Shultz-Stephenson Task Force on Energy Policy

Reinventing Nuclear Power Essay Series

Licensing Small Modular Reactors: An Overview of Regulatory and Policy Issues

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HOOVER INSTITUTION

SHULTZ-STEPHENSON TASK FORCE ON
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Hoover Institution Press
Stanford University
Stanford, California
2015

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www.hoover.org

Hoover Institution Press Publication

Hoover Institution at Leland Stanford Junior University, Stanford, California 94305-6003.

First printing 2015
21 20 19 18 17 16 15 7 6 5 4 3 2 1

Manufactured in the United States of America

This essay is part of the Hoover Institution Shultz-Stephenson Task Force on Energy Policy's Reinventing Nuclear Power project, edited by George P. Shultz and James O. Ellis Jr. Please see *http://www.hoover.org/reinventing-nuclear-power* for more information and related works.

The editors wish to acknowledge the constructive contributions made to this series by David Fedor.

Licensing Small Modular Reactors
An Overview of Regulatory and Policy Issues

William C. Ostendorff and Amy E. Cubbage

Small Modular Reactors (SMRs) have garnered significant interest in the United States and abroad over the past decade. In its Advanced Reactor Policy statement,[1] the US Nuclear Regulatory Commission (NRC) encourages early interaction between potential applicants and the NRC to provide for early identification of regulatory requirements for advanced reactors. Such early interaction adds stability and predictability to the licensing process by enabling the NRC to develop licensing guidance and to identify and resolve potential policy and technical issues early in the licensing process. In keeping with this policy, the NRC has been closely watching Small Modular Reactor developments and is conducting detailed pre-application reviews with several prospective near-term applicants.

Since the late 1980s, the NRC has developed significant experience in the use of the licensing process described in Title 10 of the Code of Federal Regulations (10 CFR), Part 52 during reviews of large light-water reactor (LLWR) applications. The NRC has certified several standard designs; issued early site permits (ESPs) and limited work authorizations;

The views in this essay are those of the authors and do not necessarily represent the official position of the US Nuclear Regulatory Commission.

1. "Policy Statement on the Regulation of Advanced Reactors: Final Policy Statement," 73 Fed. Reg. (October 14, 2008) 60612, 60616.

and issued combined licenses (COLs) to construct and operate four AP1000 reactors (Vogtle, Units 3 and 4, and V. C. Summer, Units 2 and 3) and an Economic Simplified Boiling Water Reactor (ESBWR) reactor (Fermi, Unit 3). The NRC is also implementing its construction oversight program to oversee new reactor construction activities.

In 2013, the NRC completed a comprehensive lessons-learned review to assess the implementation of the new reactor licensing process. The main objective of this review was to identify opportunities to increase the effectiveness and efficiency of future application reviews, including SMR applications.[2] The assessment revealed no significant problems or impediments associated with the Part 52 licensing process. The review identified several areas where implementation of the licensing process could be improved. This paper will provide an overview of the Part 52 licensing process and the NRC's experience to date with LLWR reviews. This paper will then discuss actions that have been taken to address lessons learned from the LLWR reviews and to prepare for review of future SMR applications. This paper will also provide an overview of the NRC's readiness to review SMR applications and will provide the status of selected SMR-related policy issues.

New Reactor Licensing Process

The NRC revised its regulations in 1989 to establish Part 52[3] as an alternative to the existing process for reactor licensing under 10 CFR Part 50. The Part 52 licensing and regulatory approval process encourages design standardization and provides a more predictable licensing process by resolving safety and environmental issues before authorizing

2. US Nuclear Regulatory Commission, "New Reactor Licensing Process Lessons Learned Review: 10 CFR Part 52, April 2013" (ADAMS Accession No. ML13059A239).

3. US Nuclear Regulatory Commission, "Licenses, Certifications, and Approvals for Nuclear Power Plants," 54 Fed. Reg. 73 (April 18, 1989), 15372-400.

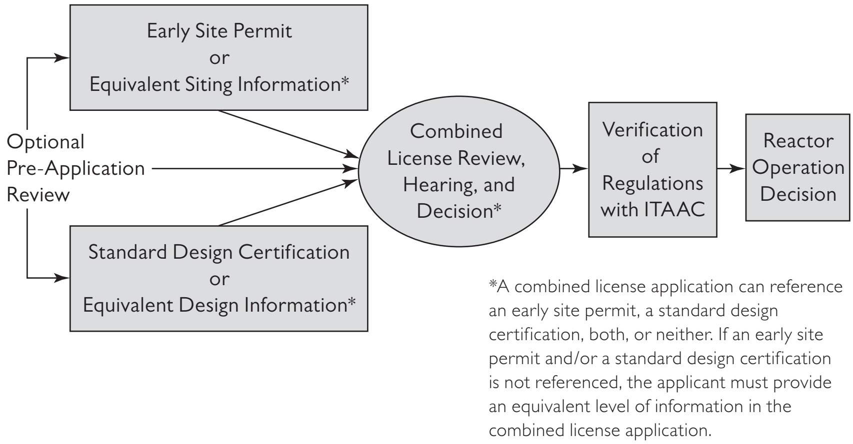

FIGURE 1. Relationship between combined licenses, early site permits, and standard design certifications

Source: Nuclear Regulatory Commission, "Nuclear Power Plant Licensing Process." July 2004, http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0298/br0298r2.pdf.

plant construction. The process also provides for early and meaningful public interaction.

The Part 52 licensing process was established to address some of the difficulties encountered with the so-called two-step Part 50 licensing process used to license the currently operating plants in the United States. Under the Part 50 licensing process, a separate construction permit and operating license were required. In this situation, the NRC reviewed the operating license while the plant was being constructed. This could result in design changes. This process also provides two hearing opportunities, one before construction begins and another after the plant is constructed. In contrast, Part 52 allows an applicant to request a COL, which authorizes both construction and conditional operation of the plant, subject to verification that the plant has been constructed and will be operated in accordance with the license and applicable regulations. The NRC's review and the COL hearing are both completed before construction is authorized, thereby minimizing potential regulatory delays during construction.

