of the nuclear material (metal or nitride rather than oxide), or the chemicals used in fuel processing operations (organics, strong oxidizers, or strong reducing agents). Such licensing reviews would require substantial effort because current experience with the design and operation of such facilities is limited. In addition, several current fabrication facilities would need to amend their licenses to possess fuels of higher enrichments. The NRC would conduct material control and accounting (MC&A) reviews and physical security reviews to ensure that nuclear material is adequately accounted for, controlled, and protected.

2.6.2 Spent Fuel and Radioactive Material Transportation It is possible that current LWR transportation packages and storage cask designs may be modified to accommodate new and spent fuel for advanced LWR and non-LWR designs, but existing packages and cask designs may require additional testing before certification, taking into account spent fuel analysis or the new designs. New transportation package and storage cask designs would likely be needed for some non-LWR fuels. Furthermore, an updated security assessment may be required to address or bound the new fuel assembly designs.

Transportation requirements for spent nuclear fuel in NRC regulations are broad enough to address any type of radionuclide or fissile material and are not specific to any fuel type. The NRC currently issues certificates of compliance for transportation packages to transport fresh and spent power reactor and research reactor fuel that may be similar to advanced LWR and some non-LWR fuels. However, for non-LWR reactor fuel, the NRC will need to prepare for shipping these fuels on a larger scale, in addition to preparing for the review and approval of new types of fuel designs. Other challenges may face the NRC with respect to licensing or certifying transportation packages for these reactors. For example, some reactor designers have expressed interest in shipping modular reactors as fully fueled units, and some reactor designs may use nonradioactive hazardous materials that may also need to be shipped, such as liquid sodium for SFRs.

2.6.3 Interim Storage The NRC licenses dry storage of spent nuclear fuel under 10 CFR Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste." Spent nuclear fuel may be stored in an NRC certified cask at an existing site with a 10 CFR Part 50 or 10 CFR Part 52 license or at a specifically licensed independent spent fuel storage installation (ISFSI) either at, or away from, a reactor site. The NRC issues certificates of compliance for cask systems and licenses for onsite storage of spent nuclear fuel in casks that meet the applicable safety requirements in 10 CFR Part 72.

Spent nuclear fuel storage regulations in 10 CFR Part 72 are generally broad enough to address new types of fuel associated with advanced reactor designs. However, minor modifications may be necessary to address new design features from any new class of cask storage technologies associated with advanced reactor fuels. The NRC would need to evaluate the adequacy of new storage cask designs for onsite storage of advanced LWR and non-LWR fuel designs and any other radioactive components not previously reviewed as part of the current LWR technology. The NRC would consider how cask designs may be affected by different discharge and loading operations, since discharged fuel may not be housed in traditional spent fuel pools. Other challenges may involve stacking spent fuel for non-LWRs during refueling operations, as well as detecting, segregating, and processing damaged fuel.

2.6.4 Waste Disposal For spent fuel and high-level waste disposal, the NRC staff expects that the use of a risk-informed, performance-based framework would provide adequate flexibility to accommodate geologic disposal of alternate waste forms arising from non-LWR fuel cycles.

2.6.5 Reprocessing The NRC is aware of continued industry interest in submitting licensing applications for reprocessing facilities. The existing regulatory framework for spent nuclear fuel reprocessing would require substantial revisions to allow NRC to effectively and efficiently review a potential application for reprocessing. In November 2011, the staff submitted SECY-11-0163, "Reprocessing Rulemaking: Draft Regulatory Basis and Path Forward," to the Commission.[25] This paper outlines the status of reprocessing rulemaking activities and schedule. ■

CHAPTER 3
RESEARCH NEEDED TO SUPPORT LICENSING

3.1 OVERVIEW

A decision by the NRC to issue a license to an applicant to operate a nuclear power plant, based on any technology, is guided by a finding that, in the opinion of the Commission, the issuance of such a license will not be inimical to the health and safety of the public or to the common defense and security. Reviews by the NRC staff to support this finding are based on careful assessments of the design and proposed operation, addressing accident prevention, accident mitigation, the protection of barriers to the release of radioactive materials, and offsite consequences in the unlikely event of a release to the environment. For LWR technology, specific criteria, established over the last 50 years, support the staff's findings. These criteria are based on extensive analysis and testing of the SSCs that make up an LWR. In large measure, the domestic and international research community have developed analysis tools, performed experiments, and conducted laboratory testing that support these criteria.

For non-LWR advanced reactor technologies, however, the research base is much more limited and, for some beyond-the-horizon design concepts, almost nonexistent. For this reason, the NRC expects that significant research efforts will need to be undertaken to support the agency's licensing decisions. Such research must be conducted so that the analysis methods and experimental data can support an independent safety finding by the NRC staff. This chapter describes the types of analysis tools and supporting data and experiments that would be needed to efficiently and effectively license the advanced reactor technologies described in Chapter 2. Chapter 5 discusses the overall plan for how the NRC might gain access to the analysis tools and data necessary for its decision making for review and approval of advanced reactor design certification and license applications.

Figure 3-1 in the Appendix of Figures depicts the key areas of the regulatory analyses conducted to support the NRC's licensing process. It is clear from this figure that a broad-scope research effort would be needed to develop the analysis methods and supporting data the agency would seek to formulate its safety findings for certifying an advanced reactor design and licensing a facility referencing a certified design based on an advanced reactor technology. The balance of this chapter explores the research needs and strategies for meeting those needs.

3.2 REACTOR SAFETY

3.2.1 Safety Analysis In support of overall reactor safety, the topic of safety analysis encompasses the areas of accident analysis and reactor and plant analysis. Reactor and plant analysis measures reactor and plant performance under normal operating and design-basis conditions, whereas accident analysis verifies reactor and plant performance under accident conditions. Both areas of analysis rely on thermal-hydraulic (or thermal-fluid in the case of non-water technologies) and neutronic (reactor physics) aspects of technologies and include, for example, accident progression modeling, primary system and containment performance, and fission product behavior modeling. The topic of consequence analysis is an extension of reactor safety analysis because it addresses the radiological consequences of a potential accident.

For any reactor design, analytical tools, data, and associated R&D are needed for confirmatory safety analysis to address challenges to three basic safety functions: (1) adequate heat removal, (2) reactivity control, and (3) confinement of radioactivity. The challenge to heat removal centers on timely and sufficient cooling of the fuel element, the core, the reactor vessel, and the confinement, which are all critical to preventing failures of fission product barriers. The challenge to reactivity control requires maintaining the reactor in a stable condition. The challenge to confinement of radioactivity calls for maintaining integrity of the fuel, the core structures, the primary pressure boundary, and the reactor confinement structures, thus limiting the release of radioactivity to the environment. Analytical tools must be able to verify the adequacy of the safety features of a given design to address these challenges.

Safety analysis tools are used to calculate heat transfer and fluid flow in the reactor core, primary pressure boundary, confinement, and other components to provide more reliable assessment of heat removal and cooling under normal operating, design basis accident, and beyond design basis accident conditions. Moreover, these tools must be able to calculate maximum fuel temperature that provides a critical input to source term (i.e., fission products) and radiological consequence calculations. The sources of heat in the reactor are fission chain reactions and fission products decay. Nuclear analysis (neutronics) tools are used at the front end of reactor safety analysis to predict in-reactor heat sources. The tools are also used at the back end of the nuclear fuel cycle for spent fuel storage, handling, and transportation analysis.

The analysis tools in thermal-hydraulic and neutronics for existing LWR designs are mature, have a fairly extensive validation database, and have been used successfully in various applications (e.g., plant license renewal, power uprate) and resolution of specific safety issues. The NRC expects that these tools can be used with minimum modifications for confirmatory safety analysis of iPWR designs. Conceivably, component models need to be developed or modified for specific SMR designs (e.g., helical coil steam generator heat transfer model, heatup model of spent fuel pool having tie-in with multiple reactor modules). Such modifications are viewed as relatively modest and can be readily accomplished once specific design information becomes available.

However, extending the capabilities of the current safety analysis tool sets to non-LWRs would require much more developmental work. For example, the HTGR designs use a fuel form significantly different from LWR fuel. The HTGR fuel form employs the coated fuel particle technology, in which the fuel itself can be a fissile-fertile mix with enrichment in excess of nominal

LWR enrichment (albeit still within the limit of LEU), and the coating is composed of multiple layers of graphitic and ceramic materials. This particular fuel form acts as a heterogeneous system with regard to its neutronic behavior. To support licensing of an HTGR, the current suite of nuclear analysis tools would need to be modified to address this heterogeneity. Nuclear analysis tools would also need to be developed for higher enrichment (greater than nominal five percent enrichment but less than twenty percent) and higher burnup fuel.

In the thermal-fluids area of HTGR safety analysis, there would be a need to develop new tools or modify existing LWR-based tools to address the most safety-significant issues and phenomena. These issues include those pertaining to primary system heat transport that impact fuel and component performance. The modular HTGR core is relatively large for its power level and operates at very high temperatures. The tall cylindrical/annular HTGR core can produce localized or asymmetric flow and temperature distributions, the effects of which can be important for reactor safety. As a result, there would be a need to develop thermal-hydraulic analysis tools to simulate the multi-dimensional temperature profiles and flow distributions in an HTGR core and pressure boundary. The full spectrum of accident scenarios for HTGR design basis has not been firmly established yet. Events involving the loss of helium pressure boundary are likely to be the most significant for radiological consequences.

The safety research needs in HTGR technology are being informed by significant research activities in the last decade, in accordance with the enactment of the Energy Policy Act of 2005 and the establishment of GIF, which is addressing a host of advanced reactor technologies. The results of completed and ongoing research are expected to significantly narrow the gap between the HTGR needs and the HTGR knowledge base.

As discussed in Chapter 2, LMR technology is being pursued. Such technology utilizes a liquid metal, which is predominantly sodium, although lead and a mixture of lead and bismuth have also been proposed as the reactor coolant. The technology of liquid sodium is more mature compared with that for lead-based coolants. In any LMR reactor or concept to date, heat from the liquid metal is transferred to water to produce steam in a liquid-metal-to-water heat exchanger. LMRs do not have a traditional emergency core cooling system as it exists in LWRs. Rather, this design employs sealed and inerted guard vessels that fit around the reactor vessel and key components to catch and retain any leaking coolant. LMRs generally rely on natural convection to remove decay heat. Sodium reacts chemically with both air and water; thus the design must limit the potential for such reactions and their consequences. Safety analysis for this concept should have the ability to analyze such issues as the metal-water reaction associated with steam generator tube rupture. There is also a need to develop verified and validated tools to address sodium fires and sodium concrete interactions.

Furthermore, research is required to adequately characterize and model the physical phenomena and design features of LMRs. These design features are relied on to achieve passively a safe response to design basis transients and anticipated transients without scram. The features include reactivity feedback properties, such as the Doppler effect, coolant void worth, axial fuel expansion, radial expansion, control rod drive line expansion, and reactor vessel expansion. Criticality tests need to be performed on a prototype test reactor to qualify reactivity feedback on the core. Some integral tests involving passive reactivity feedback have been performed in earlier sodium-cooled reactors (e.g., the experimental breeder reactor-II (EBR-II) for a small metallic core; the fast flux test facility (FFTF) for a mixed oxide core). Additional experiments are needed to extend the range of data to cover the range of conditions expected for design basis and beyond-design basis postulated initiating events. Other areas of research needs include multi-dimensional thermal-hydraulic modeling of the upper plenum of the reactor, treatment of two-phase sodium, and thermal-fluids analysis of the reactor vessel auxiliary cooling system for decay heat removal.

For reactor technologies employing innovative fuel (e.g., accident-tolerant fuel) and coolant (e.g., molten salt) in any combination and employing either active or passive safety features, the basic elements of safety analysis (i.e., thermal-hydraulics or thermal-fluids, neutronics, fission product behavior) for current reactor technologies would need to be carefully examined for their applicability to these new technologies. A precise assessment of research needs can be made only after such careful examination.

3.2.2 Fuel Analysis The analysis tools for fuel performance behavior in existing LWR designs are mature and feature a fairly extensive validation database. The fuel form is conventional (i.e., UO2-based fuel with nominally less than five percent enrichment and a clad component made from some variants of zircaloy). The fuel form for iPWRs is expected to be the same or substantially similar to the LWR fuel form. Based on this expectation, the NRC anticipates that existing fuel analysis tools can be used with minimal, if any, modifications for confirmatory safety analysis of iPWRs.

The fuel form for gas-cooled reactors is very different. Tiny kernels of uranium oxide or uranium oxycarbide fuel with enrichment in excess of five percent, but within the LEU limit of 19.9 percent, are encapsulated within multiple layers of pyrolytic carbon and a layer of silicon carbide is known as tristructural-isotropic (TRISO) fuel. This TRISO-coated particle fuel form effectively serves as a barrier to fission product release. Thousands of these particles are combined with a matrix material and pressed into spheres for pebble bed fuels or cylindrical or annular compacts for prismatic fuels. The HTGR fuel form provides challenges to both the front and back ends of the fuel cycle.

Analytical tools are needed to simulate the gas-cooled reactor fuel performance and fission product transport (FPT), retention, and release into the environment under accident conditions. The TRISO-coated particle fuel performance models are needed for reliable prediction of fuel integrity under both normal and accident conditions. Testing of HTGR-specific fuel (e.g., the NGNP fuel program) is necessary to generate the data required for development of reliable fuel performance models.

The modeling need for use in FPT analysis tools or codes depends on the safety role of the confinement or containment. The level of modeling fidelity for the FPT analysis can be evaluated properly when a conceptual design is available and the safety functions of the reactor system and confinement or containment building are more precisely defined. The FPT codes and models developed for LWRs may be applicable, with few exceptions.

Since neutron fluence strongly influences graphite properties, models need to be developed for fission product retention and transport in structural graphite that capture this influence. Fission product surface removal effects by steam and air need to be modeled adequately, as potential uncertainties in this area could lead to design compromises if the fission product contamination of the reactor circuit is significant. Reliable modeling of FPT in the presence of dust, potentially generated in large quantities in the pebble bed reactor type, is needed, since reactor circuit retention of fission products is important to the safety analysis.

As stated previously in the context of safety analysis, the Energy Policy Act of 2005 and GIF paved the way for significant research activities in the fuel and materials areas related to HTGR technology. Consequently, gaps in research needs in these areas are expected to narrow once the results of recently completed or ongoing efforts are incorporated into the knowledge base.

The LMR technology employs two fuel options: (1) mixed uranium-plutonium-zirconium metal alloy (metal) and (2) mixed oxide. More information is needed concerning metal fuel/clad interaction and the oxide fuel/sodium interactions. A third fuel form—nitride fuel—exists, but its state of development is modest when compared to either the mixed oxide or the metal alloy. Most of the metal fuel data have not been analyzed to date. Oxide fuel has the most maturity since it has been used as the fuel of choice in the majority of LMRs worldwide.

