POLICY PAPER

Making SMR Projects Blue Chip Investments: Supporting an Effective and Efficient Nuclear Licensing Process

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Executive Summary

To meet domestic decarbonization goals, the U.S. will need to maintain its current fleet of nuclear reactors *and* grow the fleet with ~200 GW of new reactors by 2050.[i] Accomplishing both domestic and global scale up requires innovation in reactor technology and the deployment of small modular reactors (SMR).

Smaller sizes and simple, modular designs promise cost competitiveness through design standardization, factory fabrication, and repetitive, onsite construction. SMRs also promise enhanced safety due to the technology profile and smaller size. However, cost reductions are only realized through the completion of consecutive units for a single, standardized design.

To unlock the orderbook for any given design, promised innovations must be thoroughly assessed and, ultimately, approved in the licensing process. Through the process of licensing, the U.S. Nuclear Regulatory Commission (NRC) evaluates new reactors to ensure the design meets public safety, security, and environmental requirements. If a review is successful, NRC authorizes an applicant to construct, operate, and decommission a commercial reactor.[ii] Licensing encapsulates a number of permits, approvals, certifications, and the ultimate license to operate. To initiate and expedite a review, NRC strongly recommends preliminary actions, referred to as pre-application engagements. This includes white papers, topical reports, and meetings.

Recent attempts to license new reactors have proven this process to be an obstacle for SMR commercialization. From the first official review to license to operate, this process can take six-to-seven years with little certainty regarding if, or when, NRC will accept novel features.

These innovations require a new paradigm of thinking regarding reactor safety. Most SMR features require a significant departure from the current regulations and the regulatory activities NRC has conducted over the past 40 years. For example, several SMR designs hope to eliminate concrete containment domes, reduce, or eliminate onsite operational labor, or locate near industrial facilities or populations.

In addition to a light-water prescriptive framework, recurring challenges reduce the efficiency and predictability of reviews for first-of-a-kind SMRs. These challenges include obtaining quality and complete information, insufficient workforce performance from NRC, inefficient external engagements, and misalignment within the NRC regarding licensing decisions. Though NRC is undergoing substantial effort to overcome these challenges and improve its ability to license SMRs, the agency's ability to respond quickly is challenged by: i) novel technologies, ii) NRC's fee structure, and iii) agency culture.

- **FOAK, Novel Technologies**

  The use of novel technologies or features that NRC has limited experience evaluating challenges a safety review. NRC must have sufficient confidence to make a safety decision regarding features that have not been previously demonstrated at commercial scale, lack operating experience, and do not have regulatory precedent. The process of reaching this confidence can be time and resource intensive for both applicants and the regulator.

- **Agency Fee Structure**

  Excluding certain activities, Congress mandates NRC to recover 100% of its budget from the fee base, including license holders and those utilizing NRC services.[iii] NRC's fee recovery model inadvertently discourages technology innovation, regulatory innovation, and the development of institutional knowledge within NRC. The fee structure limits the activities NRC can pursue, preventing the agency from taking proactive actions to prepare for SMR reviews. The fee structure also disincentivizes SMR applicants from completing robust engagements.

- **Agency Culture**

  An overly conservative culture may unnecessarily prolong timelines and engagements surrounding novel features, even when an adequate safety case with quality information is presented. A culture that is not receptive to SMR innovation may threaten the nation's climate, reliability, and security goals.

Licensing FOAK SMRs is a shared challenge between the applicant, NRC, and the DOE. The regulator must make safety determinations for the first-of-a design in a timely, predictable manner while still maintaining NRC's "gold standard" safety record. Timely decisions are enabled by high quality applications and engagements from the applicant. The DOE's R&D capabilities and laboratory capacity should be closely calibrated with applicants and NRC to enhance licensing activities and develop regulatory infrastructure over time.

As such, this paper proposes recommendations to Congress, NRC, and DOE across four dimensions:

Dimension	Recommendation
Enabling Strong Performance through Fee Reform	1.A: Congress should move hourly service fees for first-of-a-kind SMRs off- fee base.
	1.B: As the cost of licensing standardized designs are better understood, Congress should consider fixed application fees for licensing activities.
Enabling an SMR Ecosystem through	2.A: Congress should appropriate funds for a microreactor demonstration program via a public-private partnership.

Innovation Capabilities	2.B: DOE and NRC should pursue the joint-initiative model to create regulatory infrastructure and capacity via official reviews on cross-cutting technical uncertainties.
Enabling Clear External Engagement, Internal Knowledge Management	3.A: National Laboratories and NRC should collaborate through a “Sherpa” program to assist applicants during reviews.
	3.B: The Government Accountability Office should complete a study on NRC’s management practices, with a focus on improving staff performance during reviews.
	3.C: The Office of Inspector General should complete its audit of NRC’s Knowledge Management Program.
	3.D: Congress should provide the Commission with a refreshed direction as to how the agency fits within national climate, security, and reliability goals.
Enabling Efficiency through Cross-Cutting Reforms	4.A: Congress should remove the Atomic Energy Act’s Mandatory Hearing Requirement.
	4.B: NRC should develop an expedited process for reviewing licensing actions during construction.
	4.C: The Commission should revisit key challenges with Part 53 to ensure it is performance-based.
	4.D: NRC should complete a lessons learned activity following each FOAK licensing review.

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1. Introduction

To avert the worst effects of climate change, the U.S. must scale up its supply of clean, firm power by 550-770 GW by 2050.[4] Nuclear power provides the largest share of domestic clean, firm power, accounting for 18.9% of total power production and 47% of America's carbon-free electricity.[5]

Some estimates indicate that achieving domestic net-zero goals requires maintaining the current fleet of reactors *and* growing the fleet with ~200 GW of new reactors by 2050.[6] Additionally, deployment of nuclear technology abroad can play a key role in meeting global net-zero targets, promoting nuclear security, and advancing the U.S.' geopolitical strategy.