Part 52 also provides two other significant procedures: (1) review and approval of standardized designs through a design certification (DC) rulemaking; and (2) review and approval of a site's suitability through an early site permit (ESP). The issues resolved by the design certification rulemaking process and during the ESP hearing process are not reconsidered during the COL application (COLA) review or COL hearing process. The relationship between COLs, DCs, and ESPs is shown in figure 1. As shown in this figure, combined licenses also include inspections, tests, analyses, and acceptance criteria (ITAAC) that must be satisfactorily completed by the licensee to verify that the plant has been constructed and will operate in conformity with the combined license, the provisions of the Atomic Energy Act, as amended, and the Commission's rules and regulations.

Standard Design Certifications

The design certification process is one of the key elements of the Part 52 licensing process. Safety issues associated with the proposed nuclear power plant design are resolved independently of a specific site, providing resolution and finality of these issues prior to plant construction. Certification of a standard design through rulemaking is also important to promoting design standardization. There is a wide variation of design and construction attributes in the current generation of operating reactors in the United States. In contrast, all of the operating plants in France are one of three variations of the same pressurized water reactor (PWR) design, with power outputs of 900 megawatts electrical (MWe), 1,300 MWe, and 1,450 MWe. Design standardization has already demonstrated substantial efficiencies in COLA reviews in the United States. The degree of design standardization may increase in the future with proposed plans for factory fabrication of SMRs.

The NRC has significant experience with successful implementation of the design certification process. The first design to be certified was the Advanced Boiling Water Reactor (ABWR), which was certified on May 12, 1997, and has been built and operated in Japan. This was followed closely by certification of the System 80+ design on May 21, 1997. The ABWR and System 80+[4] are both evolutionary, so-called Generation III light-water reactor (LWR) designs. These evolutionary designs built directly on the experience of operating light-water reactors while increasing safety margins. Building upon the Generation III designs, the next design to be certified on December 23, 1999, was the Advanced Passive 600 (AP600), a so-called Generation III+ reactor.

In its Advanced Reactor Policy Statement (originally issued in 1986), the NRC set an expectation 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." The AP600[5] design, certified in 1997, fulfilled these expectations by using passive safety systems that rely on natural driving forces such as pressurized gas, gravity flow, and natural circulation flow. Further, the AP600 safety systems are designed to function with minimal operator action and without safety-related support systems or AC power for at least seventy-two hours. During the AP600 review, numerous policy issues related to the licensing of passive designs were identified and resolved, including the appropriate regulatory treatment of active non-safety systems. The AP600 design has not been constructed to date. However, the policies established during the AP600 review serve as the foundation for reviews of subsequent, advanced-passive designs.

In 2006, the NRC certified the AP1000[6] design, which was derived from the AP600 design but with an increased power level. The AP1000 design certification was amended in 2011 to address new regulatory requirements in 10 CFR 50.150,[7] requiring an applicant to perform a design-specific assessment of the effects of the impact of a large, commercial

4. System 80+ is a trademark of Westinghouse Electric Company.

5. AP600 is a trademark of Westinghouse Electric Company.

6. AP1000 is a trademark of Westinghouse Electric Company.

7. Nuclear Regulatory Commission, "Aircraft Impact Assessment," 74 Fed. Reg. 112 (June 12, 2009), 28112-47.

aircraft. The design certification amendment also included applicant-proposed changes intended to increase the standardization of the design. For example, standard design information was provided to generically resolve issues that have been previously deferred to COL applicants to address on a plant-specific basis. Similarly, the ABWR design certification was amended in 2011 to address 10 CFR 50.150.

The NRC staff recently completed its review of the passive ESBWR design and issued the design certification rule on October 15, 2014. Passive reactors (i.e., AP600, AP1000, and ESBWR) incorporate features that address the Fukushima lessons learned, in that these plants are designed with a coping period of seventy-two hours for a station blackout. In the event of an extended station blackout (greater than seventy-two hours), non-safety-related, active systems are available to replenish the passive systems or to perform core and containment heat removal functions directly.

Two evolutionary pressurized water reactors are under NRC review. These are the Mitsubishi Heavy Industries' US Advanced Pressurized-Water Reactor and the Korea Hydro and Nuclear Power Company (KHNP) and Korea Electric Power Corporation (KEPCO)'s US Advanced Power Reactor 1400 (APR1400). The review of the AREVA NP's US EPR was suspended in March 2015 at the request of the applicant.

Early Site Permits

The ESP process allows early resolution of siting issues. In reviewing an ESP application, the NRC addresses site safety issues, environmental protection issues, and plans for coping with emergencies, independent of the review of a specific nuclear plant design.

The NRC has issued four ESPs: at the Clinton site in Illinois, the Grand Gulf site in Mississippi, the North Anna site in Virginia, and the Vogtle site in Georgia. The North Anna and Vogtle ESPs were subsequently referenced in COL applications, meaning that siting issues resolved in the ESP did not need to be addressed in the COLA review for these sites. The NRC is currently reviewing an ESP application for

FIGURE 2. New reactor licensing process

Source: Nuclear Regulatory Commission, "New Reactors," http://www.nrc.gov/reactors/new-reactors.html.

two units in New Jersey[8] and is anticipating additional ESP applications for the Blue Castle Generation site in Utah and the Clinch River site in Tennessee.

Combined Licenses

A COL application can reference an ESP, a standard design certification, both, or neither. If an application does not reference an ESP or a standard design certification, the applicant must provide an equivalent level of information in the COL application. The combined license process is shown in figure 2.

8. The PSEG site in Salem County, New Jersey, is adjacent to the Hope Creek Nuclear Generating Station Unit 1 and Salem Nuclear Generating Station Units 1 and 2.

In preparation for a large number of COL applications, the NRC in 2006 developed a design-centered review approach.[9] This approach promotes the standardization of COL applications to facilitate a predictable and consistent method for reviewing applications. This approach uses, to the maximum extent practical, a "one issue, one review, one position" strategy in order to optimize the review effort and the resources needed to perform these reviews. This approach has been successfully implemented for completed and ongoing COL reviews and has significantly contributed to the effectiveness and efficiency of these reviews.