Experiments at EBR-II and FFTF demonstrated burnups in the range of 150–200 gigawatt-day per metric tons of heavy metal for both mixed oxide and metal fuels. However, the database for this burnup is sparse, and the quality of data may be insufficient to support a safety case. Furthermore, since most of the metal fuel testing was performed with shorter fuel pins and binary fuel, it will be necessary to verify fuel performance codes for longer fuel pins and ternary fuel (e.g., uranium-plutonium-zirconium alloy). Hence, further research is needed in this area.

For beyond-the-horizon reactor technologies, the discussion in the previous section alluded to the innovative concept of "accident-tolerant fuel" (e.g., fuel cladding that would not melt under loss of coolant accidents). In concept, there is virtually an endless possibility for accident-tolerant fuel design using both solid (oxide, metal, and mixed oxide) and liquid fuel at different enrichment and burnup levels and a host of cladding materials (metal, ceramic, ceramic-metal composites (cermet), graphite), as well as a bare fuel form. The fuel performance database for these conceptual fuel types is nonexistent or, at best, inadequate for regulatory applications. Consequently, attention would need to be paid to development of the required performance data and the associated analytical models and tools for NRC to license a design using one of these fuels. An acceptable fuel qualification test program would need to demonstrate high levels of safety performance and reliability of the reactor fuel as a barrier to fission product release during normal operation and for the selected accident conditions.

3.2.3 Materials Analysis Generally, for any reactor technology, the outcome of materials research provides the technical bases for developing staff positions pertaining to the evaluation of the designed integrity of components that protect the pressure boundary and maintain core geometry. A sound technical basis is necessary for evaluating, verifying, and confirming the applicant's data on the integrity and failure modes of components. Time-dependent failure criteria for materials need to be developed for ensuring safety and adequate operational life. Further development of the adequacy and applicability of the current American Society of Mechanical Engineers Boiler and Pressure Vessel (ASME BPV) Code for advanced reactors, and a greater understanding of the current state of design methodology for structural materials are both necessary.

The iPWR designs rely in large part on LWR technology, for which the material performance database is relatively mature. Nevertheless, new, optimized structural materials may provide enhanced safety, as well as economic incentives. In those cases, new materials need to be qualified for expected performance, and standards for these materials must be developed or existing standards must be extended. Furthermore, iPWRs may have operating regimes that vary sufficiently from the current LWR fleet to require an extension of the existing technical bases.

For non-LWR technology, or more precisely for technologies geared to elevated temperature applications, the materials performance database is not as mature. Time-dependent failure criteria for materials for high-temperature applications are being developed to ensure adequate safety during the operational life of, for example, HTGRs. Furthermore, for the same reactor technology, ASME Code and design requirements for graphite core support structures have been formulated; however, additional irradiated properties data must be acquired to confirm the design margin for the expected temperature and stress ranges during reactor operation.

There is an extensive prototype experience base with liquid sodium as the coolant from over 30 years of operation (e.g., EBR-II, Fermi I, FFTF) in the U.S. and several decades of operating experience in Russia and around the world. This experience base also includes R&D experience with more resilient, innovative clad for the fuel and steam generator tube materials. There is less experience with other liquid-metal coolants, such as lead and lead-bismuth. Although Russia has years of operating experience with lead-bismuth reactors in navy submarines and has announced its intent to commercialize the concept, no LFR demonstration or prototype has yet been built for commercial purposes. The technology and experience base for the LFR thus lags behind that supporting the SFR. Another consideration for LFRs is that the pumping power requirements for lead coolant would be much greater than for liquid sodium, which has a density similar to water. Additional research work is needed in this area to support commercial licensing of an LFR design.

For HTGRs, research needs in graphite performance include irradiation effects on material properties and consistency of graphite quality and performance over the service life. For metallic materials, research needs include high-temperature stability and a component's ability to withstand service conditions, long-term thermal aging and environmental degradation, and issues associated with fabrication of the reactor pressure vessel. More specifically, creep/fatigue properties are of concern, as well as flaw assessment and crack propagation. Detailed analyses of knowledge gaps for both graphite and high-temperature metallic materials identified further research needs.

To support the development of confirmatory analytical tools and predictive models, additional experimental data will be needed in several areas, including material behavior, effects of irradiation on material properties, aging in a radiation environment, and corrosion behavior of structural materials during accidents. The minimal operating experience for advanced reactors, coupled with the high-temperature environment, indicates the need for better understanding of the potential application of online technologies to monitor degradation of structural components.

Other materials for consideration in advanced reactor technologies include carbon-carbon composites, ceramic-ceramic (cercer) and ceramic-metal (cermet) composites, and new metal alloys. Some of these alloys will have structural applications and some can be used as fuel cladding in advanced technologies, including LMRs and other concepts. With the possible exception of the SFR, which has a proven, though limited, database of use of mostly conventional materials, the performance databases for these more novel materials are sparse, and significant research may be needed to address performance issues of these materials.

The opaque nature of the coolant used for LMRs creates unique aspects of inservice inspection which will have to be addressed. The need to keep these reactors at high temperatures, even for inservice inspection, would require development of new inservice inspection methods and processes.

3.2.4 Structural Analysis The structural analysis tools for existing LWR designs are mature, standardized, and have an extensive application database. There is well-developed guidance on the use of these tools, and the NRC anticipates that these tools can be used with minimal to no modifications for confirmatory structural analysis of iPWRs and possibly other reactor technologies because of the generic nature of the analysis scope. Nevertheless, specific design variations from one technology to another may necessitate further tailoring of structural analyses to address the pertinent issues.

As an example, in HTGR reactor vessel internal structure designs, the stability of stacked fuel compacts (in a prismatic reactor) or compaction of fuel spheres (in a pebble bed reactor) under seismic loading may become an issue for structural integrity of the core, as well as its neutronic and thermal response. Nonlinear structural analysis is needed to assess the stability of the structural integrity of the core as well as the reactor vessel internal structure during earthquake loadings and to determine the adequacy of design seismic margin.

In reactors that operate at much higher temperatures than LWRs (e.g., HTGRs, LMRs), concrete structures can be subjected to sustained high temperature. The rate of heating and cooling at elevated temperatures affects the structural performance of concrete. In addition, part of the plant concrete structure may experience radiation fluence levels that have to be considered in the initial plant design loads. Research would be needed to address the effects of high-temperature and fluence on the performance of reinforced concrete structures.

The excellent heat transfer properties of liquid sodium would allow an SFR to be compact, as compared to an LWR. The large margin to boiling of sodium would allow the SFR to operate at near atmospheric pressure and the structural components, such as the reactor vessel, to be much thinner compared to those of an LWR. The potential safety impacts of such configurations would need to be addressed.

While lead-based coolant (lead and lead-bismuth) also have a high margin to boiling, the high density (as compared to sodium) would result in a need for thicker structures to accommodate loads associated with the coolant mass as well as forces exerted by the heavy coolant. Because the lead-based coolant density exceeds that of steel structures, any internal structures of the reactor vessel would float in the coolant unless properly secured. Likewise, the density of oxide fuel would be less than that of the coolant, allowing these assemblies to float in the coolant if unrestrained. The impacts of this phenomenon would need to be assessed.

In a multimodular SMR, the nuclear island would consist of several reactor modules constructed at various stages and placed on a common foundation mat. Both the seismic capacity and the seismic response of the plant would depend on the overall foundation size (footprint) of the plant.

Confirmatory structural analysis would be needed to ensure desired seismic performance of multiple modules on a common foundation. In addition, some new reactor technologies may opt for partially or fully embedded structural designs. Because of the lack of experience regarding the seismic response of deeply buried nuclear structures, research is needed to evaluate the responses of plant structures for such designs.

3.2.5 Cross-Cutting Research Areas Supporting Licensing In addition to the aforementioned information, cross-cutting research areas exist that support reactor licensing. These include instrumentation and control (I&C) that cuts across safety analysis, fuel and material performance and structural integrity assessment, and probabilistic risk assessment (PRA) and human factors engineering that provide input to safety analysis. Research needs in these cross-cutting areas are relatively technology neutral since the identified needs and resulting products are largely applicable to all reactor technologies.

3.2.5.1 INSTRUMENTATION AND CONTROL The future designs will generally rely on passive rather than active safety features and may involve concurrent control of multiple modules from a common control room. In general, these designs will employ digital I&C technology as opposed to the predominantly analog I&C technology used in the current fleet of operating nuclear plants. These systems will provide the capability for increased automation that makes greater use of interactions between personnel and automatic functions. Automation can change the operators' role in monitoring, detection, and analysis of off-normal conditions, situation assessment, and response planning. Research is needed to determine the effect of these changes on operator safety performance and on plant safety.

Multimodular SMR facilities involve multiple modular reactors sharing balance-of-plant systems to produce electricity, process heat, or both. This configuration involves new I&C requirements, including new sensors, data integration, displays, and operational and maintenance philosophies. Some I&C systems will operate in conditions significantly different from those of the current generation of nuclear plants. Temperature, pressure, flow, and neutron instrumentation may be required to operate in higher temperature environments. The combination of high temperatures and potentially corrosive process fluids and environments in reactors can impose significant challenges to the design of instrumentation. Severe environmental conditions could also impact instrument reliability and accuracy. Research is needed to assess the performance of new types of sensors and instrument systems that will likely be developed for monitoring system and component performance.

3.2.5.2 PROBABILISTIC RISK ASSESSMENT Regulatory and licensing requirements that are not prescriptive allow the designer the flexibility to optimize the design and operations for performance and safety. The designer can use PRA tools to identify the most important SSCs and human actions, as well as the reliability, availability, and performance goals that each needs to meet. The designer may be forced to make assumptions about the reliability and performance of new and innovative SSCs because these SSCs lack historical operational data. PRA information will be used to validate these assumptions and characterize the associated uncertainties. Other research activities (e.g., development of safety analysis tools, testing and qualification programs) will support this evaluation. The PRA infrastructure development involves regulatory guidance to provide an acceptable approach for evaluating whether a proposed plant PRA is adequate for making the licensing decisions. In conjunction with this guidance, research is needed to develop the necessary standards and associated detailed technical guidance.

Both the NRC and industry have engaged in long-term efforts to develop a risk-informed, performance-based regulatory approach for licensing advanced reactor designs (e.g., HTGRs and LMRs). Such an approach would require a broader use of the design-specific PRA in establishing the licensing basis. From the NRC perspective, the scope and technical acceptability of the PRA needed to support an application under a risk-informed, performance-based regulatory approach would have to be established. The use of pilot studies, jointly supported by the NRC and industry, would provide insights to the appropriate scope and technical acceptability of the PRA.

3.2.6 Need for Additional Test Facilities Because the iPWR designs are an evolutionary development of currently-licensed LWRs, the NRC does not expect that additional test facilities beyond those planned and/or developed by the reactor vendors would be needed. The NRC will need to interact closely with the vendors to ensure that NRC's data needs will be met by the vendors' test facilities.

For HTGRs, as noted in Section 2.3.3 and further discussed in Section 4.5, an analysis of gaps between available and needed test data has been performed, and research and test facilities are being constructed and testing of HTGR designs is planned or already in progress in several areas. For LMRs, however, a less detailed analysis of gaps between currently available data and those needed to support reactor licensing has been performed. Significant gaps are likely present and, therefore, additional research facilities would likely be needed to support licensing of these reactor designs.

3.3 SECURITY AND SAFEGUARDS

For all new reactor designs, the designer is expected to integrate security into the design and conduct a security assessment to evaluate the level of protection provided. Additional research may be needed to assess the efficacy of any new security measures. Likewise, research may be needed to review the MC&A safeguards provisions and their technical basis to determine whether they are acceptable.

Advanced reactor designs using LWR fuel assemblies at less than five percent enrichment can meet MC&A requirements established in NRC regulations by following the existing NRC guidance. HTGR fuels (e.g., TRISO) and LMR fuels require further evaluation to determine whether existing MC&A requirements are applicable.

3.4 CODES AND STANDARDS

The use of consensus standards, where available, is fundamental to the NRC's regulatory practices and the industry's needs. The NRC has been proactive in working to identify future needs for development of codes and standards necessary to support advanced reactor regulatory actions.

The NRC references approximately 520 standards in its regulations, regulatory guides, and the staff's Standard Review Plan. Over 160 NRC staff members participate in approximately 300 committees of standards development organizations (SDOs), such as ASME and the Institute of Electronic and Electrical Engineers (IEEE). The NRC regularly reviews consensus standards developed by these SDOs and, if appropriate, endorses them in its regulations, regulatory guides, and the Standard Review Plan. In particular, ASME Code and IEEE standards incorporated by reference in 10 CFR 50.55a, "Codes and Standards," are updated on a regular basis. On a 5-year cycle, approximately 425 regulatory guides, the most common source of referenced consensus standards, are reevaluated to determine whether they need updating, including the endorsement of new or revised consensus standards. More frequent revisions may occur based on technical evolutions and users needs.

In 2009, the Nuclear Energy Standards Coordination Collaborative (NESCC) was established under the sponsorship and coordination of the American National Standard Institute (ANSI) and the National Institute of Standards Technology (NIST), with the sponsorship of DOE26 and the NRC. NESCC provides a cross-stakeholder forum to bring together representatives of the nuclear industry, SDOs, subject matter experts, academia, and national and international governmental organizations to facilitate and coordinate the timely identification, development, or revision of standards that support the design, operation, development, licensing, and deployment of new nuclear plants and other nuclear technologies, including advanced reactor concepts. NESCC formulates, coordinates, and recommends priorities for revising existing standards and developing new standards to support plant operation, license renewals, new plant construction, and development of advanced technologies. NESCC also defines needs, gaps, and challenges; proposes solutions; and promotes collaborations and cooperation among SDOs to address the identified needs and ensure timely responses.

Designers of advanced reactor technologies may also employ consensus standards to realize cost savings and increased standardization of designs. However, the ability of SDOs to produce these standards early in the advanced reactor development process may be limited for several reasons. For example, SDOs are customer driven, and the customer community for new designs is small. The details necessary for consensus standard development are often not available early enough, considering the typical 4 to 5 years required to develop and publish such a standard, to allow its use to support licensing of a first-of-a-kind reactor. Also, advanced reactor designers may be reluctant to share the proprietary technical design details and methodologies necessary to develop consensus standards. For these reasons, the R&D needs specifically for codes and standards are fundamentally the same as the research needs for licensing, particularly for materials issues. For example, for HTGRs, data developed to address licensing issues for materials performance has supported development of ASME code and design requirements. However, in general, standards development would likely be of lower priority for industry and the technical community than much other work in support of licensing new reactor designs.