Though an increasing number of countries are considering investment in nuclear, the ultimate role nuclear will play as climate solution remains unclear. Currently, the cumulative nuclear capacity worldwide is about 413 GW.[7] As shown in Table 1, there are ranging estimates as to how this may change in the coming decades:

Table 1
Estimates for Global Nuclear Power by 2050

Organization	Analysis	Global Nuclear Power Estimates (GW)
International Energy Agency	Net Zero Emissions (NZE) by 2050 Scenario	871 GW
	Stated Policies Scenario (STEPS) (by 2050)	590 GW
	Announced Pledges Scenario (APS) (by 2050)	716 GW
International Atomic Energy Agency	Energy, Electricity, and Nuclear Power Estimates for the Period	Low Case Projection: 404 GW High Case Projection: 873 GW

STEPS: global trajectory implied by today's policy settings. APS: assumes that aspirational targets announced by governments are met on time and in full. NZE: maps out a way to achieve a 1.5°C stabilization in rise global average temperature, alongside universal access to modern energy by 2030. Sources: IEA, 2022; IAEA, 2022 [8,9]

Meeting domestic and global climate goals will be difficult without nuclear playing a larger role in the energy mix; however, high capital costs and cost overruns associated with large nuclear projects prevent meaningful consideration of nuclear as an option. The deployment of small modular reactors (SMR) may be the solution to unlock nuclear demand.

SMRs comprise of any nuclear reactor, up to 300 MWe, with nuclear components that are factory-fabricated, pre-assembled, and transported as modules to a site for installation. In addition to light water SMRs (Gen III+) that operate with the light water technology used by the current fleet, advanced SMR technologies (Gen IV) may offer additional decarbonization solutions.

Gen IV SMRs are different reactor technologies, cooled by metals, gases, and molten salts, that offer inherent safety features, higher efficiency, and broader applications. Gen IV reactors can provide high-quality heat or combined heat and power (CHP) for industrial uses, firm power for hydrogen production and desalination, and are better suited to complement renewables.

Generally, the smaller size and modular design across Gen III+ and Gen IV designs promise cost competitiveness through design standardization, factory fabrication, and repetitive, onsite construction. These learnings are gained through a complete orderbook of consecutive units for a standardized design.

While SMRs promise enhanced safety by nature of their technology profile and smaller size, design innovations and safety claims must be thoroughly assessed and, ultimately, approved in the licensing process for unit one to operate.

The Licensing Challenge

With 92 reactors in operation, the U.S. Nuclear Regulatory Commission (NRC), reactor operators, utilities, and the nuclear industry have enabled nuclear to be one of the safest forms of power production. According to the Institute of Nuclear Power Operations (INPO), the nuclear industry has improved reactor, safety system, occupational safety, chemistry, and radiation exposure performance across over forty years of operation.[10]

While the U.S. has safely operated its existing fleet of reactors, recent attempts to license new reactors have proven this process to be a significant obstacle for SMR commercialization. Through the process of licensing, NRC evaluates new reactors to ensure the design meets public safety, security, and environmental requirements. If a review is successful, NRC authorizes an applicant to construct, operate, and decommission a commercial reactor.[11] Licensing encapsulates a combination of permits, approvals, certifications, and the ultimate license to operate. To initiate and expedite a review, NRC strongly recommends preliminary actions, referred to as pre-application engagements. This includes white papers, topical reports, and meetings.

Investors, vendors, and utilities find the cost, time, and uncertainty associated with first-of-a-kind (FOAK) SMR licensing prohibitive:

- The process to license new reactors from application submittal to license to operate takes about 6-7 years.
- In addition to the hundreds of millions of dollars needed for testing and engineering to develop a robust NRC application, applicants will likely spend over $100 million to partake in the many reviews in pursuit of an operating license. This includes hourly service fees for agency time spent on application materials, and internal costs to complete additional tests, analyses, and revisions in response to agency feedback.
- There is little certainty regarding if, or how long it will take, for NRC to accept SMR design innovations.

NRC faces a steep learning curve in licensing SMRs. Though SMRs anticipate innovations that reduce cost and enhance safety, these innovations are a significant departure from current regulations and the regulatory activities NRC has conducted over the past 40 years. For example, several SMR designs hope to eliminate concrete containment domes, reduce, or eliminate onsite operational labor, or locate near industrial facilities or populations. Additionally, licensing experiences from 2000 onward have been limited. In many cases, staff may be completing licensing activities for the first time.

The regulatory and policy landscape that impacts new reactor licensing makes this process an area of uncertainty for SMR commercialization. Navigating this landscape is a shared challenge between the applicant, NRC, and DOE.

Getting the first-of-any design with innovative features through the licensing process requires substantial investment from both the applicant and the regulator over several years.

Engagement with the regulator is encouraged to begin as early as possible, sometimes 5 - 10 years before a vendor submits an application. NuScale, a Gen III+ vendor with the first SMR design to complete one of NRC's licensing review, initiated engagements in 2008, while an official licensing application was not submitted until 2017.[13] During review engagements, applicants and regulators must resolve complex issues that often take weeks, if not months, to resolve.

In developing an application and making revisions as the review progresses, vendors often require access to or the build of expensive laboratories to obtain the breadth of test data required for a strong application. Many of the leading SMR designers utilize DOE laboratory capacity or financial support to complete application development and interactions with NRC.

After a complete review for the FOAK, sequential orders of a given design are expected to show considerable improvements in licensing predictability, as key design features have already been approved by NRC. However, NRC must also be positioned to ensure throughput of standardized and FOAK designs in the coming decades. Timely reviews of standardized designs may be challenged if NRC receives a high volume of applications from fast followers. as some nuclear projections suggest.

Table 2
Licensing Projections in 2025, 2030

Year	Number of Applications
2025	12 or more
2030	Over 60

Source: NEI[12]

For the U.S. to overcome the present challenge — to design, license, and build new reactors quickly and safely— policy and regulatory reforms are required to provide relief to first movers in the near term and enable continued, efficient licensing of standardized designs in the long term. Furthermore, reforms should foster continued technology innovation as new entrants compete in the emerging SMR market.