Since 2007, the NRC has received eighteen combined license applications for twenty-eight new reactor units. In light of decreased electrical power demand, reduced natural gas prices, and other economic factors, nine COL application reviews were suspended or cancelled at the request of the applicants. One ESP application for two units and six COL applications for ten units are still under active review, as shown in figure 3. In 2012, the first COLs were granted for Vogtle, Units 2 and 3, and V. C. Summer, Units 3 and 4, representing the first licenses for new commercial nuclear facilities to be issued in the United States since 1978. Issuance of the Vogtle and Summer COLs represented a significant milestone for the NRC's new reactor licensing program by demonstrating that the Part 52 licensing process could be effectively implemented. More recently, in May 2015, the NRC issued a COL for the Enrico Fermi Nuclear Plant, Unit 3. This is the first COL to reference the ESBWR design certification.

The NRC continues to make progress on the COL applications under active review. The schedules for these reviews have been affected by factors including design changes initiated by applicants and the need for supplemental information to address seismology and hydrology lessons learned from Fukushima. Most significantly, review schedules for the referenced design certification applications have been affected in cases

9. US Nuclear Regulatory Commission, "NRC Regulatory Issue Summary 2006-06, New Reactor Standardization Needed to Support the Design-Centered Licensing Review Approach," May 31, 2006.

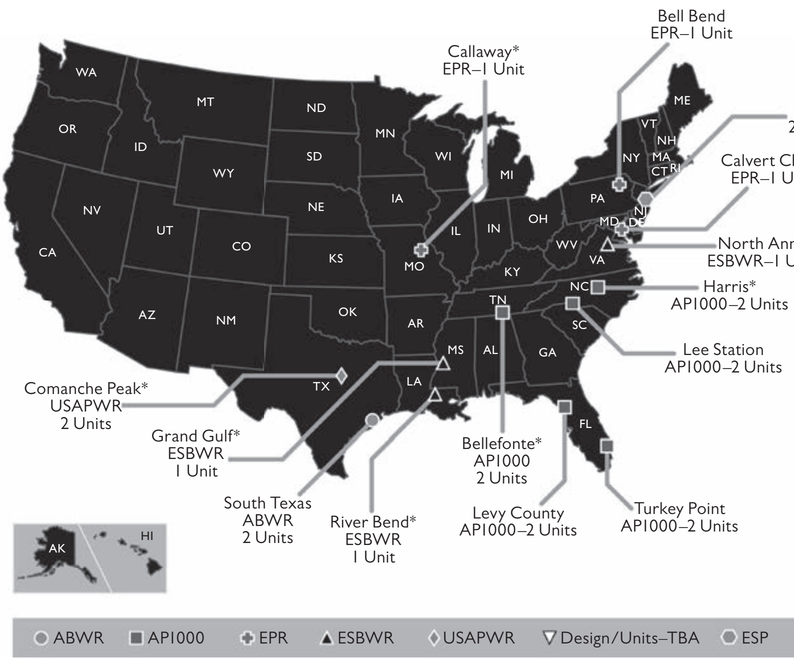

FIGURE 3. New reactor applications under review as of May 2015
Source: Nuclear Regulatory Commission, "Location of Projected New Nuclear Reactors," http://www.nrc.gov/reactors/new-reactors/col/new-reactor-map.html.

where the design certification applicant has requested that the NRC suspend all or portions of the design certification review.

New Reactor Licensing Lessons Learned

The NRC continuously evaluates itself in order to improve agency processes, procedures, and programs. Application of this practice has been evident with the development and evolution of the new reactor licensing process. The Part 52 licensing process itself was developed to address lessons learned from licensing the current fleet of operating reactors. The

Part 52 requirements and associated guidance documents have been routinely updated to factor in the NRC's experience with implementation of the new reactor licensing process. More recently, the NRC's Office of New Reactors performed two comprehensive self-assessments to evaluate the NRC's review of the first COLAs and the first year of post-combined-license implementation of Part 52. Implementation of program enhancements identified by these lessons-learned reviews is under way.

New Reactor Licensing Process Lessons-Learned Review

In April 2013, the NRC issued a report of lessons learned during the first-time implementation of the licensing portion of 10 CFR Part 52.[10] The report contained several suggestions to enhance the licensing process for future application reviews, as shown in the accompanying text box, "Part 52 Licensing Lessons Learned."

Part 52 Licensing Lessons Learned

Lesson 1: Quality of Applications
Lesson 2: New Reactor Review Guidance
Lesson 3: Design Standardization
Lesson 4: Identification and Resolution of Technical Issues
Lesson 5: Knowledge Management
Lesson 6: Application Timing and Sequencing
Lesson 7: Updates to Regulations

These enhancements are intended to support achievement of the NRC's goal to conduct shorter and less costly design certification reviews. One of the key lessons is that high-quality applications with a

10. US Nuclear Regulatory Commission, "New Reactor Licensing Process Lessons Learned Review: 10 CFR Part 52."

sufficient level of design detail significantly contribute to overall project performance. A complete, high-quality application is an essential prerequisite for the efficient use of NRC resources and for the establishment of realistic and predictable schedules. In response to this insight, the NRC is enhancing its license application acceptance review process in two ways. First, the NRC revised its acceptance review process by accelerating the timing of robust pre-application audits of applicant readiness. Second, the NRC is changing the acceptance review criteria from sufficient information to *begin* an application review to sufficient information to *conduct* an application review in order to support timely outcomes. The NRC implemented these criteria during the acceptance review of the APR1400 design certification application submitted to the NRC in September 2013. Consistent with its "Part 52 Licensing Process Lessons Learned Review," the NRC conducted a thorough acceptance review of the APR1400 DC application and determined that additional information was required before the application could be docketed for NRC review. The applicant submitted a revised application in December 2014 that was subsequently docketed. This standard for acceptance will also be applied to future applications, including those for SMR designs.

Another key lesson was that strong design standardization contributes to an efficient regulatory review while ongoing design changes have the opposite effect. Experience has shown in many cases that extended review schedules have been caused by applicant design changes during the review process. This results in rework and escalation of review costs. Applicants should ensure that their designs are stable and mature before submitting applications to the NRC to avoid such schedule challenges.

The "Lessons Learned" report reinforced the benefits of early identification and resolution of issues through robust pre-application interactions. Despite these pre-application interactions, emerging technical issues will undoubtedly arise during the review. These emerging issues are typically resolved through the staff issuing requests for additional information (RAIs).[11] Resolution of complex issues and the associated RAIs presents significant challenges to project resources and schedules. These challenges are often exacerbated when multiple rounds of RAIs and responses result in little progress toward issue resolution. One lesson learned from this experience is that both the NRC and applicants need to identify issues as early as possible and elevate them to appropriate levels of NRC and applicant management to bring about timely resolution.