In addition, there are codes and standards activities in cross-cutting areas that are relatively technology neutral in that the standards involve new materials, techniques, or methods that are applicable to essentially all reactor technologies for use in new design or construction. Examples include high-density polyethylene piping, digital instrumentation and controls, composite concrete construction, and risk methodologies for advanced reactors. Because of the broader interest and experience base for these issues, SDOs, with appropriate involvement of the NRC, are currently addressing and resolving them; such efforts include necessary research and development. The NRC, DOE, NIST, vendors, and SDOs will continue to promote interaction among key standards stakeholders and designers of advanced reactors so that new or revised standards can be initiated when sufficient design detail and stakeholder interest are available. ■

CHAPTER 4
HUMAN RESOURCE AND FACILITY REQUIREMENTS

4.1 OVERVIEW

The evolution of advanced reactor technologies from the status quo to commercialization will require extensive investment in research and, correspondingly, the extensive use of resources—both personnel and facilities (i.e., laboratory, testing, experimental, and training). Developing a new reactor technology to include a design certification and COL application is a significant undertaking for a reactor vendor and the operating company seeking to install and operate the new technology. Such an effort requires an appreciable cadre of scientists and engineers familiar with the technology, the licensing and operation requirements, and the underlying research and databases needed to support the development and licensing. The general needs are similar for both the industry and the NRC. These needs include a workforce with the right knowledge and skill sets and access to research capabilities, as well as test facilities that can provide data and analyses to support the design and licensing review.

These needs represent challenges for the NRC and the industry. For the LWR designs and the evolution of those designs over the last 50 years, the challenges have been met. As other technologies have been developed and licensed, the basic human resource needs have been met, and adequate test facilities have been developed to support the licensing reviews and safe operation. However, as LWRs have become the dominant technology used by the international nuclear power industry, the academic community has tended to emphasize that technology and large-scale test facilities have also tended to be designed for LWR technology and fuel types.

As new technologies are being developed and progress toward licensing, it is becoming increasingly important for Government, academia, and industry to develop the training and research facilities that will be needed to support the commercialization of these new technologies. This chapter explores how the NRC addresses human resource needs to support licensing reviews and provides a brief overview of large-scale test facilities available in the national and international community that have the potential to support both development and confirmatory research needs. As discussed further in Chapter 5, the industry and the NRC share this challenge, and a comprehensive national strategy to support technology development, closing skill gaps in the workforce, and supporting a licensing infrastructure would best serve the needs of all stakeholders.

4.2 NRC HUMAN RESOURCE PLANNING

The NRC's Strategic Human Capital Plan for FY 2010–14[27] is a pivotal step in continuing the agency's efforts to build a highly effective, performance-based organization by attracting, retaining, developing, motivating, and rewarding a high-performing, top-quality workforce. The NRC believes that strategic management of human capital must be the centerpiece of any organization that expects to fulfill critical skill needs and sustain a high level of performance. As the agency prepares for new responsibilities, this plan serves as a cornerstone for future change management initiatives and extends and builds upon what the NRC has already accomplished. The Strategic Human Capital Plan is directly linked to the NRC Strategic Plan and its overall strategic goals.

The NRC implements plans of action to acquire, develop, maintain, deploy, and retain its core scientific, engineering, and technical capacity. The objective of this planning process is to ensure that the required number of staff with the right knowledge and skills are in the right jobs at the right time. This systematic planning allows managers to anticipate changes rather than being surprised by events and provides strategic methods for addressing current and anticipated workforce issues. Workload demand, capacity requirements, quantifying the labor supply, and designing workforce strategies become part of this continuous process, which is annually integrated into the NRC's planning, budgeting, and performance management cycle. As the NRC foresees future change, such as licensing applications for iPWRs and non-LWRs, the staff works together to identify where gaps would exist and develops strategies to maintain the NRC's core capacity to support the strategic goals into the future. Foreseeing future budgetary constraints, the agency employs broad strategic perspective in human capital strategies to project future workforce needs.

As an example of the process that NRC uses to identify and meet future critical skill needs, the NRC has currently taken decisive steps to identify critical skills and potential knowledge gaps and has implemented strategies to address these gaps in order to ensure that the agency is hiring with the proper focus on future needs. Additionally, the agency's hiring guidance encourages internal moves in order to ensure that skills are appropriately matched with the work that needs to be done to meet the agency's mission both now and in the future. The NRC has been proactive and creative in the use of knowledge management (KM) as a means of building and maintaining needed critical skills. The agency implemented three enterprise-wide KM initiatives in this regard: 1) identifying high-value/high-risk (of loss) knowledge and skills the staff currently possesses; 2) capturing and sharing that high value/high risk knowledge with other agency staff before it is lost; and 3) identifying high-value opportunities for creation of Communities of Practice that enable the sharing of knowledge and skills among those employees who perform the same job function. The agency is also expanding its menu of KM options to capture and share valuable knowledge. Other ways the agency is ensuring that critical skills are available in the future include the Grants Program and the Graduate Fellowship Program. The agency currently has nine employees in the Graduate Fellowship Program pursuing advanced degrees in the critical skill areas. The Grants Program supports professors who are needed to educate and train nuclear engineering, health physics, and radiochemistry students. The program also supports students through scholarships and fellowships to help ensure that the U.S. will have a trained nuclear workforce.

Another example of addressing a skill gap is the NRC's internal initiative to recruit, hire, train and develop subject matter experts in its Probabilistic Risk Analysis (PRA) program. Current risk-informed initiatives and future expected initiatives are expected to create an increasing need for PRA expertise, and the agency has lost PRA analysts due to retirements and promotions and occasionally due to resignation. Because past attempts to attract PRA analysts from internal and external sources provided limited success, the NRC developed a strategic approach to address recruitment, hiring, training/qualification, and retention of PRA experts. This initiative is designed to create a larger pool of analysts who can be qualified to a core standard and shared more readily between offices as the needs arise and change over time.

4.3 HUMAN RESOURCE GROWTH FORECAST

The NRC currently employs a skilled workforce of approximately 4,000 permanent employees. The agency's key occupations are engineers and scientists, attorneys, and various professional administrative occupations. The NRC's workforce has grown 33 percent over the approximately 3,000 employees working at the agency in FY 2004. This growth corresponded to the increased workload arising from the new reactor applications during this period. The advanced reactor licensing applications identified in Chapter 2 may similarly require additional professional staff in future years. However, because of anticipated resource limitations, the NRC recognizes that it is not realistic to plan for continued staff increases commensurate with the number of advanced reactor applications expected.

From the industry's perspective, NEI reports on its Web site that, "Nearly 38 percent of the nuclear industry work force will be eligible to retire within the next five years. To maintain the current work force, the industry will need to hire approximately 25,000 more workers by 2015." The industry and the NRC will be seeking expertise from the same finite pool of candidates.

While U.S. nuclear generating capacity is expected to grow by 9 percent by 2035, its share of the Nation's total electricity output is projected to drop slightly, according to a forecast by the U.S. Energy Information Administration (**http://www.eia.gov/forecasts/aeo/er/early_fuel.cfm**). This modest forecast implies that the current 104 plant operating fleet would increase by approximately nine plants, or their equivalent power output, by 2035. The licensing applications corresponding to this growth could impact the NRC's human resource requirements, and the subsequent plant construction and operation would require additional industry personnel.

As recognition that growth in the nuclear industry necessitates a broad and coordinated outlook on human resources requirements, BRC stated the following:

> We recommend expanded federal, joint labor-management, and university-based support for advanced science, technology, engineering, and mathematics training to develop the skilled workforce needed to support an effective waste management program as well as a viable domestic nuclear industry.[28]

To address these human resource needs, the NRC, along with DOE, maintain ongoing efforts to attract new professionals for the skilled nuclear workforce of the future, which include Government grants and scholarships for nuclear energy education programs at universities and community colleges. For example, DOE's Nuclear Energy University Program funds varied nuclear energy research at a number of U.S. universities. Similarly, the nuclear industry (e.g., NEI) and professional societies (e.g., the American Nuclear Society) maintain ongoing efforts to develop and retain the skilled nuclear workforce.

Despite these multiple efforts, there are likely to be continued and increasing personnel challenges going forward in support of the advanced reactor initiatives. Collaborative and integrated planning efforts are needed at the national and international levels to meet the human resource needs.

4.4 NRC TRAINING REQUIREMENTS

The NRC anticipates that the evolution of advanced reactor technologies will necessitate training needs for the NRC staff in nearly every topical area. In general, the topical areas for training needs correspond to the topical areas of research needed as discussed in Chapter 3. The NRC intends to evaluate these training needs and incorporate, as practicable, applicable training into its curriculum for the staff. The NRC anticipates outreach efforts to other entities (e.g., DOE, industry, professional societies) for coordinated and collaborative efforts to meet the training needs of its staff.

In the near term (5 years), the NRC will focus its training on areas that support iPWR technologies and the anticipated licensing reviews of applications for iPWR designs. Because of the NRC staff's familiarity with LWR technology and multiple LWR designs, including the Generation III+ designs, the agency expects the iPWR training needs to be limited in scope. Training needs would likely focus on design-specific topics (e.g., helical coil steam generators, digital I&C designs).

For the longer term, the focus of NRC training will shift to the broad needs related to the different non-LWR technologies. Training needs will be extensive in scope, and topics will range from technology generic (e.g., neutronic and coolant characteristics for lead-bismuth fast reactors) to design specific. Externally, NRC is able to influence academic focus on emerging training needs through the topical areas selected for funding opportunities under its educational grants program.

To support training needs, the NRC has two dedicated training facilities—the Professional Development Center, located at its Headquarters complex, and the Technical Training Center (TTC), located in Chattanooga, TN—in addition to Web-based options and contractor resources. Both facilities provide overall agencywide staff training and development programs. The programs include systems designed to determine and project critical skill needs and to establish, maintain, and enhance the skills that employees need to perform their jobs effectively and to meet the future skill needs of the agency. The TTC also includes two multi-application reactor simulators (MARS). MARS are computerized simulators that can be utilized as part of the planned iPWR training, and computer-based digital models can be loaded into the MARS units. MARS can also be further utilized, perhaps with limitations, for non-LWR designs.

4.5 EXPERIMENTAL AND TEST FACILITIES

For advanced reactor technologies to evolve from the concept stage to commercialization, varied experimental and test facilities are needed to support both developmental and confirmatory research.

Within the national and international nuclear community, a number of such facilities currently exist, ranging from some with multipurpose research capabilities to those with dedicated or unique capabilities. In the U.S., the majority of Government-sponsored, nuclear-related experimental and test facilities are within the auspices of DOE, with a variety of facilities located at the national laboratories.

One example of a multipurpose facility is the high flux isotope reactor (HFIR) at Oak Ridge National Laboratory. HFIR is the highest flux reactor-based source of neutrons for research in the U.S. and is used in the study of physics, chemistry, materials science, engineering, and biology. HFIR uses include fundamental and applied research on the structure and dynamics of matter; medical, industrial, and research isotope production; research on neutron damage to materials; and neutron activation to examine trace elements in the environment.

At the Idaho National Laboratory, the Advanced Test Reactor (ATR) and the Materials and Fuel Complex (MFC) offer key capabilities to support advanced reactors. The ATR provides a unique, thermal-spectrum irradiation capability to support material testing. The MFC has a number of large hot cells, post irradiation examination equipment and capabilities, and specialized glove boxes for handling special nuclear material and irradiated fuel samples. In addition, the Transient Reactor Experiment and Test Facility (TREAT) is the only transient test facility in the world capable of conducting tests on full-size fast reactor fuel. It is in cold standby status but could be restarted to meet U.S. and international transient-testing needs.

Further representative examples of DOE-supported research facilities include the High Temperature Test Facility at Oregon State University, the Sodium Fast Reactor Mechanisms Engineering Test Facility and the sodium plugging test loop at Argonne National Laboratory, the Lead/Lead Bismuth Loop at Los Alamos National Laboratory, and the test loop for FHR technology demonstration under construction at Oak Ridge National Laboratory.

To facilitate confirmatory research in human factors aspects of new and advanced reactor designs, the NRC is creating a Human Performance Test Facility in collaboration with the University of Central Florida. This facility features a digital nuclear control room simulator to be used for conducting human-in-the-loop-experiments. This research is expected to produce nuclear-specific human performance data for evaluating the impact that new and advanced designs, technologies, and concepts of operation have on human and system performance.

In addition to Government-sponsored facilities, reactor designers and vendors in the private sector maintain a number of special-purpose facilities to support their unique designs. For example, both B&W and NuScale developed specialized facilities for testing components (e.g., fuel) and conducting integrated systems tests for their respective iPWR designs. Also, different universities support nuclear research. For example, the Center for Advanced Engineering and Research, a partnership between the University of Virginia and Virginia Polytechnic Institute and State University, has created the Center for Safe and Secure Nuclear Energy to conduct applied and basic research for use in the nuclear industry.

At the international level, many experimental and test facilities relevant to advanced reactor technologies exist worldwide, both in countries with developed, as well as those with developing, nuclear programs. An exhaustive listing is not practicable in this report. Rather, reference is made to an extensive list of facilities for two technologies—sodium fast reactors and gas-cooled reactors—as compiled by NEA.

NEA is a specialized agency within the Organisation for Economic Co-operation and Development, an intergovernmental organization of industrialized countries based in Paris, France. NEA's mission includes the following:

> To assist its member countries in maintaining and further developing, through international cooperation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes.[29]

NEA works closely with the IAEA and functions as the technical secretariat to GIF and MDEP. The U.S. is one of 30 member countries.

Among the technical publications provided by NEA are two that address the experimental and test facilities pertaining to sodium fast reactor and gas-cooled reactor technologies:

- "Experimental Facilities for Sodium Fast Reactor Safety Studies," Task Group on Advanced Reactor Experimental Facilities (TAREF), NEA No. 6908, April 15, 2011, http://www.oecd-nea.org/nsd/docs/2010/csni-r2010-12.pdf

- "Experimental Facilities for Gas-cooled Reactor Safety Studies," Task Group on Advanced Reactor Experimental Facilities (TAREF), NEA No. 6864, December 31, 2009, http://www.oecd-nea.org/nsd/reports/2009/nea6864-TAREF.pdf

The two reports, NEA No. 6908 and No. 6864, provide overviews of experimental facilities that can be used to carry out nuclear safety research for sodium fast reactors and gas-cooled reactors, respectively, and identify priorities for organizing international cooperative programs at selected facilities. The information has been collected and analyzed by a TAREF as part of an ongoing initiative of the NEA Committee on the Safety of Nuclear Installations (CSNI), which aims to define and implement a strategy for the efficient utilization of facilities and resources for GIF reactor systems.