NRC, applicants, and DOE each play an important role. The regulator must make safety determinations for FOAK in a timely, predictable manner while still maintaining NRC's "gold standard" safety record. Timely decisions are enabled by high quality applications and engagements from the applicant, given the suite of novel features that lack operating experience. The DOE's R&D capabilities and laboratory capacity should be closely calibrated with applicants and NRC to enhance licensing activities and develop regulatory infrastructure over time.

This report aims to examine opportunities for meeting the goal of safe, timely, and predictable licensing of new reactor designs.

This paper will explore the historical lessons that inform modern licensing, examine the licensing experiences of recent applicants, identify root causes of shared challenges, and suggest reforms to improve the licensing landscape and create investor and customer confidence.

2. We Have Done This Before: Lessons Learned from the Standup of the Commercial Nuclear Industry

The formation of today's operating fleet provides a model as to how NRC, DOE, and industry should collaborate to enable efficient SMR licensing.

A majority of today's operating fleet was entirely or partially licensed by the country's past nuclear regulator, the Atomic Energy Commission (AEC). Under the oversight of the AEC, installed nuclear capacity in the U.S. grew from 0.2 GW to 50.451 GW between 1960 and 1978.[14] For comparison, the U.S. will need to install over 200 GW of new capacity in around the same time period (2030-2050) to meet decarbonization goals.[15]

As the country attempts to stand up a new nuclear industry, a reexamination into the AEC's resources, flexibility, and decision-making reveals positive lessons learned.

Background

Similar to the challenges NRC faces in licensing novel SMR designs, the AEC was tasked with the standup of a technology that had never been demonstrated in a civilian, commercial setting.

The AEC was formed in 1946 following WWII. With the passage of the Atomic Energy Act of 1954 (AEA 1954), Congress directed the AEC to complete three functions: i) continue the weapons program, ii) promote commercial uses of nuclear power, and iii) protect public health and safety from radiation hazards

The non-regulatory functions of the Commission would complete R&D and provide financial subsidies to accelerate technology commercialization. The separate regulatory functions would be responsible for regulating and licensing commercial activities.[16]

Positive Lessons from the AEC

The AEC's regulatory arm, innovation arm, and commercial entities each played an essential role, and in many ways collaborated, to stand up the nuclear industry.

To demonstrate the technical and economic viability of different reactor designs, the AEC launched the Power Demonstration Reactor Program in 1955. This program, cost-shared by AEC and industry, led to 11 demonstration projects and two commercial scale reactors covering eight technologies.[17] Industry played a significant role in this program. While AEC provided the facilities within its National Laboratories, waived fuel-use charges, and conducted research, the private sector supplied the capital for the construction of the plants and the operating expenses.[18] This program created operating experience and data collection that informed the AEC's regulators and the foundation of nuclear regulation in the United States.

To kickstart the industry amidst technical and economic uncertainties associated with nuclear in the 1950s, the nation's top nuclear developers, General Electric (GE) and Westinghouse, offered turnkey contracts at a fixed cost to supply an entire plant.[19] Though leading to hundreds of millions of dollars in losses for the vendors, this strategy was effective. Between 1965-1968, utilities ordered 72 nuclear reactors.[20] Not only were unit orders growing exponentially, but the sizes of reactors grew, in some cases tripling or quadrupling in capacity.

Table 3
Orders for Nuclear Steam Supply System Units, 1965-1968

Year	Units Ordered	Capacity Purchased by Utilities that Year
1965	4	17%
1966	20	36%
1967	31	49%
1968	17	47%

Source: Nuclear Regulatory Commission, 2010[21]

The AEC managed a number of licensing challenges during the "bandwagon market" that resemble modern obstacles. Growth in reactor size and complexity of LWR systems presented novel safety uncertainties for AEC staff. At the start of the bandwagon market, nuclear operating experience was limited to 200 MW or less, whereas new units ranged between 500-1000 MW.[22] Larger, more complex facilities raised safety questions that could not be answered by early demonstration reactors.

At the same time, between 1965 and 1970, the size of the licensing and inspection caseload increased by 600%, while the size of the regulatory staff only increased by about 50%.[23] The AEC took a number of actions, such as hiring, and investing in new R&D capabilities to minimize licensing delays on the applicant and industry confidence. The R&D arm of the AEC constructed new testing facilities and assembled task forces to answer safety uncertainties. These findings improved knowledge of reactor safety and enhanced regulations.

The large workload stressed the staff, leading to an eight-month delay in the construction review process. Still, the AEC enabled throughput to maintain industry confidence. Between 1963 and 1969, the AEC issued 38 construction permits, 28 of which were in the 800-1100 MWe range.[24]