Finally, the report emphasized the importance of developing and maintaining regulatory guidance as a key factor in successful implementation of the licensing process. Numerous new and revised Standard Review Plan[12] (SRP) sections have been published to incorporate lessons learned from completed licensing reviews. The NRC also publishes interim staff guidance documents to make guidance available in a timely manner as new technical issues arise during reviews. The NRC is focusing its guidance development efforts on areas where significant complex RAIs have been needed and areas that have been a critical path on review schedules, such as seismic and structural reviews. As discussed later in this paper, these insights are also being applied to the development of design-specific review standards for SMRs.

Part 52 Implementation Self-Assessment Review

In July 2013,[13] the NRC issued a report of lessons learned during the first year of post-COL implementation of Part 52 following an in-depth review of actions taken by the NRC following issuance of the COLs at Vogtle, Units 3 and 4, and V. C. Summer, Units 2 and 3. The report con-

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11. The NRC uses the RAI process to request supplemental information from applicants when needed to conduct the review.

12. US Nuclear Regulatory Commission, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," NUREG-0800, March 29, 2007.

13. US Nuclear Regulatory Commission, "Title 10 of the Code of Federal Regulations Part 52 Implementation Self-Assessment Review: 1 Year Post-Combined License Issuance," July 2013 (ADAMS Accession No. ML13196A403).

cluded that most aspects of implementation were performed effectively and efficiently, and identified some areas that could be improved. While this report was primarily aimed at post-licensing actions, including construction oversight and vendor inspections, the report provided valuable insights for future applicants. As an example, the report emphasized the importance of clarity in the licensing basis to avoid ambiguity and confusion during the construction and oversight process. For example, for the AP1000 Auxiliary and Shield Building Critical Sections, the design control document notes, "The design implemented in fabrication and construction drawings and instructions will have the design shown, an equal design, or a better design for key structural components." The NRC staff interpreted this statement to apply only to minor dimensional deviations. The licensee interpreted it more broadly. Resolving this conflict resulted in significant construction delays.

The report also raised issues regarding vendor oversight. As noted in the report, there are over 400 domestic and 160 foreign vendors in at least seventeen countries supplying the US nuclear industry. Reactor licensees are responsible for the quality of the components used in their facilities. The report suggested that NRC programs and processes should continue to communicate and clarify the different roles and responsibilities of vendors and licensees. This will continue to be of importance in the future when planning for potential SMR construction projects. New licensees, new vendors, new suppliers, and the potential for factory-fabricated reactors could introduce additional complexities in roles and responsibilities and could introduce complexities in the implementation of the NRC's construction oversight and vendor oversight programs.

Overview of Small Modular Reactor Designs

Numerous SMR concepts are being developed domestically and internationally. In the interest of simplicity, this paper will focus on SMRs whose designers are currently engaged in pre-application discussions with the NRC. Although definitions of SMRs vary, for the purpose of this paper, "SMR" will be defined consistent with the Department of Energy (DOE) which refers to SMRs as nuclear power plants generating 300 MWe or less.[14] DOE also refers to SMRs as "factory-fabricated reactors" that can be transported by truck or rail to a nuclear power site. This section of the report will address the technical and policy issues associated with so-called integral pressurized water reactor (iPWR) designs, which are a subset of SMRs. In large pressurized water reactors (PWRs) such as the AP1000, the reactor vessel, steam generator, and pressurizer are separate components connected by reactor coolant system piping. In iPWRs, primary and secondary systems are combined into a single assembly such that reactor coolant system piping external to the reactor vessel is not required.[15] While iPWR designers have introduced novel design features and safety advancements, the technology is largely based on the experience of the current operating reactor fleet and builds off the experience with certifying the advanced passive LLWR designs that have been approved by the NRC. A brief discussion of advanced non-light-water reactors (non-LWRs) is also provided later in the paper.

Please visit Hoover's Reinventing Nuclear Power project online to view a separate slide deck with diagrams and specifications for the SMR designs described below, at *http://www.hoover.org/reinventing-nuclear-power.*

US Department of Energy's SMR Licensing Technical Support Program

In fiscal year 2012, the Department of Energy (DOE) initiated a Small Modular Reactor Licensing Technical Support program. The goal of

14. Megawatt electrical (MWe) refers to electric power, while megawatt thermal (MWt) refers to thermal power produced.

15. In some iPWR designs, the steam generator and pressurizer are directly adjacent to the reactor pressure vessel rather than placed inside.

DOE's program is to advance the certification and licensing of domestic SMR designs. DOE believes that SMRs may play an important role in addressing the energy, economic, and climate goals of the United States if they can be commercially deployed within the next decade. To that end, DOE had formed cost-share partnerships with NuScale Power[16] and Generation mPower.[17]

mPower Design

The mPower[18] design is an iPWR with passive safety systems with the reactor and steam generator placed in a single vessel located in an underground containment. The mPower reactor has a rated thermal output of 530 MWt and electrical output of 180 MWe. Generation mPower LLC has engaged in extensive pre-application discussions with the NRC. The NRC was prepared to receive an application for design certification in the fall of 2014. However, in April 2014, the applicant informed the NRC that its schedule for the design certification submission would be delayed.

NuScale Design

The NuScale design is a natural circulation iPWR with the reactor core and helical coil steam generator located in a common reactor vessel in a cylindrical steel containment. The reactor vessel/containment module is submerged in water in the reactor building safety-related pool. The reactor building is located below grade. The reactor building is designed to hold twelve SMRs. Each NuScale SMR has a rated thermal output of 160 MWt and electrical output of 50 MWe,[19] yielding a total capacity of 600 MWe for twelve SMRs. The NRC has been engaged in pre-application interactions regarding the NuScale design since 2008. The

16. NuScale Power is a registered trademark of NuScale Power LLC.

17. Generation mPower is a joint company formed by Babcock & Wilcox and Bechtel.

18. mPower is a registered trademark of Babcock & Wilcox Nuclear Energy.

19. In 2014, NuScale Power changed the rated power level from 45 MWe to 50 MWe (gross).

NuScale design certification application is currently scheduled to be submitted to the NRC in the second half of 2016.