Continuing at the international level, the Halden Man and Machine Lab (HAMMLAB) at Halden Reactor Project, Norway is an example of a technology-neutral research facility. This facility provides for human factors and human performance research in nuclear power plants. Efficient interaction between the operator and the process through the control room interface is the key to operational safety and reliability. The aim of HAMMLAB is to extend the knowledge of human performance in complex process environments to adapt new technology to the needs of the human operators. The lab's activities include studies of human behavior in interaction with complex process systems and the development, test, and evaluation of advanced digital I&C technologies in control rooms. Studies conducted in HAMMLAB enable operator performance within different systems to be compared and provide a technical basis for guidance for designing and evaluating advanced systems and staffing in control rooms. HAMMLAB provides these activities through its modern, computer-based, experimental control room and its four simulators—three nuclear reactors and an offshore oil-production process.

A further international example supports the SCWR technology. The supercritical water loop experimental facility, operating with water at supercritical conditions, was built in 2008 for operation in the research reactor LVR-15 in the Research Center Rez, Ltd., at the Nuclear Research Institute in Husinec–Rez, Czech Republic. The loop serves as an experimental facility for corrosion tests of materials for in-core as well as out-of-core structures, for testing and optimization of suitable water chemistry for a future SCWR, and for studies of radiolysis of water at supercritical conditions. This facility was designed and built under a European joint research project entitled, High Performance Light Water Reactor Phase 2. ■

CHAPTER 5
THE OVERALL PLAN

5.1 PLANNING CONSIDERATIONS

5.1.1 Advanced Reactor Initiatives There is significant and growing interest in deploying advanced reactor systems for a variety of purposes in this country. In recent years, the NRC has observed an increasing number of initiatives related to advanced reactor designs and technologies, either underway or being considered by varied private and national and international governmental entities which may lead to commercial licensing applications. Examples include U.S. private firms pursuing iPWR designs, the recent DOE FOA and DOE request for information on advanced reactor technologies, privately-funded fast reactor initiatives (e.g., Toshiba's 4S, Gen4 Energy, TerraPower), and the BRC recommendations. Further evidence of increased interest is exemplified by the nuclear-friendly legislation proposed or enacted by several State governments, the increasing number of commercial conferences and academic conferences and symposia focused on SMRs, and increased nuclear-related media attention. Continued pursuit of these advanced reactor initiatives could lead to submittal of commercial licensing applications to the NRC.

5.1.2 Planning Scenario To address potential regulatory challenges and identify necessary research needed and resources required, the planning discussed in this chapter reflects the possibility that some number of the advanced reactor initiatives, consistent with the timeframes discussed in Chapter 2, will evolve to result in commercial licensing applications. Consequently, a plan is necessary to address both the research needs discussed in Chapter 3 and the resource requirements discussed in Chapter 4.

It is important to remember, however, that this report was developed solely for the purpose of providing the information Congress has requested. The planning discussion is not intended to promote the use of nuclear energy or any particular design or technology, and does not reflect any correlation with the NRC's planning or budgeting for 2014 or beyond. Such matters are outside NRC's statutory authority to promote or implement, but could be addressed by Congress as part of an integrated, national-level nuclear strategy.

5.1.3 NRC Perspective The international nuclear community has characterized the NRC's regulatory structure and its programs, processes, and practices as the "gold standard." This recognition was earned over decades of reactor regulation evolution, with a focus on LWR technology and designs. However, other nations have moved forward with non-LWR technologies, and the NRC intends to take full advantage of their experience and expertise. The NRC envisions having a key role in future international regulatory initiatives.

The NRC's viewpoint regarding international regulation derives from the recognition that a number of nations, both developed and developing, are striving to commercialize advanced reactor technologies. Collaboration and harmonization of regulatory requirements, processes, and technical guidance at the international level is crucial to the safe evolution and deployment of such technologies.

Consistent with the above planning scenario, the NRC would expand its level of participation from the current stance of maintaining awareness of technical and regulatory issues pertaining to advanced reactors toward a greater level of concerted participation. The NRC would participate in efforts for internationally accepted regulatory standards and processes, coordinated research activities, and sharing of resources. Such NRC efforts would be initiated in the near term and progress at a measured pace over future timeframes. Figure 5.1 in the Appendix of Figures provides an illustrative representation of potential advanced reactor licensing.

5.1.4 Applications—Quality is Key to Planning It is important to recognize that the "robustness" (i.e., overall quality, completeness, and level of detail) of a licensing application directly impacts the work needed to support the licensing review and, correspondingly, the resources required to conduct the review. In compliance with current NRC regulations, applicants have the primary responsibility to demonstrate the "safety case," which is further described below, for their applications. The NRC expects that license applications will be complete, high-quality submittals supported by sufficient R&D (where necessary), and any follow-up submittals will provide timely and sufficient information to address the staff's questions and concerns. The NRC expects that required testing and code development will be completed to support the application and that preapplication reviews will have been successfully completed with no remaining open policy or technical issues or only a limited number with a clear path to resolution identified.

The applicant's demonstration of the "safety case" supporting its application requires comprehensive documentation of the research conducted, testing accomplished, and analyses performed necessary to support both the design and the technical basis for the safety analysis. For example, applicants are responsible for conducting R&D to (1) demonstrate safe performance of the proposed design and applied technology, (2) provide the technical basis for the application, (3) demonstrate sufficient margins to safety-significant SSC design and safety limits, (4) search for and identify, as well as assess and resolve, safety issues involving large uncertainties, (5) develop, verify, and validate the proposed safety analysis evaluation methods, (6) provide the technical basis for requirements, criteria, codes, or standards that are proposed for the licensing design basis, (7) quantify the failure thresholds for safety-significant SSCs, and (8) support NRC regulatory and licensing decisions.

5.2 THE PLAN

Chapter 2 describes technologies for which applications may be submitted for licensing over broad timeframes: near term and longer term (10 years), horizon (10–20 years), and beyond the horizon (20+ years). The overarching plan for developing the regulatory infrastructure necessary for NRC to be ready to license this wide range of technologies is essentially the same for each of the timeframes. Clearly, specifics of the overarching plan for the different timeframes will vary, and the plan is much more clear for the near and longer term activities than it can be for the beyond-the-horizon activities.

The overarching plan involves initiatives and efforts that are national and international in nature and it anticipates significant interaction with stakeholders including DOE, the commercial industry (represented by both NEI and the Electric Power Research Institute (EPRI)), and academia. The plan also anticipates significant involvement of the international nuclear community.

The plan has three major components: (1) regulatory structure, (2) research efforts, and (3) human resource development. These components, as discussed in Chapters 3 and 4, are closely intertwined—the regulatory structure (i.e., the safety basis component) derives from regulatory research; and regulatory research correlates with, and may be conducted in parallel with, research for technology development. Each of the plan components is described below.

5.2.1 Regulatory Structure Historically, the NRC has worked extensively with regulatory bodies worldwide. These interactions have fostered significant information sharing that has facilitated strong similarities among the regulatory requirements of the nations that have licensed and operated LWRs over past decades. With the relatively recent interest in Generation III+ designs (e.g., AP1000, ESBWR), the regulatory bodies from the countries actively involved in licensing reviews for these designs formed MDEP, with the objective to make regulatory design reviews more safety focused and to leverage regulatory resources to ensure the safe operation of tomorrow's reactors. The information sharing among member countries has led to a much improved understanding of the specific regulatory requirements in each country and strong interactions and sharing of licensing review insights for the various designs.

The plan is predicated on expansion of the MDEP approach for advanced reactor technologies, directly through an expansion of MDEP, formation of MDEP-like structures through the IAEA, or through specific bilateral or multilateral international agreements with countries currently operating or actively interested in licensing specific advanced reactor technologies. Examples of plan execution for the regulatory structure component include the following:

- The NRC was actively involved with the South African regulator, the National Nuclear Regulator, when the pebble bed reactor technology was being developed in South Africa and was being considered as part of the NGNP Program. Specific information regarding details of the PBMR design, and the supporting research, were shared with the NRC, as well as regulatory review insights and conclusions. This information contributed to the NRC's efforts to formulate review criteria and licensing basis considerations for a pebble bed reactor that might be developed for licensing in the U.S. In addition, the NRC became actively involved in an internationally funded research program, managed by NEA and conducted in Japan, addressing pebble bed technology. Interaction with the other regulatory bodies cofunding the NEA program provided additional insights into the technology and into issues and concerns from other regulators. Over time, as the Chinese pebble bed demonstration and power reactor programs developed, the NRC has been exploring expanded interaction with both research and regulatory programs to evaluate the potential for mutual benefit in exchanging information and insights into this technology.

- The NRC has been interacting with DOE as part of a trilateral activity, involving the U.S., France, and Japan, regarding SFR technology. While the trilateral group was initially focused on research activities, the participating countries recently began to emphasize the role of regulatory bodies in advancing SFR technology. The NRC initiated participation in the ongoing trilateral workshops in 2011 and is exploring expanded regulatory interactions.

- IAEA is extensively involved with advanced reactor technologies through its INPRO program. This program addresses innovative technologies, as well as the "new entrant" countries (countries that are seeking to develop a domestic nuclear power program). INPRO was established in 2000 to help ensure that nuclear energy is available to contribute to meeting the energy needs of the 21st century in a sustainable manner. To achieve this, INPRO brings together nuclear technology holders and users to consider joint international and national actions that would result in required innovations in nuclear reactors, fuel cycles, or institutional approaches. INPRO promotes a mutually beneficial dialogue between countries with nuclear technology and countries considering these technologies and supports national strategic and long-term planning and awareness of technology innovation options for the future. The NRC is becoming increasingly involved with INPRO, in a supporting role, to share the agency's regulatory philosophy with the other countries and to gain insights into the technologies involved and the broad-based regulatory considerations from the other participating countries, some of which are further along in licensing fast reactor technologies than the U.S.

The plan envisions significant expansion of these international interactions, first through MDEP-like activities and then through the full spectrum of international activities that could benefit NRC's efforts to be ready to license advanced reactor technologies. Clearly, there are relevant activities conducted in the international community by organizations additional to NEA and IAEA, and NRC would seek to take full advantage of those activities. The NRC would prioritize its engagements to first support the near and longer term activities, followed by engagements that would support the horizon and beyond-the-horizon activities.

While the NRC will, of course, retain the responsibility to develop and promulgate regulatory requirements for the advanced reactor technologies specifically germane to its regulatory philosophy, it would use these interactions to inform those requirements based on specific experiences from countries that are licensing or operating these technologies. In pursuing these international engagements, the NRC would maintain interaction with DOE and the domestic industry and public stakeholders to ensure a balance in perspective regarding the technologies, licensing and operating experience, and overall safety philosophy.

5.2.2 Research Efforts Research to support licensing is fundamentally the responsibility of the applicant in that applicants have the primary responsibility to demonstrate safety of the designs for which license applications are submitted. In general, the NRC will conduct or support safety R&D if it is needed to develop adequate staff technical knowledge, expertise, and capabilities to independently review and effectively evaluate the acceptability of the application, including the safety analysis and the technical basis for the safety analysis; or if it is needed to independently confirm the technical basis for the requirements and criteria needed for plant licensing. The research program therefore provides analytical tools and information for staff to identify and resolve safety issues, conduct independent analyses to support regulatory decisions, develop regulations and guidance, and reduce uncertainties in areas where safety margins are not well characterized and where regulatory decisions need to be confirmed.

The NRC has a long-standing reputation as a leader in the national and international research community, specifically related to LWR technology. The NRC has, historically, had a lead role in motivating, leading, and jointly funding research initiatives related to LWR technology. NRC's involvement with, and leadership of, nationally and internationally funded research activities sets the standard for research supporting the safe regulation of reactor technology.

The plan envisions the NRC working closely with DOE, EPRI, NEA, IAEA, and the nuclear industry to motivate, manage, and cofund the research efforts, including unique facility development needed to support development and licensing of advanced reactor technologies. While the NRC's mission only involves licensing activities, on occasion, jointly funded research programs can serve development and licensing missions equally well, while avoiding conflict of interest concerns. The NRC will continue to be mindful of the need for regulatory independence in entering cooperatively funded research activities. Challenges between cooperation and regulatory independence will continue, but the NRC is effectively addressing these in the current environment and will do so in the future.

NRC will take full advantage of the R&D that may be sponsored by DOE, in particular those activities dealing with generation of experimental data (e.g., experiments on HTGR fuel and graphite being conducted at the Idaho National Laboratory). NRC will also explore international R&D programs (e.g., GIF program), particularly those activities dealing with generation of experimental data. NRC will explore limited experimental programs only in those situations where an applicant is not required to provide the information under the current regulatory framework and it is not available through any other channel. In addition, NRC will depend on international and national codes and standards bodies to develop approved codes and standards or to modify existing ones, as appropriate. Examples of ways in which the research effort component may be executed include the following:

- As provided in the Energy Policy Act of 2005, the NGNP project supports the design, licensing, and R&D necessary to accelerate the commercialization of gas-cooled reactor technology in the U.S. The project is a collaborative enterprise with participation by the national laboratories, U.S. universities, the nuclear industry, international partners, and the NRC. The project works to develop the regulatory framework, design, and R&D to reduce technical uncertainties sufficient to support a license application to the NRC. DOE provides support through R&D ranging from fundamental nuclear phenomena to the development of advanced fuels. The NRC and DOE jointly developed a licensing strategy and engage in ongoing interactions to (1) support decisions that will achieve adequate safety margins in the design, (2) develop tools to facilitate inspection and maintenance needed for safety purposes, and (3) develop risk-based criteria for any future commercial development. The NRC and DOE collaborated on the varied topics of safety-related research.

  As discussed in Chapter 3, DOE is conducting multiyear R&D of the TRISO fuel to support the technology. Both DOE and the NRC recognize that fuel, in commercial quantities, manufactured at an NRC-licensed fabrication facility under appropriate quality and security controls by a trained workforce is key to commercialization.

Related to fuel for other non-LWR technologies (specifically SFRs), the NRC recognizes that the U.S. has several decades of operating and research experience with both metallic and mixed oxide fuel designs, as discussed in Chapter 3. The NRC is aware that potential applicants for SFR designs may use fuel similar in design and reference prior operating and research experience to support fuel qualification. Accordingly, the NRC engaged the national laboratories to review prior fuel research and experience for potential applicability to qualification for new reactor designs.

For non-LWR designs, fuel presents a key challenge to be addressed in the plan and coordinated among the NRC, DOE, national laboratories, industry, academia, and international bodies. As noted in Chapter 2, on a commercial scale, there are currently no established fuel fabrication facilities in the U.S. Developing, licensing, and constructing such a facility, as well as addressing waste storage and transportation considerations for the fuels, present a substantial challenge to commercialization.