3. Current Regulatory Landscape: Licensing Frameworks and Cost of Licensing

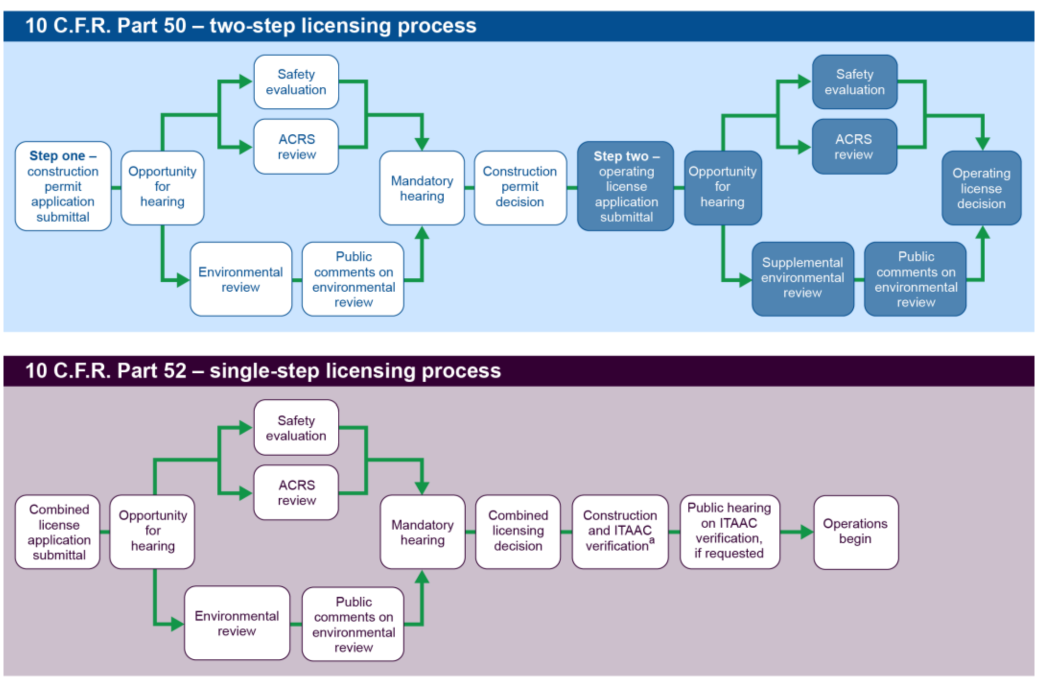
Nuclear reactor licensing is a complex, time-intensive process, often requiring years of engagement with the regulator to receive the eventual license to operate. The prescriptive nature of regulations further complicates this process for SMRs.

Costs to the developer for licensing can be substantial, including costs from application development, hourly fees for NRC services, and compliance with NRC information requests. Hourly service fees are typically on the scale of tens of millions of dollars, whereas costs to assemble the necessary tests, analyses, and documentation to support a license application are on the scale of hundreds of millions of dollars.[25]

Part 50 and 52

Applicants pursuing a commercial power facility can select one of two licensing pathways: 10 CFR 50 (Part 50), the two-step licensing approach, or 10 CFR 52 (Part 52), the one-step licensing approach.

Figure 1: Power Reactor Commercial Licensing Pathways, Steps



Source: "Nuclear Power: NRC Needs to Take Additional Actions to Prepare to License Advanced Reactors." U.S. Government Accountability Office, July 27, 2023. https://www.gao.gov/products/gao-23-105997.

Each pathway requires a safety review, in which staff scrutinizes the design to ensure it meets the required safety margins, and an environmental review, in which staff weigh the facility's environmental, economic, and technical benefits against environmental and other impacts.[26] Each path also contains a review from the Advisory Committee on Reactor Safeguards (ACRS), an advisory committee that independently evaluates each application's safety report.

Prior to the start of an official review, NRC recommends pre-application engagements, encompassing a variety of white papers, topical reports, and meetings.

Part 50

Excluding Vogtle 3, all operating reactors in the U.S. have been licensed under Part 50. Amended in 1956, the two-part licensing pathway (Part 50) requires an applicant to first seek a construction permit (CP), which initiates the construction of a power plant, and then an operating license (OL), to fuel and operate the reactor. The CP application requires a preliminary safety analysis report and a preliminary environmental impact statement. The OL contains the final design, with a final safety analysis report and a final environmental impact statement with the final design.

Part 50 allows for more flexibility to make design changes as construction is ongoing but provides less licensing certainty throughout the process. Under Part 50, a plant may receive a CP, build the plant, but then fail to receive an OL or may require expensive retrofits. This could occur due to major changes in the design that require NRC approval, or due to regulatory changes outside the permit holder's control. For example, regulatory changes following Three Mile Island had detrimental impacts to schedule and cost for reactors under construction.[27] This risk, in part with other factors, led to the creation of Part 52.

Part 52

NRC established Part 52 in 1989 to provide more regulatory certainty and standardization to the process

Part 52 is a "one step" approach in which applicants pursue a combined license (COL) that allows both construction and operation. In the COL, the applicant submits the complete information regarding site, design, and operation required for an OL in Part 50.[28] Additionally, the applicant includes certain inspections, tests, analyses, and acceptance criteria (ITAAC) that is verified by NRC after construction is complete and before the reactor operates.

To reduce regulatory risk, Part 52 contains optional pre-licensing steps that provide staff or Commission approval on key design or site features. These options include design certifications (DC), standard design approvals (SDA), and early site permits (ESP).

Both DCs and ESPs require Commission approval and result in a rulemaking. Rules essentially become the applicants' regulatory requirements if they plan to use said design or site.[29] As such, DCs and ESPs can be referenced in COL reviews with little dispute regarding content.

SDAs only receive staff approval and do not become rules. This provides less certainty in the eventual COL review, but still provides some regulatory certainty and more flexibility for change, as necessary.

Though Part 52 allows for a high degree of standardization, it also requires a high degree of design finality early on, which reduces flexibility during construction. Applicants must know the final design at application submittal, a challenging task for FOAK reactors. More likely than not, applicants will make changes as the design progresses or after construction commences. The process of making changes often requires time intensive rulemakings, as the DC, ESP, or COL rule must be amended to reflect changes.

Box 1

Optional Steps for Part 52

Early Site Permit: Approval of one or more sites from the Commission for a nuclear power facility, independent of an application for a construction permit or combined license.[30]

Design Certification: Certification and approval by the Commission of a standard nuclear power plant design, independent of a specific site or an application to construct or operate a plant.[31]

Standard Design Approval: Determination by NRC staff that a reactor design meets the agency's applicable design requirements, either for the final design of the entire reactor facility or major portions of a facility.[32,33]

A vendor may select an SDA for several reasons:

For more advanced, novel designs, SDAs can demonstrate incremental licensing progress by receiving staff approval on portions of a facility.[34] Early certainty on some portions while deferring the rest of the review reduces risk of re-design and re-review if NRC requires a major change during the SDA.[35] Lowering risk on portions critical to their safety or business case may also encourage investment.[36]

SDAs allow for a design feature to be added following submission of a DC. Design features may include hydrogen production, desalination, and power upratings. [37] For example, NuScale is pursuing an SDA to receive approval on its 77 MW NuScale power modules (NPM), as NuScale's DC was for the 50 MW NPMs.[38]