Other iPWR Designs in Pre-application with NRC

Westinghouse SMR Design

The Westinghouse SMR is an iPWR with passive cooling. It is a light-water reactor with the reactor and steam generator located in a single reactor vessel. The reactor building is located below grade. The Westinghouse SMR has a rated thermal output of 800 MWt and electrical output of 225 MWe. Westinghouse has engaged with the NRC in limited pre-application discussions. The timing of a potential application for design certification is not yet determined.

SMR-160 Design

The Holtec SMR-160 design is a passively cooled SMR.[20] The reactor, steam generator, and spent fuel pool are located inside containment and the reactor core is located below grade. The Holtec SMR-160 has a rated thermal output of 525 MWt and a rated electrical output of 160 MWe. Holtec has also engaged with the NRC in limited pre-application discussions. The timing of a potential application for design certification is not yet determined.

Preparation for SMR Applications

The NRC's preparation for SMR application reviews began in earnest in 2001, when the NRC established a future licensing organization within the Office of Nuclear Reactor Regulation to prepare for and manage

20. The primary and secondary components are not integrated into the SMR-160 reactor vessel. However, these components are close-coupled and there is no large reactor coolant system piping.

future reactor and site licensing applications. One of the primary tasks of this fledgling organization was to assess the NRC's readiness to review applications for licenses and to inspect new nuclear power plants in response to Commission direction,[21] which stated in part:

> *The staff should assess its technical, licensing, and inspection capabilities and identify enhancements, if any, that would be necessary to ensure that the agency can effectively carry out its responsibilities associated with an early site permit application, a license application, and the construction of a new nuclear power plant. This effort should consider not only the nuclear power plant designs that have been certified by the NRC pursuant to 10 CFR Part 52, but also the Pebble Bed Modular Reactor and other generation 3+ or generation 4 light water reactors such as the AP-1000 and the International Reactor Innovative and Secure designs.*

In response, the NRC staff prepared a Future Licensing and Inspection Readiness Assessment[22] in 2001 which guided the NRC's preparation for future applications including SMRs and non-LWR designs. During that time, the NRC was also conducting a detailed pre-application review of the Pebble Bed Modular Reactor (PBMR).[23] In support of the PBMR pre-application review, the NRC discussed policy issues including operator staffing, number of licenses, and annual fees in SECY-01-0207[24] and SECY-02-0180.[25] In general, these issues were not specific to the PBMR and would have been equally relevant to the licensing of any SMR.

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21. US Nuclear Regulatory Commission, staff requirements memorandum for COMJSM-00-0003, "Staff Readiness for New Nuclear Plant Construction and the Pebble Bed Modular Reactor," February 13, 2001.

22. US Nuclear Regulatory Commission, SECY-01-0188, "Future Licensing and Inspection Readiness Assessment," October 12, 2001.

23. The PBMR is a modular, high-temperature, helium-cooled, graphite-moderated reactor.

24. Nuclear Regulatory Commission, SECY-01-0270, "Legal and Financial Issues Related to Exelon's Pebble Bed Modular Reactor (PBMR)," November 20, 2001.

25. Nuclear Regulatory Commission, SECY-02-0180, "Legal and Financial Policy Issues Associated with Licensing New Nuclear Power Plants," October 7, 2002.

Progress was made on these issues. However, the PBMR pre-application review was subsequently suspended at the request of the applicant. NRC efforts were redirected to preparation for anticipated ESP, COL, and DC reviews.

With renewed interest in SMRs, the NRC in 2008 formed a dedicated Advanced Reactor Program (later the Division of Advanced Reactors and Rulemaking) to focus its preparations for SMR applications and to prepare for potential non-LWR applications. As part of its preparation activities, the staff has developed a thirty-nine-month optimum baseline schedule for light-water SMR DC application reviews. This schedule includes review by the Advisory Committee for Reactor Safeguards (ACRS) and the design certification rulemaking with a public comment period. The baseline schedule, as shown in figure 4, is formulated using the agency's six-phase new reactor licensing review process, as follows:

- **Phase 1:** prepare requests for additional information (RAIs) and preliminary safety evaluation report (PSER)
- **Phase 2:** prepare safety evaluation report (SER) with open items (O/Is)
- **Phase 3:** ACRS review of SER with O/Is
- **Phase 4:** prepare advanced SER with no O/Is
- **Phase 5:** ACRS review of advanced SER with no O/Is
- **Phase 6:** prepare final SER with no O/Is
- **Rulemaking:** proposed and final design certification rulemaking (including public comment period)

A thirty-nine-month review schedule would be a significantly shorter review period than experience has shown for completed LLWR DC reviews. The actual duration of SMR DC application reviews will be contingent upon a number of factors, such as the degree of productive pre-application engagement with the NRC by the applicant, the completeness and adequacy of the SMR application, and the applicant's ability to respond to RAIs in a timely fashion. This section of the paper

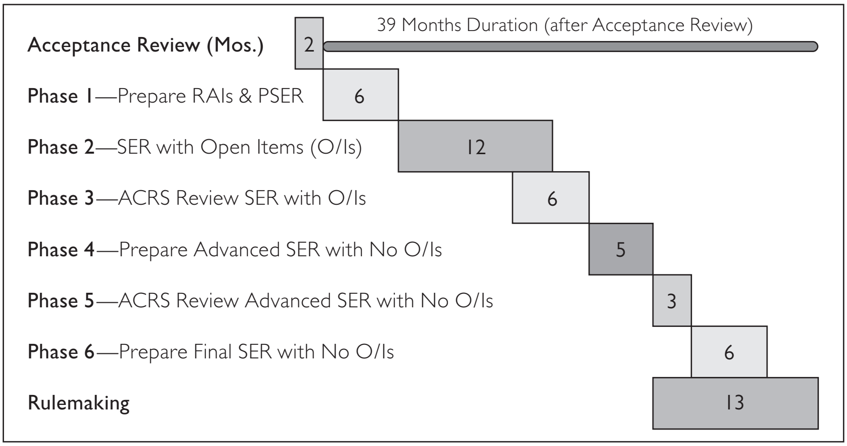

FIGURE 4. Baseline SMR design certification rulemaking schedule
Source: Nuclear Regulatory Commission, "Baseline Schedule for SMR Design Certification Reviews," Presentation by Mike Jones, project manager, NRO/DARR/SMRLB2, Rockville, Maryland, February 24, 2014, http://pbadupws.nrc.gov/docs/ML1405/ML14050A063.pdf.

will discuss the status of SMR-related policy issues and provide a general assessment of the readiness for SMR reviews, including the development of design-specific review guidance. These activities are essential to achieving the goal of an optimum review schedule and must be fully supported by prospective applicants.