- DOE's Light Water Reactor Sustainability Program explores the means to maintain safe and economic operation of the existing fleet of commercial nuclear plants for a longer than initially licensed lifetime. DOE, the NRC, and EPRI are partnered to conduct the long-term research needed to inform major component refurbishment and replacement strategies, performance enhancements, plant license extensions, and age-related regulatory oversight decisions. The goals of the program are to (1) develop the fundamental scientific basis to understand, predict, and measure changes in materials and SSCs as they age in environments associated with continued long-term operations, (2) develop and demonstrate methods and technologies that support safe and economical long-term operation, and (3) research new technologies to address enhanced plant performance, economics, and safety. The primary technical areas of R&D are materials aging and degradation, advanced LWR nuclear fuels, advanced I&C systems technologies, and risk-informed safety margin characterization. The NRC envisions similar partnering relationships for technology and safety research as integral to the plan for advanced reactor technologies.

- The DOE Nuclear Power 2010 program, initiated in 2002, focused on Generation III+ LWR designs and supported the deployment of new commercial nuclear plants. The program addressed first-of-a-kind reactor technology development and the demonstration of then-untested Federal regulatory and licensing processes. Included was a cooperative agreement with EPRI to develop generic guidance for preparing a COL application and to resolve anticipated generic COL regulatory issues. DOE acquired cooperation with industry on a cost-share basis with contributions from utilities, NEI, EPRI, and other industry organizations. DOE and others worked cooperatively with the NRC to resolve generic technical and regulatory issues associated with the 10 CFR Part 52 process, define the form and content of applications, and address processes for verifying inspections, tests, analyses and acceptance criteria. The NRC actively engaged with DOE and industry throughout the program, and the extensive interactions resulted in enhancements to the NRC's regulatory structure. The NRC envisions similar opportunities with DOE and industry going forward with advanced reactor technologies, for example, the DOE FOA for SMRs.

Based on specific research needs such as those summarized in Chapter 3, the NRC would work with the key national and international stakeholders to develop cooperative research activities to address those needs. The NRC will remain mindful of the need for clear independence in the regulatory aspects of these research endeavors so that a clear and defensible set of research results (test data as well as analysis methods or analysis results) is developed to support regulatory decisions.

5.2.3 Human Resource Development For the last several years, the NRC and DOE have supported educational institution grant programs. While the specific interests of each agency have been different, the net result has been a general U.S. Government support of academic programs that support nuclear power development and licensing programs. The U.S. industry has similarly supported specific programs to develop expertise that would support the safe operation of nuclear power plants. Additionally, a number of national and international training courses, conferences, seminars, and workshops offer the opportunity for both general and specific training on topics related to the safe design, construction, and operation of nuclear power plants.

The plan is predicated on the notion of coordination among the NRC, DOE, the domestic nuclear industry, and academia to develop a national program of classroom, laboratory, and field experience, funded in part by the NRC Educational Grants Program, that would support developing, licensing, constructing, and operating nuclear power plants and the associated fuel fabrication facilities. To the extent that interaction with international programs would facilitate NRC's mission in the licensing and oversight of new reactor technologies and fuel facility technology operations, those interactions will be made part of the plan. It is anticipated that the near-term activities will follow along the path of the current NRC and DOE programs. For advanced technologies, the NRC expects that coordinated programs led by DOE and the industry will support NRC's skill needs for advanced reactor technologies, perhaps supplemented for specific technologies by training within the international nuclear community.

Reactor plant control room simulators serve a specialized, but important, training need. The NRC anticipates that its training simulator capabilities will be expanded or supplemented to accommodate advanced reactor technologies. Individual designers and vendors will develop simulators specific to their designs, and, at the international level, there will be expanded support for research facilities, such as the HAMMLAB discussed in Chapter 4.

5.2.4 Research Facility Capabilities The plan envisions continued and expanded national and international support for experimental and test facilities for advanced reactor technology research, such as those discussed in Chapter 4. The NRC expects that DOE would lead U.S. programs for such support. In addition, the NRC anticipates continued efforts by reactor designers and vendors, particularly iPWR vendors, to develop the separate test facilities needed to support their licensing applications.

5.3 THE PLAN SUMMARY

The overall plan discussed in this chapter reflects the possibility that some number of the advanced reactor initiatives, consistent with the timeframes discussed in Chapter 2, will evolve to result in commercial licensing applications and, therefore, an overall plan is necessary to address both the research needs discussed in Chapter 3 and the resource requirements discussed in Chapter 4.

The plan, consistent with the discussion of advanced reactor technologies and timeframes in Chapter 2 and the planning provisions to consider regulatory challenges, research needs, and resource requirements discussed in this chapter, addresses the future licensing of advanced reactor technologies. Potential future licensing is summarized as follows:

- Within the near term, the NRC anticipates that new reactor licensing will consist of (1) continuation of Generation III+ LWR application reviews currently underway plus review of several additional applications, (2) continuation of preapplication activities for iPWR designs and, to a lesser extent, LMR designs, and (3) receipt and review of two or more licensing applications pertaining to iPWR designs. Within the longer term, the NRC anticipates continuation of these activities and, additionally, receipt and review of one or more licensing applications pertaining to LMR designs.

- Within the horizon timeframe, the NRC anticipates that licensing work, in addition to continuation of licensing from the prior timeframe, will include (1) application reviews for one or more additional iPWR designs and (2) application reviews for one or more additional LMR designs. In addition, the work could include (1) preapplication activities for one or more advanced reactor concepts currently identified for research by GIF and supported by DOE and (2) application reviews for one or more GIF-identified and DOE-supported advanced concepts.

- For the beyond-the-horizon timeframe, the NRC anticipates, in addition to continuation of licensing from the prior timeframe, licensing activities that correlate with (1) the DOE Nuclear Energy Research and Development Roadmap—Report to Congress, issued April 2010, (2) recommendations of the Blue Ribbon Commission on America's Nuclear Future—Report to the Secretary of Energy, issued January 2012, and (3) the U.S. national policy regarding the nuclear fuel cycle. As concluded by the BRC, alternatives to the once-through fuel cycle will require decades of R&D before being available for widespread commercial application.

In conclusion, the NRC is resolved to continue to plan in a manner designed to effectively and efficiently accomplish the agency's anticipated advanced reactor licensing workload consistent with its mission and goals and with no compromise to the continued safety of the operating reactor fleet. ■

ENDNOTES

1. U.S. Nuclear Regulatory Commission, "Policy Statement on the Regulation of Advanced Reactors," 73 Fed. Reg. 60612 (October 14, 2008), page 60615.

2. Consolidated Appropriations Act, 2012, Division B: Energy and Water Development Appropriations Act, 2012, PL 112-74, 125 Stat 786 (December 23, 2011).

3. H.R. Rep. No. 112-118, at 192 (June 24, 2011).

4. U.S. Nuclear Regulatory Commission, "Policy Statement on the Regulation of Advanced Nuclear Power Plants," 51 Fed. Reg. 24643, (July 8, 1986).

5. U.S. Nuclear Regulatory Commission, "Revision of Regulation of Advanced Nuclear Power Plants: Statement of Policy," 59 Fed. Reg. 35461, (July 12, 1994).

6. U.S. Nuclear Regulatory Commission, "Policy Statement on the Regulation of Advanced Reactors," 73 Fed. Reg. 60612 (October 14, 2008).

7. U.S. Nuclear Regulatory Commission, "Policy Statement on the Regulation of Advanced Reactors," 73 Fed. Reg. 60612 (October 14, 2008), pg 60615.

8. U.S. Code of Federal Regulations, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter I, Title 10, "Energy."

9. Energy Policy Act of 2005, Pub. L. 109-58.

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11. U.S. Nuclear Regulatory Commission, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," NUREG-0800, March 2007.

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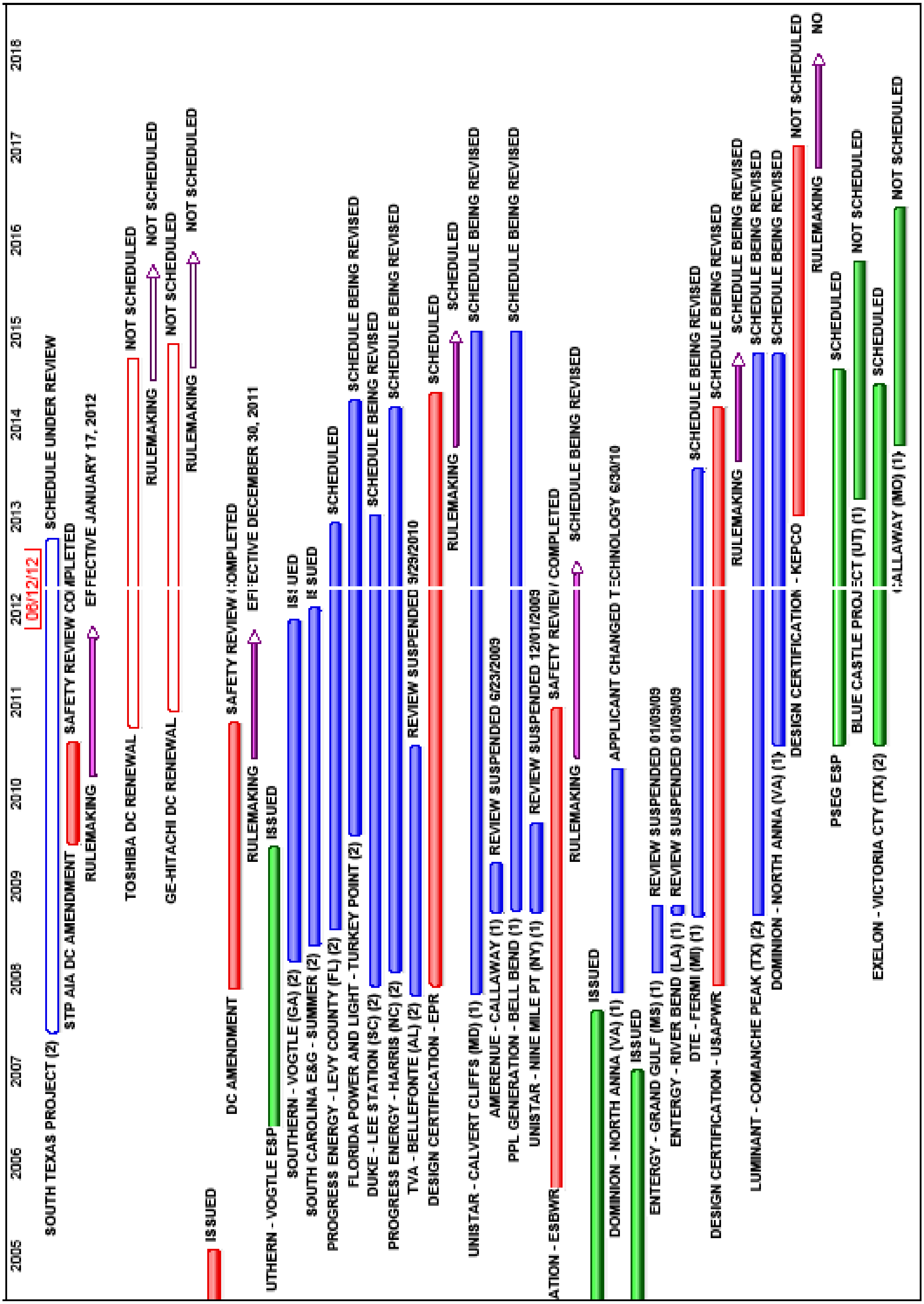
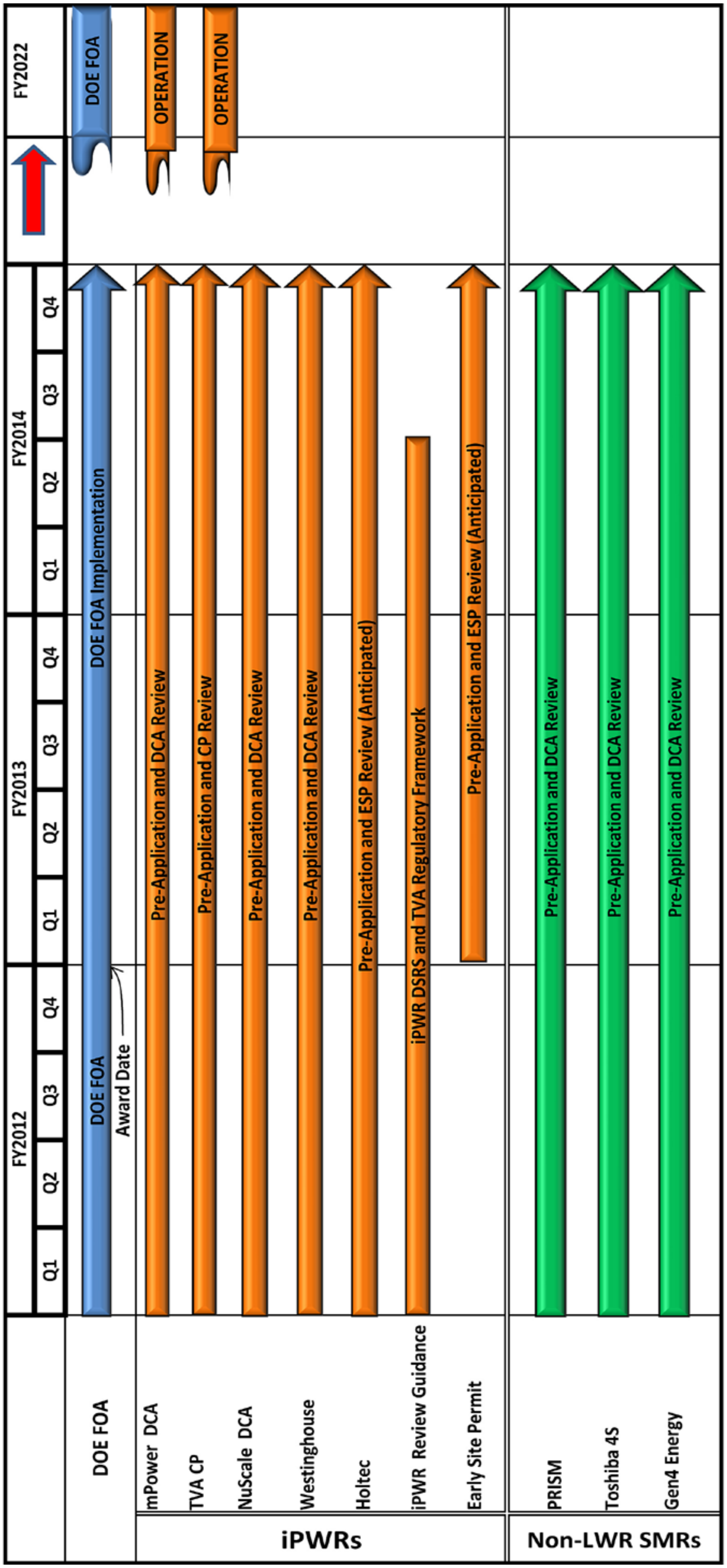
Appendix of Figures