As shown in Table 4, most FOAK Gen IV SMR designers have chosen part 50. Some vendors, such as Terrapower and Holtec, have expressed that Part 50 is optimal for a first demonstration due to inevitable design changes.[39] Other designers are still opting for part 52, however. According to Oklo, the part 52 pathway facilitates greater spread and repeatability by licensing plants of the same design.[43]

Table 4
Licensing Pathways Chosen by SMR Vendors

Part 50	Part 52	Not Publicly Available
Abilene Christian University (Molten Salt Research Reactor) Holtec International (SMR-160) Kairos Power (Hermes Test Reactor 1 & 2) Terrapower & GE Hitachi (Natrium) University of Illinois at Urbana-Champaign & Ultra Safe Nuclear Corporation (Micro Modular Reactor, Research Reactor) X-Energy (Xe-100)	NuScale Power (US 600) Oklo (Aurora Powerhouse) Terrestrial Energy (Integral Molten Salt Reactor) Westinghouse Electric Company (eVinci)	Terrapower (Molten Chloride Fast Reactor) General Atomics (Energy Multiplier Module; Fast Modular Reactor) Arc Clean Energy Technology (ARC-100) Westinghouse Electric Company (AP300) GE-Hitachi (BWRX-300)

Including commercial, research, and test reactors as of October 2023. Sources: Nuclear Regulatory Commission, 2023; Government Accountability Office, 2023 [40,41,42]

Historical time and costs associated with each licensing pathway are shown in Table 5:

Table 5
Recent Licensing Experiences for Commercial Power Reactors, Cost and Schedule

	Licensing step	NRC Estimates for Review Duration		NRC Estimates for Cost	
				Low Effort	High Effort
Part 50	CP	36 months		N/A	N/A
	OL	36 months		N/A	N/A
Part 52	DC (optional step)	36 months for non-LWR, 42 months for LWR		$34,668,000	$82,530,384
	ESP (optional step)	24 months		$4,694,496	$20,845,749
	COL	LWR or non-LWR referencing a certified design	30 months	$14,210,349	$57,189,360
		LWR not referencing a certified design	42 months		
		Non- LWR not referencing a certified design	36 months		

NRC estimates are derived from the agency's generic schedule milestones. NRC costs are calculated based on the hourly estimates within NRC's New Reactors Business Line Fee Estimates and the FY2024 hourly labor rate. These estimates only include Part 52. Sources: Nuclear Regulatory Commission, 2010 [44]; Nuclear Regulatory Commission, 2023 [45]

Both pathways have associated risks; however, the prescriptive nature across both pathways is a fundamental challenge for FOAK SMRs.

Consequences of Prescriptive Regulations on Efficiency, Predictability

Part 50 and 52 assess reactors on design criteria highly prescriptive to large LWRs and impose broad facility requirements that may not be commensurate with the risks posed by novel designs.

Vendors argue that smaller, simpler SMRs reduce risks and accident scenarios by virtue of their size and design. Most designs remove entire components and systems found in

Box 2

Enhanced Safety Profile of SMRs

The design attributes of Gen III+ and Gen IV technologies hope to fulfill key safety functions with more simplicity, reliability, cost effectiveness, and tolerance to human errors.[46]

In most operating LWR systems today, safety functions are accomplished by a redundant combination of backup systems, alternate sources of water, and prescribed operator actions.[47] Some backup systems are active safety systems, defined by the IAEA as those that rely on external electrical or mechanical power, signals, or operator actions to complete a safety function.[48] For example, large LWRs typically include an emergency auxiliary diesel generator for AC-powered electrical systems.[49]

Gen III+ and Gen IV SMRs, and some GenIII/GenIII+ large reactors, utilize a combination of passive and inherent safety features to accomplish most, if not all, safety functions. The IAEA defines passive safety features as those that only require natural forces, such as gravity or gas pressure, properties of materials, or internally stored energy to actuate safety functions.[50] For example, loss of power in NuScale's VOYGR SMR results in gravity insertion of control rods and alignment of safety valves.[51] Passive features in Gen IV reactors include passive heat removal from the reactor vessel as well as passive shutdown from negative reactivity feedbacks.[52,a]

Inherent safety features rely on materials or basic properties of the material or design choices to complete a safety function.[53] By utilizing compatible coolants, moderators, and fuel that result in a set of core materials that has high chemical and physical stability, high heat capacity, and high retention of fission products, the possibility of some accidents are eliminated.[54] Some examples of inherent safety attributes include accident-tolerant fuels, low chemical reactivity coolants, and large margins between operating temperature and boiling temperatures of coolants.[55]

Some Gen IV reactors, such as the sodium-cooled fast reactor, like the Terrapower Natrium, and the high-temperature gas-cooled reactor, like the X-Energy Xe-100, have confirmed some passive and inherent safety characteristics through testing in prototypes.[56,57] Less mature concepts require further demonstration and sufficient test data, however, to validate safety claims and meet regulatory requirements.[58]

traditional LWRs and rely on proposed uses near populated areas or on-site at industrial or military facilities. In some cases, plants hope to operate with little-to-no staff.

Even though SMRs offer an enhanced safety profile, each designer must demonstrate that safety functions satisfy regulatory requirements.

Regulatory requirements may not apply to an SMR, however, as they are prescriptive to large LWR designs. For example, 50 and 52 require microreactors with a 10 MW capacity to have the same 10-mile EPZ that is required of gigawatt-scale LWRs. 50 and 52 also prescribe staffing requirements on all facilities, even though many microreactors may not

[a] Negative reactivity feedback effects make reactors self-regulating. If the power rises, the temperature rises and generates negative reactivity that in turn reduces the power.

need the same personnel due to the autonomous operations of the facility. Though Gen III+ technologies still face hurdles, these hurdles for Gen IV SMRs are particularly salient.[59]

To avoid design changes that impact reactor economics while still meeting requirements, SMR developers must undergo an exemption process to demonstrate a facility can operate safely without meeting existing criteria. Though possible, the exemption process reduces efficiency and increases the licensing burden for FOAK SMRs.