SMR Policy Issues

Under the Atomic Energy Act and relevant case law, the Commission's mission with respect to regulating nuclear power reactors is to ensure adequate protection of the environment and public health and safety and the common defense and security. The Advanced Reactor Policy states:

> *[T]he 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. 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.

The SMR designs currently under NRC pre-application review meet the Commission's expectations for advanced reactors due to inherent safety features (e.g., elimination of reactor coolant system piping and reduced core decay heat) and innovative approaches to safety such as natural circulation and passive cooling systems. In an effort to increase the potential geographic locations where an SMR could be sited and to increase the economic attractiveness of SMRs, industry has proposed some alternate licensing strategies that involve policy issues, such as proposed reductions in control room staffing and proposed reductions in the size of emergency planning zones. It is important to note that the NRC's existing regulatory framework, regulations, and guidance, coupled with the foundation of extensive experience in licensing LLWRs, provides a sufficient framework for the licensing of Small Modular Reactors. That said, the NRC is working with industry to address these policy issues in a manner that preserves the NRC's safety and security mission and fulfills the Commission's expectations for advanced reactors.

In 2010, the NRC identified a range of potential policy issues in SECY-10-0034.[26] Since that time, the NRC has been working with industry, as represented by the Nuclear Energy Institute (NEI), prospective applicants, and other stakeholders to bring additional clarity to these issues and to establish NRC policy when enough information (i.e., clear industry proposals with supporting design detail and analysis) is available to support decision-making. The status of key SMR policy issues is discussed in the following paragraphs.

26. Nuclear Regulatory Commission, SECY-10-0034, "Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactor Designs," March 28, 2010 (ADAMS Accession No. ML093290268).

Number of nuclear power units operating	Position	One unit	Two units		Three units	
		One control room	One control room	Two control rooms	Two control rooms	Three control rooms
None	Senior operator	1	1	1	1	1
	Operator	1	2	2	3	3
One	Senior operator	2	2	2	2	2
	Operator	2	3	3	4	4
Two	Senior operator		2	3	3	3
	Operator		3	4	5	5
Three	Senior operator				3	4
	Operator				5	6

TABLE 1. Minimum requirements per shift for on-site staffing of nuclear power units by licensed operators and senior operators (10 CFR 50.54)
Source: Nuclear Regulatory Commission, regulation 10 CFR 50.54, "Conditions of licenses," http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0054.html.

Requirements for Operator Staffing for Small or Multi-Module Facilities

SMR designers are considering whether their designs can operate with a staffing complement that is less than that currently required by NRC regulations and how many units can be controlled from a common control room. Current regulations do not address the possibility of more than three reactors at a site or more than two reactors being controlled from one control room, as shown in table 1.

In SECY-11-0098,[27] the NRC concluded that evaluating applicant operator staffing exemption requests is the best short-term response for

27. Nuclear Regulatory Commission, SECY-11-0098, "Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities," July 22, 2011 (ADAMS Accession No. ML111870574).

this issue. The NRC has determined that adequate guidance is available to evaluate plant-specific operator staffing exemption requests based on factors such as the applicant's concept of operations, task analysis, and staffing plan. Accordingly, this issue is now resolved from a generic policy perspective and will be addressed on a plant-specific basis. As experience is gained in performing the operator staffing exemption requests, the need for a long-term approach will be further evaluated.

Security Requirements for SMRs

Following the terrorist attacks of September 11, 2001, the NRC enhanced its security requirements. This resulted in a significant increase in security staffing. Further, in 2008 the NRC revised its Advanced Reactor Policy to encourage applicants to incorporate security features at the design stage and to incorporate innovative means to accomplish security functions.

SMR designers and potential applicants have indicated their intent to adhere to the Commission's Advanced Reactor Policy Statement by addressing security during the design process to increase reliance on engineered systems and reduce reliance on operational requirements and staffing. This may include optimized site layout for security, a reduced number of vital areas, and design approaches that incorporate safety systems underground and within the containment.

The NRC has completed an assessment of the current security regulatory framework and whether there are any policy issues for the proposed iPWRs. In SECY-11-0184,[28] the NRC concluded that current NRC regulations allow SMR designers and potential applicants to propose alternative methods or approaches to meet the performance-based and prescriptive security requirements based on the unique characteristics of a particular SMR design without necessitating regulatory exemptions. Based on this assessment, this potential policy issue is now resolved from

28. US Nuclear Regulatory Commission, SECY-11-0184, "Security Regulatory Framework for Certifying, Approving, and Licensing Small Modular Nuclear Reactors," December 29, 2011 (ADAMS Accession No. ML112991113).

a generic perspective. Security strategies will be reviewed on a plant-specific basis using existing regulatory requirements and guidance.

Source Term for SMRs

Accident source terms[29] are used for the assessment of the effectiveness of the containment and plant mitigation features, site suitability, and emergency planning. Accident source terms are expected to be reduced for SMRs due to their reduced fuel inventory and passive safety features that reduce the probability and consequence of postulated accidents. SMR applicants are also considering using a mechanistic source term method to determine accident dose. A mechanistic source term is developed using best-estimate phenomenological models of the transport of the fission products from the fuel through the reactor coolant system, through all holdup volumes and barriers, taking into account mitigation features, and into the environment. This approach varies from the more conservative approach used for licensing existing operating reactors and for licensing new reactors to date, which did not account for design-specific features and accident progression timelines.

A reduced source term would facilitate siting SMRs in locations where nuclear plants have not been traditionally sited—for example, as replacements for aging fossil units, on military installations, or collocated with industrial facilities for process heat applications. This issue is also closely related to the emergency planning requirements for SMRs. The NRC believes that, with appropriate justification, applicants may be able to take information from current guidance on design-basis accident analysis for large light-water reactors and apply it to light-water Small Modular Reactors.[30] The NRC is currently engaged with the mPower

29. Source term refers to the quantities, timing, physical and chemical forms, and thermal energy of radionuclides (fission products) released from the reactor building to the environment during postulated accidents.