Figure 1.1 NRC New Reactor Licensing Schedule



www.nrc.gov/reactors/new-reactors/new-licensing-files/new-rx-licensing-app-legend.pdf



FY2012
FY2013
FY2014
FY2022
Q1
Q2
Q3
Q4
DOE FOA
DOE FOA
Award Date
DOE FOA Implementation
DOE FOA
iPWRs
mPower DCA
TVA CP
NuScale DCA
Westinghouse
Holtec
iPWR Review Guidance
Early Site Permit
Pre-Application and DCA Review
Pre-Application and CP Review
Pre-Application and DCA Review
Pre-Application and DCA Review
Pre-Application and ESP Review (Anticipated)
iPWR DSRS and TVA Regulatory Framework
Pre-Application and ESP Review (Anticipated)
OPERATION
OPERATION
Non-LWR SMRs
PRISM
Toshiba 4S
Gen4 Energy
Pre-Application and DCA Review
Pre-Application and DCA Review
Pre-Application and DCA Review

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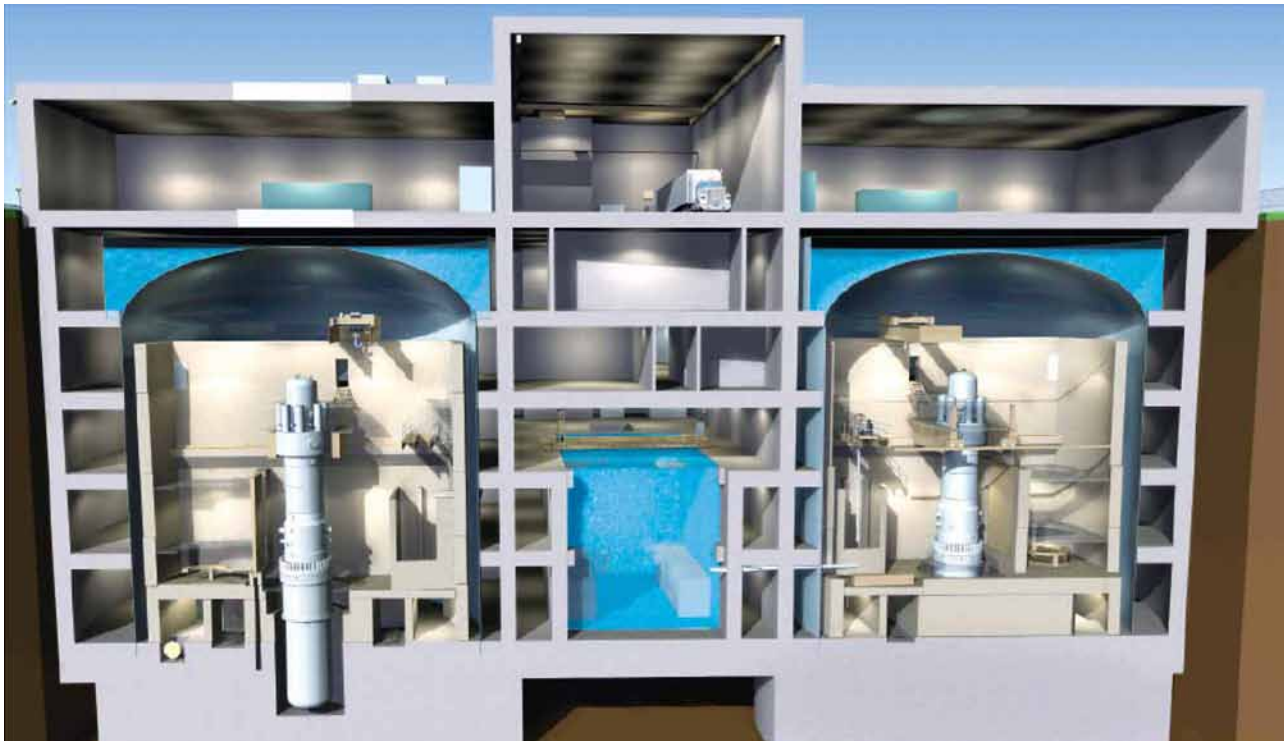


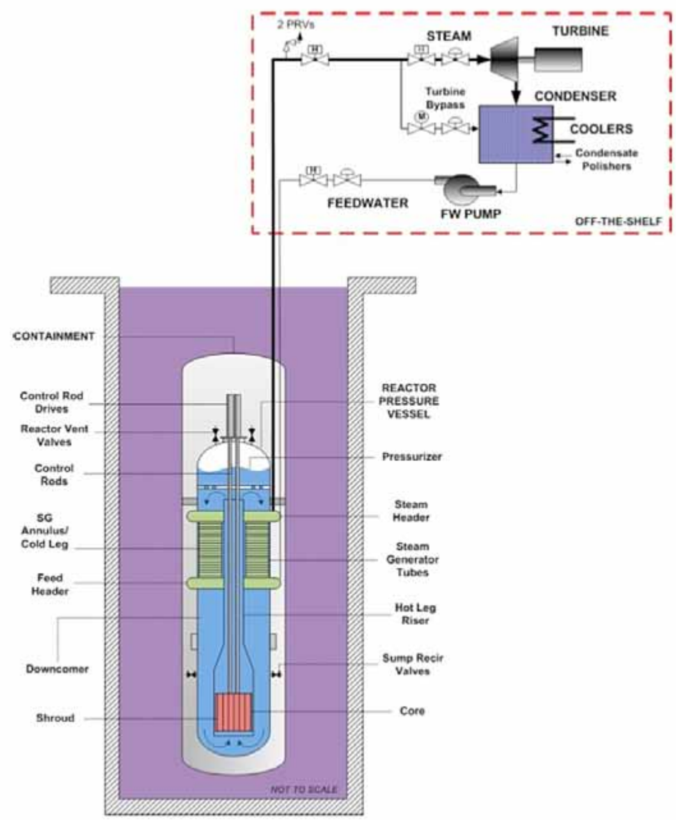
generation mPower

www.generationmpower.com

Figure 2.3 (iPWR)

NuScale Power™

www.nuscale.com/index.php



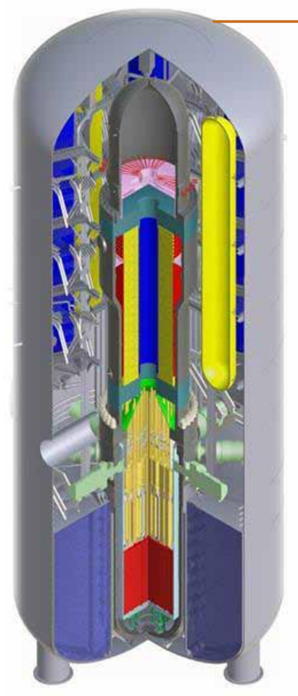


Figure 2.4 (iPWR)

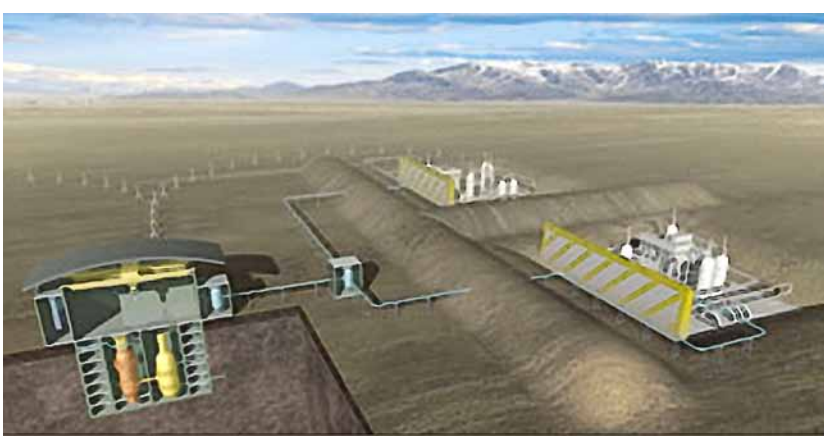
Westinghouse

www.westinghousenuclear.com/smr/index.htm

Figure 2.5 (iPWR)

HOLTEC INTERNATIONAL

holtecinternational.com/divisions/smr-llc



www.ne.doe.gov/neri/neneriresearch.html

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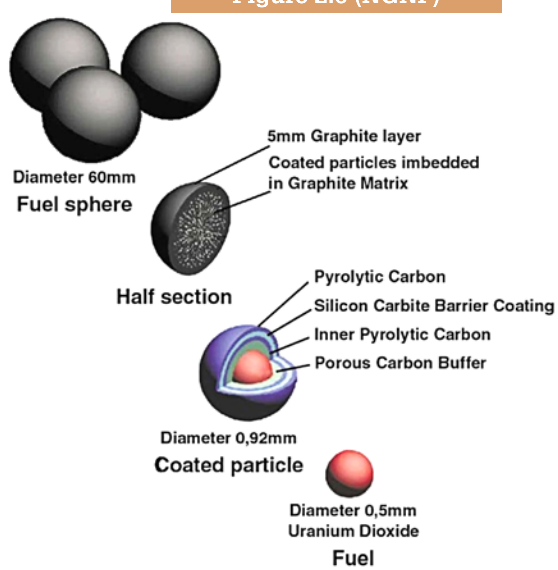

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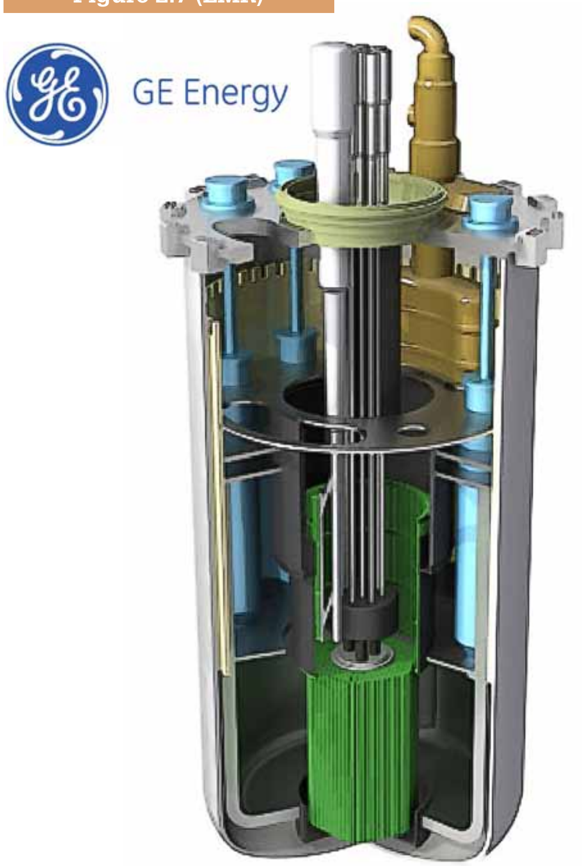

www.geenergy.com/products_and_services/products/nuclear_energy/prism_sodium_cooled_reactor.jsp

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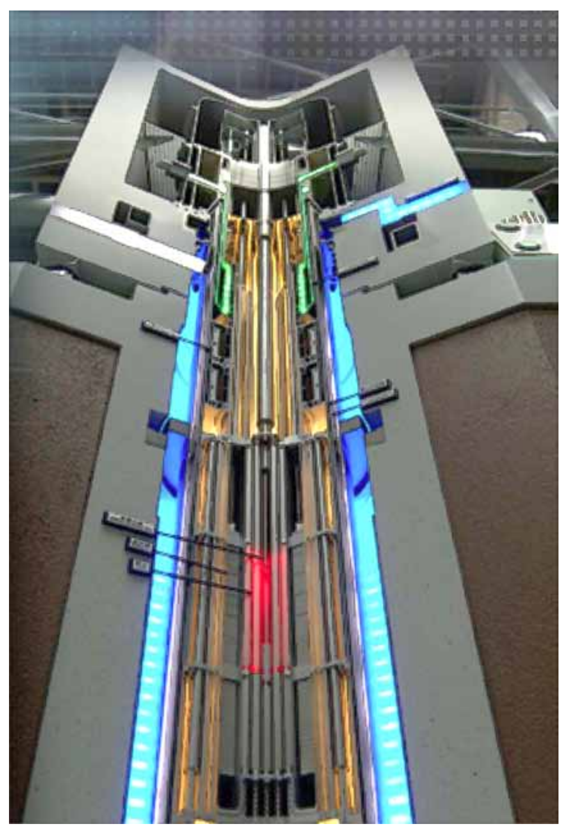