The NuScale design, a modified Gen III+ LWR SMR, required 17 exemptions, one of which being a disagreement between the applicant and the regulator that lasted for several years.[60,61] The regulatory analysis for Kairos Power's Fluoride Salt-Cooled High Temperature Reactor (KP-FHR), a less mature Gen IV design, indicates that applicants pursuing either 50 or 52 would require exemptions from regulatory requirements across 13 topics, encompassing an even larger amount of exemptions, the exact number of which depending on the application type.[62]

While it is achievable to conform a novel design to Part 50 and 52, there is still risk that NRC may find novel features unacceptable and impose prescriptive requirements on an SMR design.[63,64]

Part 53

Congress recognized the need for a non-prescriptive regulatory framework with the passage of Nuclear Energy Innovation and Modernization Act (NEIMA). NEIMA requires NRC to establish a risk-informed and performance-based regulatory framework by 2027.[65] Instead of utilizing pre-defined outcomes for FOAK designs, a performance- based approach establishes performance goals in the form of numerical risk targets.[66,67]

While the original draft rulemaking received criticism from industry and NGO stakeholders alike, the Commission's direction for the final rule, released in March 2024, removes key challenges with the draft and requires staff to address additional areas of regulatory uncertainty in the final rule.[b,68] For example, fuel loading requirements for microreactors.

Ultimately, the applicant bears responsibility to demonstrate that a design meets safety requirements. NRC's review of applications should be thorough and rigorous; however, the current framework as drafted imposes overly burdensome, prescriptive regulations which reduce the review efficiency, increases licensing burden, and creates risk of overregulation for SMRs. Successful implementation of Part 53 may avoid several inefficiencies surrounding broad SMR characteristics.

[b] Early criticism was attributed to the prescriptive analytic and programmatic approaches to demonstrate compliance with safety limits.

Cost of Licensing

The cost of licensing to a developer can be significant, particularly when a reactor contains novel features. How these costs accumulate across the stages of licensing is best shown in Table 6.

Table 6
NuScale DC Licensing Costs as of July 2022

Licensing Step	Estimated Hours	Approximate Cost
Testing and Engineering Costs to Develop the DC Application	2,000,000 labor hours	$500,000,000
Licensing Fees	250,000 review hours	$70,000,000
Responding to Information Requests, Analyses, and Audits during the DC review	N/A	$130,000,000

Data from the Securities and Exchange Commission, 2022[70]

Table 6 illustrates DC licensing costs NuScale has accumulated as of July 2022. When incorporating all stages of licensing development, review, and revisions, the vendor's total costs are approximately $700 million.[69]

Traditional nuclear licensing processes are lengthy and costly, even for large LWR.[71]

The cost to develop an application for any nuclear design is substantial, as the design and engineering work for licensing often overlaps with the costly work to complete the design, ensure it works as planned, and support construction (e.g., development of construction and supply chain documentation).[72] Maturing a nuclear design typically costs between $1-2 billion per concept, with several million person-hours of design/engineering work and 15-20 years to do a demonstration with the technical confidence required by NRC.[73] In the case of NuScale, the vendor spent $500 million to develop the DC application.

The costs borne during a licensing review, in terms of regulatory fees and actions to support the review process, can also be sizeable across nuclear designs and sizes. Applicants must pay hourly staff fees for NRC time spent on an application.[c] The World Nuclear Association (WNA) estimates that, when considering nuclear power broadly and not focusing on a specific technology, licensing fees accumulated during the review are around $60 million per reactor per country, and costs to support

[c] NRC applies annual fees to license holders and hourly fees to an entity receiving licensing, inspection, or other services.

the licensing process are $180-240 million per design per country.[74,d] NuScale paid $70 million in review fees for its DC, but spent almost double that amount, an additional $130 million, to respond to information requests, complete analyses, and participate in audits.[75]

Novel, commercially unproven technologies are at the beginning of a steep learning curve, for both the applicant and the regulator.[76] Consequently, FOAK SMRs will experience more hurdles during the regulatory process, and, thus, face higher costs.[77,78] These obstacles will be discussed further in later sections.

Even if the costs for FOAK SMRs are ultimately similar to the licensing costs associated with traditional large LWRs, costs are still a relevant barrier due to the smaller capacity of SMRs. At least for the first few designs, the cost of licensing is almost independent of the reactor size; therefore, the cost per kW is higher for SMRs with respect to large reactors due to reduced output.[79] Operating large LWRs produce relatively low-cost energy despite the high licensing costs as the economies of scale and large lifetime of the plant allows them to absorb high regulatory and licensing fixed costs.[80] SMRs cannot dilute this cost on a larger output until a sufficient number of standardized units are manufactured at scale.[81] This problem is particularly salient for microreactors, whose licensing costs account for an even higher portion of the cost overall in comparison to SMRs.[82]

[d] WNA's estimates are based on a ratio of 1:3 to 1:4 of regulatory fees to internal support costs. It is not clear if internal support costs include prior costs to develop the application, or exclusively support the regulatory activities after an application has been submitted.

4. Recurring Challenges from Past Licensing Experiences

A literature review was performed to better understand the current state of licensing and sources of inefficiencies. This review includes case studies on the Westinghouse AP1000 DC and amendment, NuScale DC, Oklo COL, and Kairos Test Reactor CP. This review also incorporates lessons learned documents that cover a collection of licensing experiences, unattributed to any particular case. This includes a NRC Part 52 lessons learned activity, a U.S. Nuclear Industry Council (USNIC) lessons learned activity, roundtable convened by Nuclear Innovation Alliance (NIA) in 2023, NASEM's 2023 Consensus Study Report on advanced reactors, and IAEA's 2022 lessons learned from regulating SMRs.

Evidence was also gathered from conversations with current and former members of NRC, at varying levels of leadership, as well as with nuclear experts and vendors undergoing licensing activities.