30. Nuclear Regulatory Commission memo, "Status of Mechanistic Source Term Policy Issue for Small Modular Reactors," June 20, 2014 (ADAMS Accession No. ML14135A482).

and NuScale vendors to review design-specific approaches for accident source terms.

Emergency Planning Requirements for SMRs

Prospective SMR applicants may propose reduced emergency planning zones for SMRs based on the enhanced safety inherent in the design of SMRs (e.g., reduced risk, smaller source term, slower fission product accident release, and reduced potential for dose consequences to populations in the vicinity of the plan). In SECY-11-0152, the staff stated that emergency planning requirements could be scaled (e.g., reduced emergency planning zone size) for SMRs to be commensurate with the accident source term, fission product release, and associated dose characteristics for the designs. The NRC informed industry that it would not go further in proposing new policy or revising guidance for specific changes to emergency planning requirements absent specific proposals from an applicant or nuclear-industry group. However, NEI recently proposed a generic methodology and criteria for establishing the technical basis for SMR-appropriate emergency planning zones.[31] While no specific applicants have formally indicated that they plan to use an alternative emergency planning approach, the NRC is actively engaged with NEI to review its proposed methodology to bring additional clarity to this issue. However, plant-specific source term and other design details will be needed from prospective applicants along with a compelling justification for proposed exemptions or changes to emergency planning requirements, particularly due to heightened interest in this topic after the Fukushima Daiichi accident.

Annual Fees for SMRs

In 2009, the NRC issued an advance notice of proposed rulemaking to review whether the existing single annual fee structure for power reactors

31. Nuclear Energy Institute, "A Proposed Methodology and Criteria for Establishing the Technical Basis for Small Modular Reactor Emergency Planning Zone," white paper, December 2103 (ADAMS Accession No. ML13364A345).

was appropriate in light of the potential for future licensing of SMRs. Based on stakeholder feedback and proposals, the NRC considered several alternatives. The NRC is proceeding to develop a variable annual fee structure for small and medium-size reactors. The approach provides a clear, reliable, and efficient method of calculating annual fees for reactor licensees. Further, by linking the annual fees to the licensed thermal power level, the costs would be allocated based on a benefit received from the NRC license. The NRC plans to complete this rulemaking in 2015 to resolve this policy issue.

Design-Specific Review Standards

The NRC has undertaken an initiative to streamline its review of iPWR applications by using risk insights and design information obtained through detailed pre-application interactions to create design-specific review standards (DSRSs). The DSRSs serve the same purpose and have the same objectives that the Standard Review Plan has for non-iPWR application reviews. The DSRS review framework allows a graded review approach to SMR structures, systems, and components (SSCs) in consideration of the safety and risk significance of SSCs.[32] The framework also allows an integrated review approach whereby programmatic requirements such as quality assurance, equipment qualification, and in-service testing and in-service inspections can be relied on to provide reasonable assurance of some aspects of SSC performance (e.g., capability, reliability, and availability). DSRS development facilitates identification and resolution of complex technical issues in advance of the application, allowing the applicant to provide a more complete application that will be easier to review.

The DSRS approach also incorporates lessons learned from LLWR reviews. For example, the NRC is incorporating key lessons learned with completed and ongoing reviews of digital instrumentation and

32. Policy Issue Notation Vote, February 18, 2011, SECY-11-0024, http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2011/2011-0024scy.pdf.

control (I&C) systems. New reactor designs typically include highly integrated and complex I&C systems. The reviews of these systems have been resource-intensive and challenging. To address the significant lessons learned from these reviews, the NRC undertook an innovative, integrated approach to develop design-specific review standards for digital I&C systems to facilitate more effective and efficient reviews.

The NRC has made significant progress in developing DSRSs for the mPower and NuScale designs. The NRC published the draft DSRS for the mPower design as "Proposed—For Interim Use and Comment" in May 2013.[33] The mPower DSRS will be made final no later than the time of docketing of the anticipated DC application. The NRC is proceeding with efforts to develop a draft DSRS for the NuScale design with the goal to issue the draft DSRS about one year before the scheduled date of the design certification application.

Non-Light-Water Reactors

The NRC's recent efforts to prepare for SMRs have focused on iPWR technologies due to the greater potential for near-term applicants. However, there is US licensing experience with non-light-water reactors (e.g., Peach Bottom Unit 1[34] and Fort St. Vrain[35]). The NRC has also engaged in significant pre-application interactions with prospective applicants for non-LWR designs over the past several decades. These engagements included pre-application reviews of a high-temperature gas-cooled reactor such as the PBMR, the Gas Turbine-Modular Helium Reactor, and its predecessor, the Modular High-Temperature Gas-Cooled Reactor. The NRC also previously engaged in pre-application reviews of

33. Nuclear Regulatory Commission, "mPower Design-Specific Review Standard," 78 Fed. Reg. 93 (May 14, 2013), 28258-28262.

34. Peach Bottom Atomic Power Station Unit 1 was a 115 MWt, high-temperature, gas-cooled reactor that operated from 1966 until 1974.

35. Fort St. Vrain Generating Station was an 842 MWt, high-temperature, gas-cooled reactor that operated from 1976 until 1989.

Power Reactor Innovative Small Module and Sodium Advanced Fast Reactor advanced liquid-metal reactors.

More recently, the NRC actively participated with DOE in regulatory activities for the Next Generation Nuclear Plant project (NGNP). The NGNP project was formally established by the Energy Policy Act of 2005[36] to develop, license, build, and operate a prototype high-temperature gas-cooled reactor that generates high-temperature process heat for use in hydrogen production and other energy-intensive industries while also generating electric power. Consistent with the act, the NRC has been working with DOE on resolving policy issues intended to support licensing of any future high-temperature gas-cooled reactor designs that might be submitted or licensing of other advanced reactor technologies. In 2011, the DOE announced it would not proceed with Phase II NGNP design activities. Therefore, the NRC and DOE agreed to focus remaining interactions on resolving four key issues: (1) licensing basis event selection; (2) radionuclide release source terms; (3) containment functional performance; and (4) emergency preparedness. The NRC recently issued assessment reports[37] summarizing the results from these NGNP interactions.