TOSHIBA

www.toshiba.co.jp/nuclearenergy/english/business/4s/introduction.htm

Figure 2.9 (LMR)

gen4energy.com

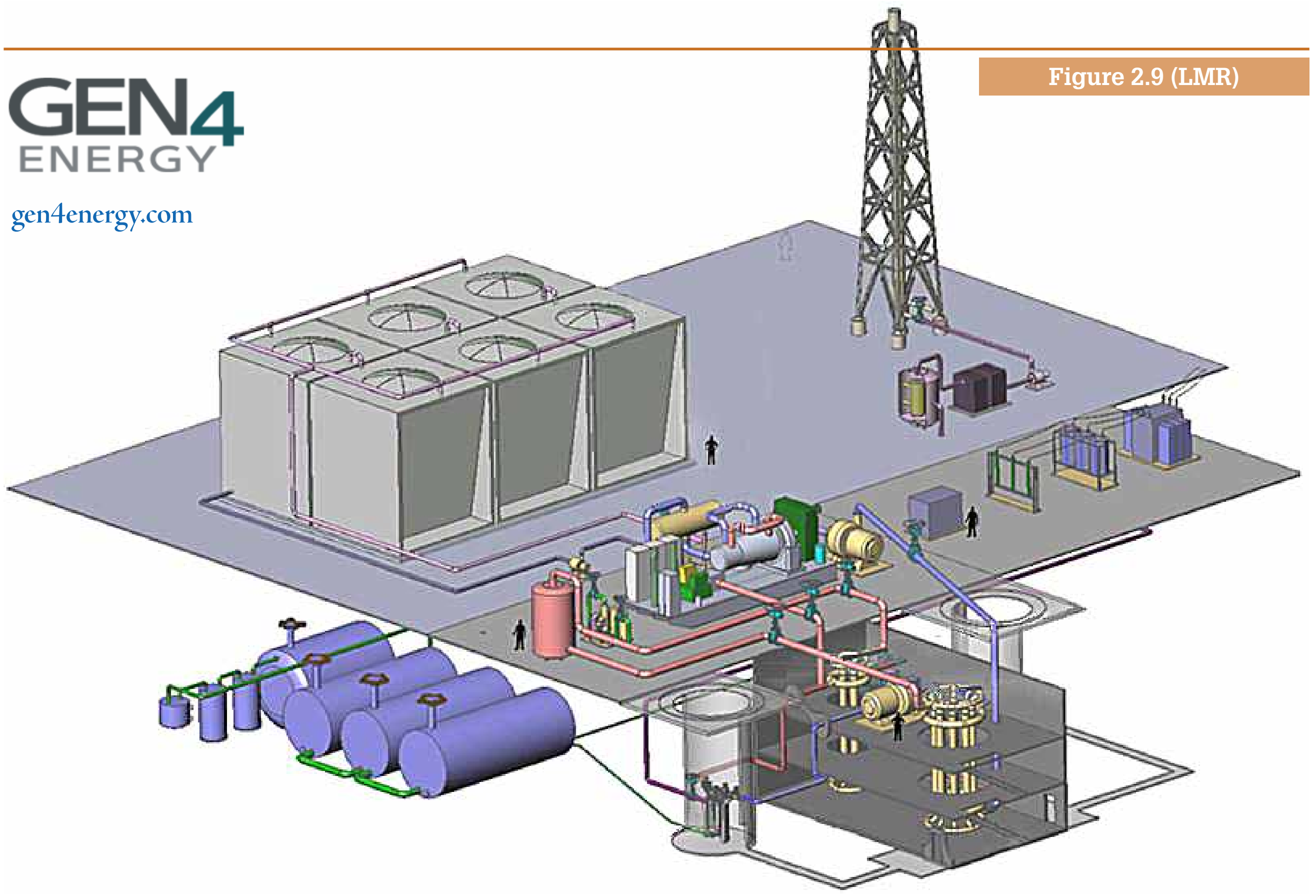
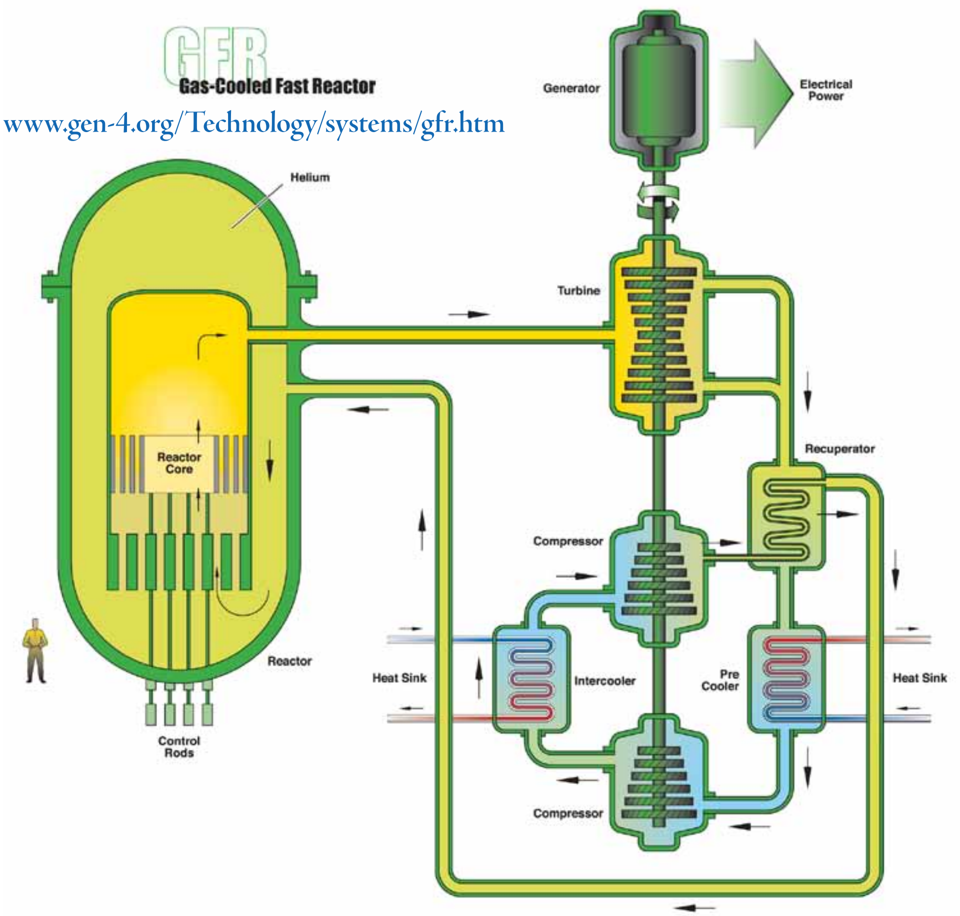


Figure 2.10 (GIF)

www.gen-4.org/Technology/systems/gfr.htm



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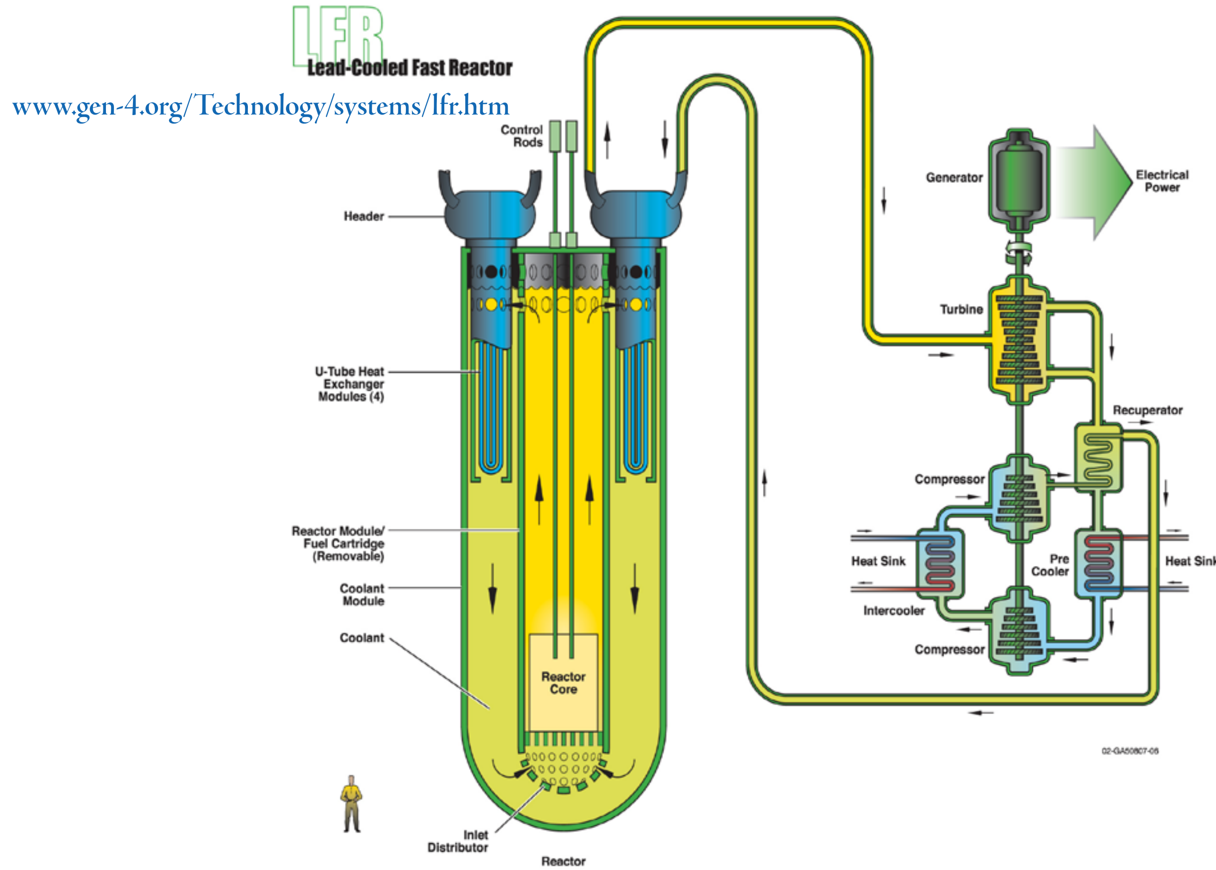

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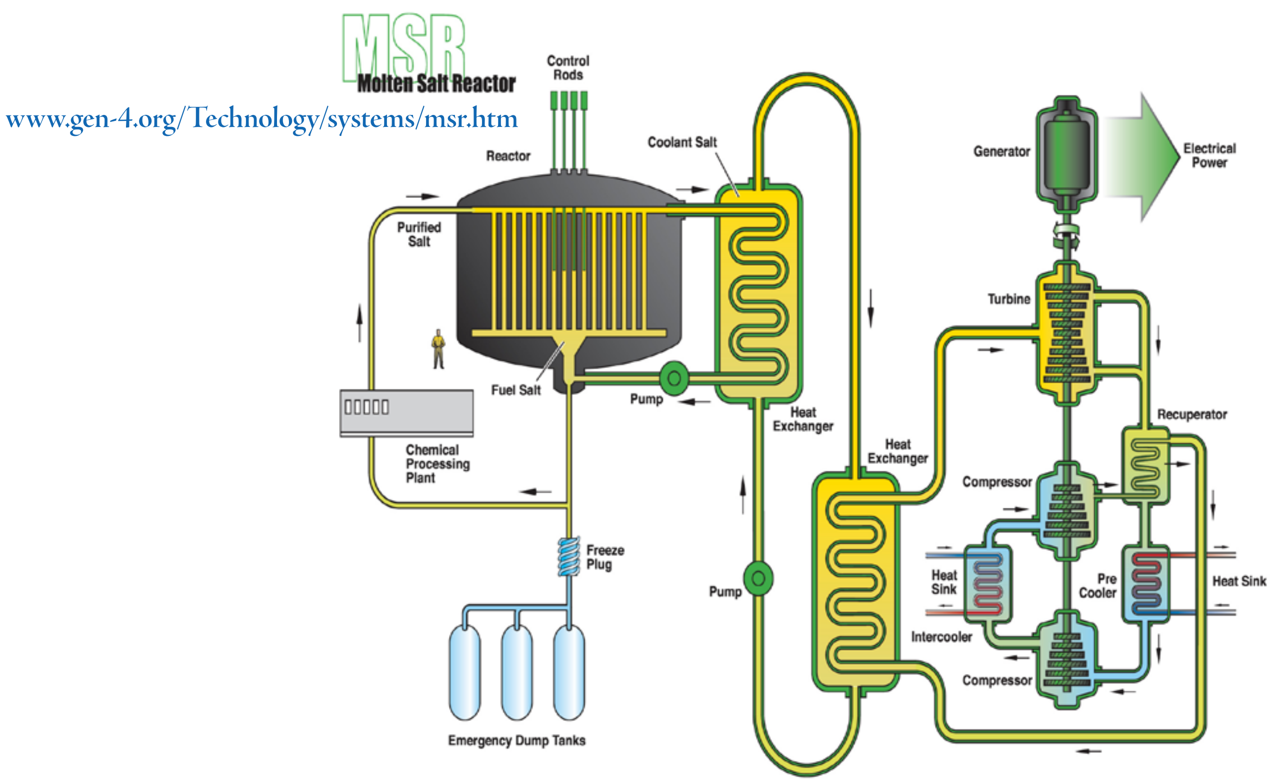

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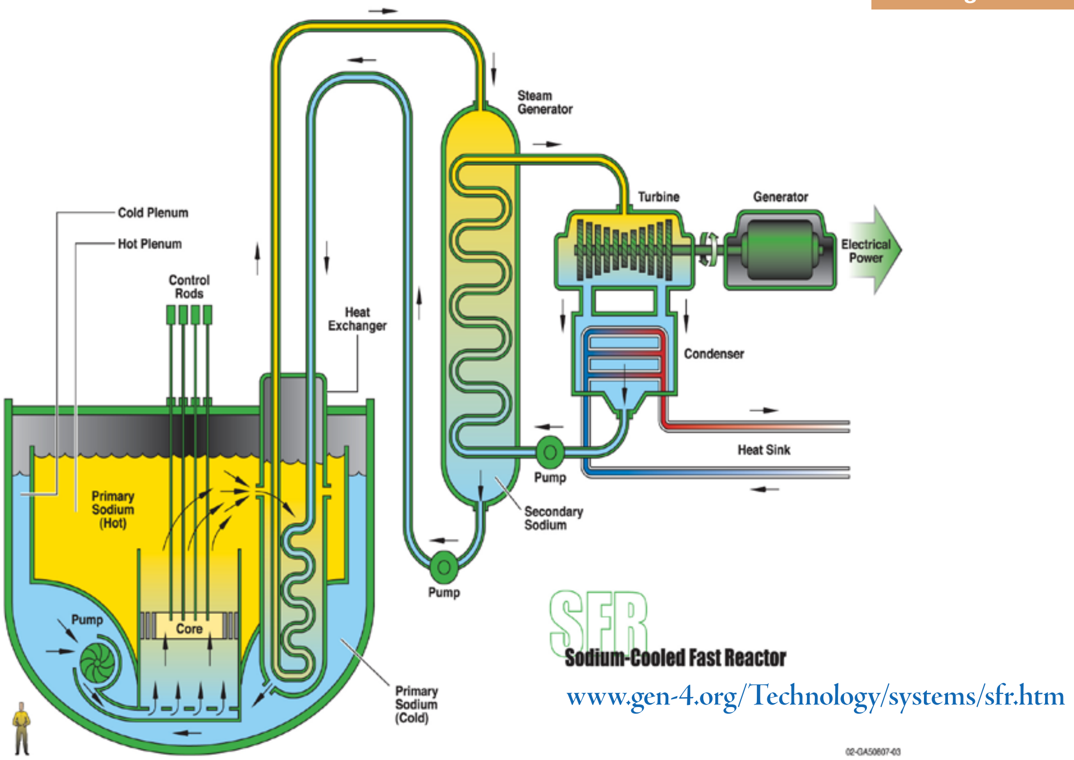