Findings suggest that licensing the FOAK for any design is a time-intensive, challenging exercise for both the applicant and the regulator. This is especially true if the design introduces many novel safety features that greatly depart from large, LWR systems.

In addition to the prescriptive framework, key recurring challenges across case studies explain common sources of resource-intensive delays during the licensing process:

i) Complete and Quality Information— the difficulty of obtaining and relaying the quality and depth of application information to enable a safety determination

ii) NRC Workforce Capacity— poor implementation of licensing procedures and insufficient project management from NRC

iii) External Engagements— disagreements and frictions between NRC and applicants that arise during complex issue resolution

iv) Internal Alignment and Knowledge Management— risk of rework or delays due to internal misalignment and knowledge transfer within NRC

Challenge 1: Complete and Quality Information

A strong safety case is reliant upon complete and high quality information. It is a challenge for the applicant to provide, and NRC to interpret, this information for a FOAK SMR.

The completeness and stability of application information over time is a persistent challenge for any first design under review, from large LWR to a Gen IV. Though inherent to the progression of a new design, this is a necessary inefficiency in the co-learning process due to rework.

Substantial design changes in several large LWRs during the former "nuclear renaissance" led to schedule delays and review inefficiency.[83,e] In the case of the AP1000, Westinghouse underwent a 45-month design certification process, then decided to amend said certification to account for significant design changes.[f,84] This amendment process took an additional 35 months, with substantial rework on both sides due to additional design changes.[85]

While the AP1000 was a FOAK implementation of Part 52, it still remains a challenge to know what level of information is enough to do a conceptual review.[86] On one hand, the greater level of design maturity and completeness of a nuclear design, the more predictable licensing timelines and costs will be.[87,88] On the other, FOAK SMR designs struggle to obtain sufficiently complete information; development often requires an incremental approach to validate the design and obtain funding, creating stages in which the design develops over time.[89]

NuScale had not completed important testing, analyses, or engineering evaluations on safety significant FOAK design features, and made substantial design changes throughout its review.[90] Several of the 29 highly complex issues (HCI) identified by NRC were associated with completeness of design or availability of information, resulting in substantial unanticipated resource use and time expenditures for both parties mid-review. [91,92]

Though Oklo pursued pre-application engagement with NRC, the developer made significant changes to its safety methodology for the actual review that were not previously reviewed.[93] Oklo's COL ultimately failed to progress due to information gaps in the application and the applicant's response to information requests. [94]

In addition to challenges obtaining complete information, FOAK SMRs utilize alternative methods to demonstrate compliance with regulations. In doing so, there are often shortfalls between the applicants and regulator regarding what the sufficient quality and depth of information should be.

Though NRC has utilized risk information to adjust or supplement regulation of the operating fleet for years, use of risk information to determine facility requirements for SMRs is a challenge. In the case of NuScale's DC review, the vendor felt that risk information provided to staff was not "duly considered", causing lengthy back-and-forth that resulted in prescriptive regulations for specific systems.[95] NRC concurred that risk information was not optimally coordinated and focused to maximize effectiveness, and the use of risk-information could be improved.[96] At the same time, NRC implies the applicant may not have always provided NRC with sufficient demonstration of safety to support its risk analysis.[97]

In other cases, however, alternative methods to demonstrate compliance failed because the quality of information is insufficient, preventing NRC from evaluation. According to an NRC official, vendors may provide conceptual information regarding safety functions rather than scientific evidence to

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[e] In 2009, NRC had three DC applications, two DC amendment applications, and COL applications for 28 reactors at 18 sites.

[f] These changes were motivated by a variety of influences, including feedback from equipment suppliers, construction projects in China, construction preparation projects in the United States, and regulatory changes from NRC following 09/11.

demonstrate compliance. In these instances, the agency does not have a sufficient level of reasoning to enable a safety determination.

Taken together, acquiring the satisfactory breadth and depth information for a safety review is a common, sometimes unavoidable source of delays and inefficiencies in the regulatory review.

Challenge 2: NRC Workforce

NRC workforce performance can be variable and unpredictable, which can lead to prolonged review schedules and unnecessary resource use.

The application acceptance process appears to be a challenge. A lessons learned exercise in 2013 found that staff preemptively accepted applications for docketing, even though applications had numerous deficiencies.[98] This led to significant challenges in conducting an efficient review and lengthened the review schedules. Similarly, a July 2023 GAO analysis found that NRC does not have sufficient guidance for accepting and establishing a review schedule for incomplete applications, including FOAK designs.[99]

NRC staff have administered requests for additional information (RAI) in the wrong context. RAIs obtain information the staff deems necessary for resolving safety or environmental issues not adequately addressed in an application.[100] However, staff have used RAIs to receive confirmation about application information or to learn about a technology. USNIC's assessment found that inexperienced reviewers administered "teach me" RAIs that lacked a safety focus, causing extra work for applicants and delaying responses to safety related RAIs.[101] Following NuScale's review, NRC reported that some RAIs, particularly early on in the process, did not focus on safety significant information.[102] A former Commissioner shared that staff administered an RAI to a U.S. government reactor to demonstrate non-foreign ownership. Staff relied heavily on RAIs to obtain design information that could have been acquired in an audit.[103,g] Audits can be effective at providing NRC with information on specific technical issues without requiring formal submission of documents. Though there are costs and times associated, audits can reduce unnecessary RAIs that are on the critical path to licensing.

Recent SMR applicants report variable project management abilities within NRC.[104] An inexperienced or inadequately supported project manager can be detrimental to project scope and timelines. An NRC official said project managers are crucial to timely reviews, as they both hold the applicant and the technical reviewers accountable.