In 2012, the NRC prepared a report to Congress[38] addressing the NRC's overall strategy for, and approach to, preparing for the licensing of advanced reactors. The report to Congress listed the key activities necessary to prepare the agency for reviews of applications related to the design, construction, and operation of advanced non-LWRs as follows:

- 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.

36. Energy Policy Act of 2005, Pub. L. No. 109-58, 42 USC (16021).

37. Nuclear Regulatory Commission, "Next Generation Nuclear Plant-Assessment of Key Licensing Issues," July 17, 2014 (ADAMS Accession No. ML14174A626).

38. US Nuclear Regulatory Commission, "Report to Congress: Advanced Reactor Licensing," August 2012 (ADAMS Accession No. ML12153A014).

- Engage reactor designers, potential applicants, industry, and DOE in meaningful pre-application 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.

Since 2012, there has been diminished support from DOE and industry for potential near-term non-LWR applications. As a result, the NRC's readiness to license non-LWR designs has not changed significantly since issuance of the 2012 report. However, in July 2013,[39] the DOE and the NRC embarked on an initiative to develop advanced reactor design criteria that could be used for the licensing of non-LWR designs. The DOE submitted a draft set of design criteria for advanced reactors to the NRC in late 2014.[40] The intended outcome of this initiative is NRC-issued regulatory guidance pertaining to principal design criteria for advanced reactor designs for use by applicants in preparing licensing applications or for use by NRC staff for application review. The NRC also continues to engage with DOE and international counterparts to maintain cognizance of non-LWR developments and will continue to prepare for potential applications. In early 2014,[41] X Energy LLC notified the NRC of its intent to submit a future application for certification of its Xe-100 High Temperature Pebble Bed Small Modular Reactor. Other potential non-LWR applicants have also reached out to the NRC to discuss licensing, schedule, and resource topics. The NRC stands ready to support pre-application interactions with prospective non-LWR applicants.

39. Letter from Glenn Tracy to the Department of Energy (ADAMS Accession No. ML13141A276) and John Kelley's letter to the NRC (ADAMS Accession No. ML14029A017).

40. Idaho National Laboratory report INL/EXT-14-31179, Revision 1, "Guidance for Developing Principal Design Criteria for Advanced (Non-Light Water) Reactors," December 2014 (ADAMS Accession No. ML14353A246).

41. Letter from X-Energy to NRC, "Submittal of Application for Design Certification," January 10, 2014 (ADAMS Accession No. ML14023A799).

International Engagement

The NRC maintains a robust international program by participating in international working groups and providing advice and assistance to international organizations and regulatory bodies. Specific to new reactors, the NRC is actively engaged in international cooperative activities to promote enhanced safety in new reactor designs, improve the effectiveness and efficiency of inspections, and ensure that construction experience is shared internationally.

One of the key international activities in this area is the NRC's participation and leadership role in the Multinational Design Evaluation Program (MDEP). MDEP is an initiative to develop innovative approaches to leverage the resources and knowledge of the national regulatory authorities of fourteen countries involved with new reactor design reviews. While each national regulatory authority retains the rights and responsibility for licensing new reactors in its country, the MDEP activities have been mutually beneficial to the NRC and its counterparts. The NRC leads the MDEP working groups for the AP1000 design, digital instrumentation and controls, and vendor inspection cooperation. The NRC also actively participates in the US EPR and APR1400 working groups and the codes and standards working group. MDEP working groups have established common positions on generic issues such as digital instrumentation and control design and design-specific issues such as the AP1000 squib valves.

The AP1000 working group has been particularly beneficial to the NRC and the Chinese National Nuclear Safety Administration as AP1000 reactors are currently being built in both the United States and China. The NRC and the Chinese agency are cooperating on AP1000 topics of mutual interest, including exchange of inspection staff during construction and pre-operational testing.

The NRC has taken a leadership role in the development of an international regulatory forum for cooperation on SMR issues. The purpose of this forum is to identify, understand, and address key regulatory challenges that may emerge in future SMR regulatory discussions.

This will help enhance safety and efficiency in licensing and will enable regulators to inform changes, if necessary, to their requirements and regulatory practices. This effort has included chairing consultancy meetings at the International Atomic Energy Agency on licensing and safety policy issues for SMRs. The NRC will continue international engagement on SMRs to leverage international experience and research and development efforts to inform the NRC's SMR design reviews. 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 are important to the safe and efficient evolution and eventual deployment of such technologies.

As a safety regulator, the NRC does not play any promotional role with regard to the deployment of SMRs, domestically or abroad. Absent the submittal of a license application in the United States, cooperation will be limited to key generic topics of interest to the forum members. NRC can, it is hoped, play a leadership role in those discussions.

Summary

Market factors and business decisions will ultimately determine whether Small Modular Reactors are deployed in the United States.[42] The NRC has not identified any significant technical or policy issues that would represent an impediment to licensing iPWRs and the NRC is prepared to review iPWR applications. Uncertainty in iPWR submittal schedules and evolving design concepts continue to be significant planning challenges for the NRC. Furthermore, the schedule for such reviews will depend in large part on the degree to which prospective applicants interact with the NRC to facilitate early identification and resolution of

42. As an independent regulatory agency, the NRC is focused on the health and safety of the public and common defense and security. The NRC does not promote any particular technology or design or the use of nuclear energy.

design-specific technical and policy issues before applications are submitted. It is incumbent on all applicants to submit complete, high-quality applications that provide the safety basis of their proposed designs and to provide the justification for any requested policy changes or exemptions. The accompanying text box, "Strategies for an Efficient Application Review," provides strategies to enhance the efficiency of SMR application reviews. In anticipation of the first iPWR application in 2016, the NRC will continue to engage with prospective applicants to resolve technical and policy issues while remaining focused on fulfilling its safety and security mission.

Strategies for an Efficient Application Review

- Arrange early engagement with regulatory authorities.
- Rely on proven technology and methods when possible.
- Provide thorough justification for new design features and methods including sufficient testing.
- Provide a complete, high-quality application supported by sufficient design detail.
- Minimize design changes after submittal.
- Maximize design standardization.
- Provide justification for alternative approaches such as regulatory exemptions and changes to NRC policy.

About the Authors

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