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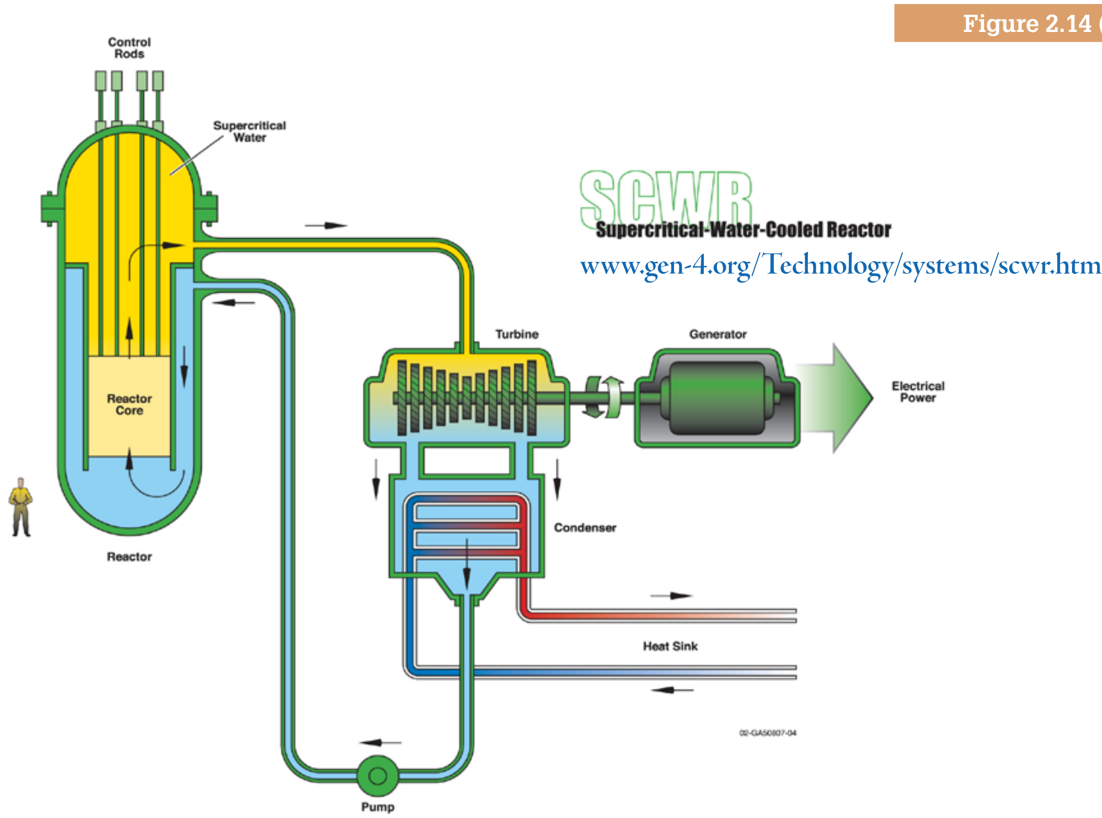

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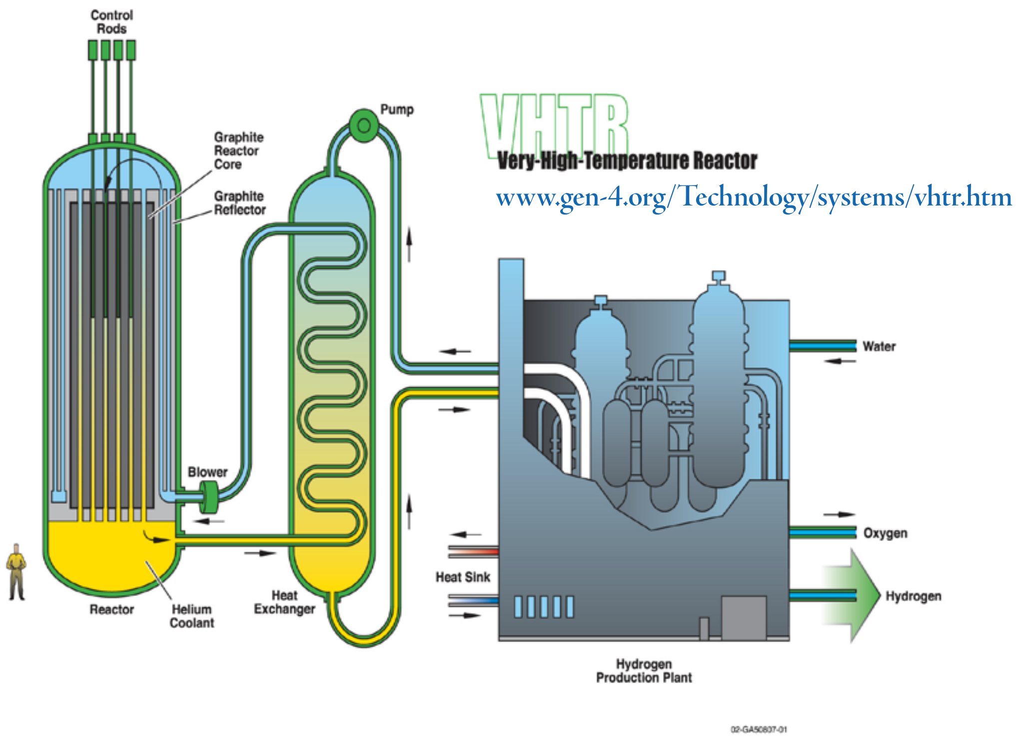


Figure 3.1 Key Research Areas to Support Reactor Licensing

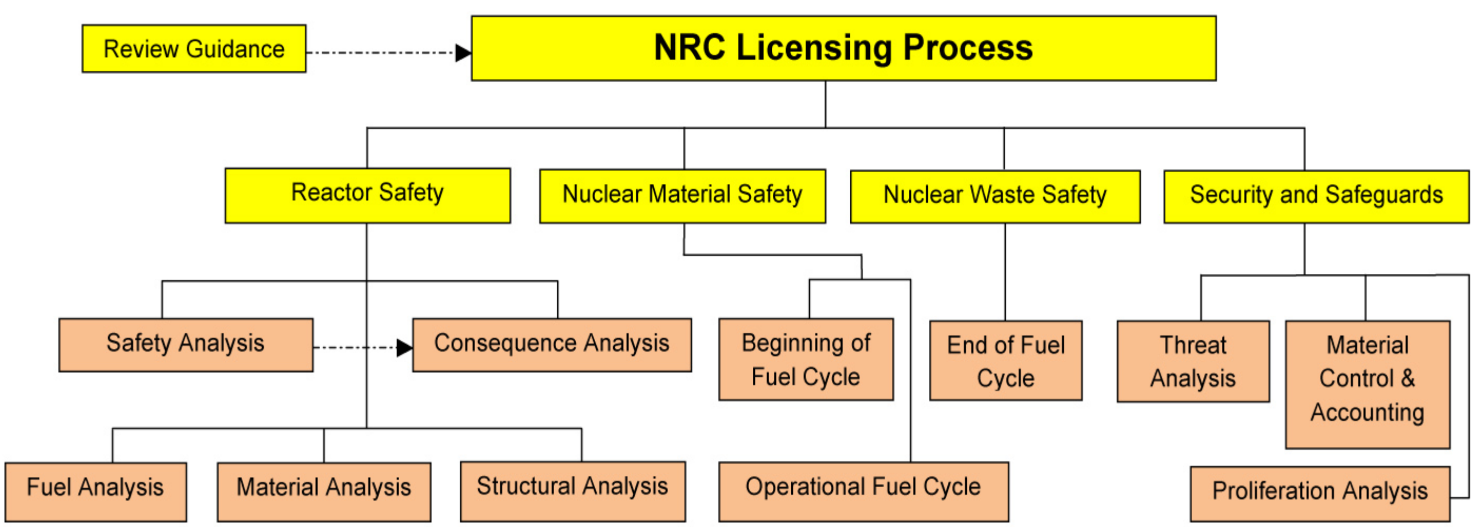
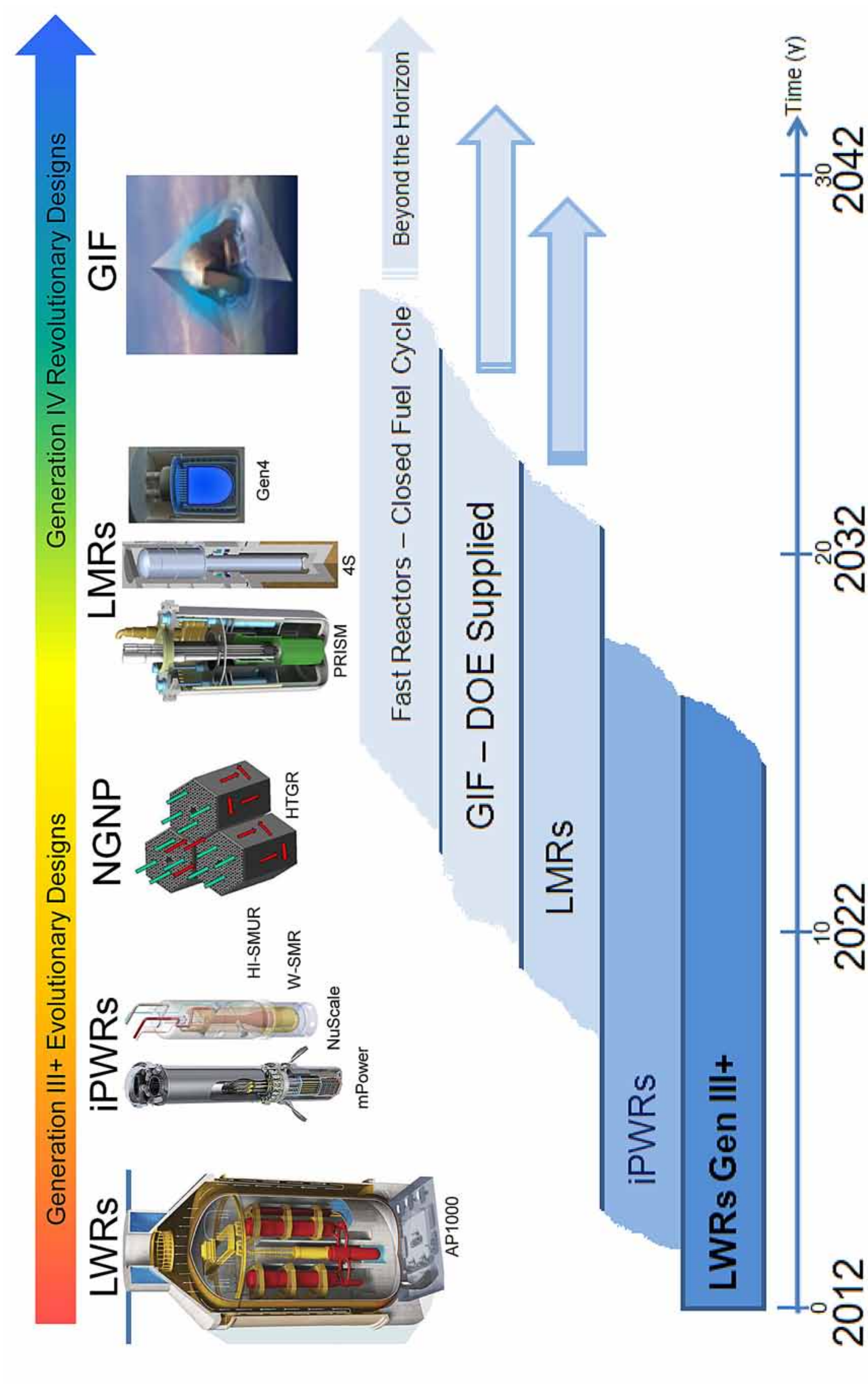
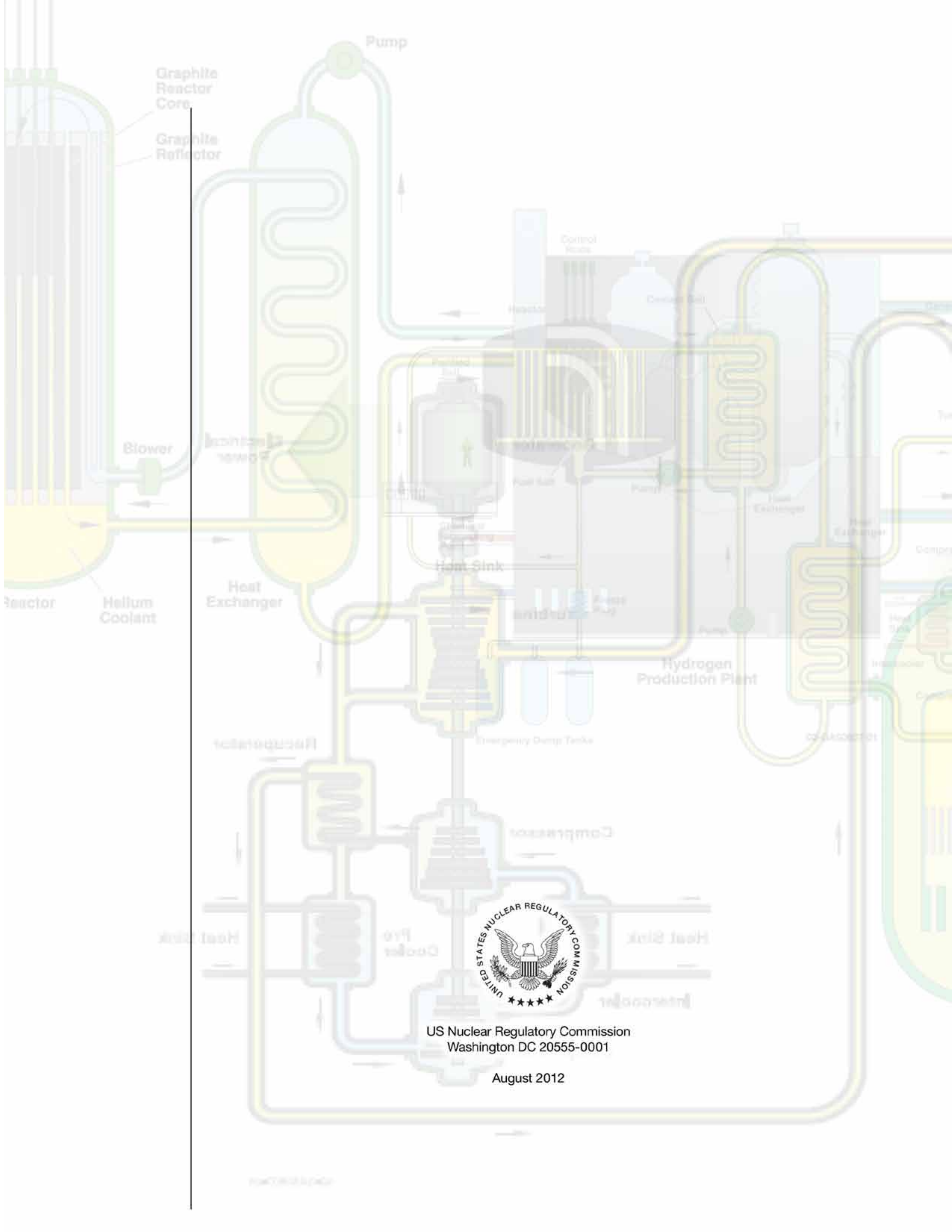


Figure 5.1 Potential Future Reactor Licensing





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