Poor project management can cause a cascade of challenges during reviews, such as unnecessary delays, conflicting policy or technical decisions, or ineffective use of NRC resources.[105] In addition to the delays, varying skills among project management makes it difficult for applicants to know what to expect and plan for engagement with staff and management.[106]

[g] Audits allow NRC staff access to review a selection of an applicant's internal documents without submitting those documents as part of the docketed licensing basis or record for the plant. Audits can be an effective method to provide NRC information that would normally fall outside the scope of a standard review to help the staff efficiently reach a safety determination and review (Nuclear Innovation Alliance, 2023)

Overall, NRC technical reviewers may lack accountability to make safety determinations in a timely manner. The causes for these delays are unclear to applicants.[107] NASEM's 2023 study found that lack of technical expertise on new technologies can delay regulatory decision making.[108] Former NRC Commissioners said that, without proper oversight, lack of certainty within NRC regarding if or how requirements apply to new designs can drag decision making for months.[109]

Challenge 3: External Engagement during reviews

A licensing review requires a multi-year relationship with substantial back-and-forth between the parties to resolve complex issues to enable the staff to make a safety determination. Though critical, productive engagement and communication are a persistent challenge across reviews.

The RAI process is a common area for delays. This is typically when complex issues are raised and disagreements occur, in some cases on significant design issues. These challenges are exacerbated when multiple rounds of RAI result in little progress toward resolution.[110]

A frequent critique is that RAIs lack clarity, often being referred to as a "bring me a rock request." Industry representatives report that NRC asks open-ended questions, requiring repeated submissions of information until the applicant finally submits what NRC staff expects.[111]

RAIs can be resource and time intensive, making this process on the critical path to a timely review. Though NRC suggested a 30-day response period for RAIs, NuScale required a 60-day response period to provide the information and analysis to answer NRC requests. [112] 30% of the time, NuScale required more than 60 days to respond.[113]

Broadly, applicants might incorrectly assume the staff's familiarity with a new reactor design, while NRC staff may not know what answer or information they need to make a safety determination, resulting in back-and forth with little resolution.[114]

Challenge 4: Internal Alignment and Knowledge Management

Internal alignment within the NRC and transfer of knowledge between staff, across reviews and levels of leadership, is a challenge.

Stakeholders have reported communication gaps between staff and management, and across staff working on different license applications. This leads to delays inconsistencies across reviews, or reopening of previously closed issues.[115,116]

USNIC's analysis found that long license cycles and poor transfer of knowledge during personnel changes have led previously closed issues to be re-opened.[117] Even when an applicant refers to previous feedback that enabled resolution, new staff may not accept the prior reviewer's analysis.[118]

This can greatly impact an applicant's design and licensing strategy, requiring costly rework by both the applicant and NRC.[119]

Communication silos between the various ranks of NRC pose even larger risks for application review predictability. An override of technical or policy decisions is an abrupt, unexpected change that requires a cascade of timely rework.[120]

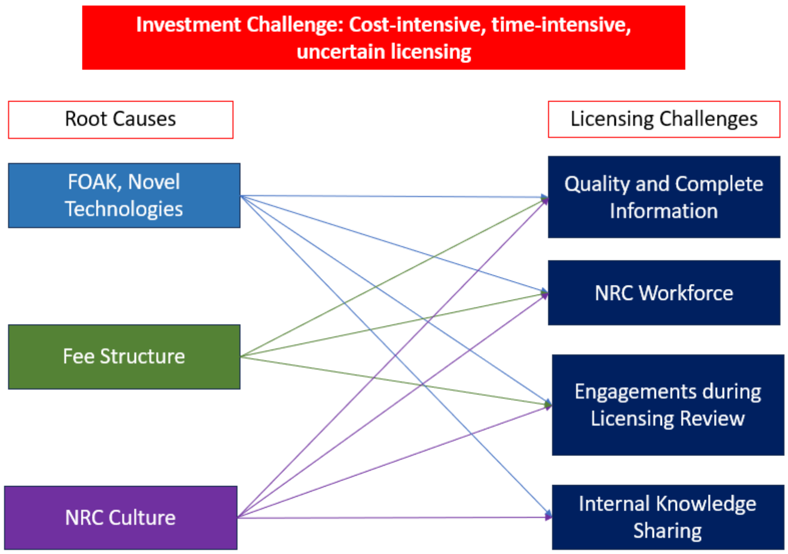
If a valid, safety significant concern is raised, reexamining the issue is necessary to ensure adequate protection. However, reopening issues unnecessarily due to poor knowledge transfer within NRC imposes unnecessary costs and reduces predictability for the applicant.

Additionally, a former Commissioner shared that delays in decision making can root from misalignment in staff and management regarding if requirements apply to a design, sometimes requiring a final Commission decision during a review.[121]

5. Root Cause Analysis: Why Do Recurring Licensing Challenges Occur?

NRC is undergoing substantial effort to license SMRs; however, the agency's agility is hindered by three root challenges:

Figure 2
Licensing Challenges and Root Causes



FOAK, Novel Technologies

The use of novel technologies or features that NRC has limited experience evaluating greatly complicates a safety review. NRC must have sufficient confidence to make a safety decision regarding features that have not been previously demonstrated at commercial scale nor have regulatory precedent. The process of reaching this confidence can be time and resource intensive.

Obtaining quality data is an obstacle. While large LWR, and even Gen III+ SMRs, can build safety cases atop decades of operating experience, new reactor technologies must complete substantial testing and data collection to reach the same certainty. For both Gen III+ and Gen IV, the absence of a full-scale hardware demonstration creates uncertainties regarding how safety functions will behave in operating conditions. As such, the burden of proof for first mover SMR applicants is substantial. For example, in addition to NuScale's 12,000-page DC application, the vendor also provided NRC with two million additional pages to assist NRC's understanding of the information included in the DC application.[122]

NRC is at the beginning of a learning curve for most novel technologies. Decision making during a review is challenged by a lack of applicable technical expertise within NRC, operating experience, and regulatory precedent and infrastructure on novel technologies.[123, 124] To adapt to the new methods SMR applicants use to demonstrate compliance, NRC must also develop new review processes and acceptance criteria to interpret this information.[125] Uncertainties within the NRC make it challenging for the agency to administer guidance. Indeed, the IAEA found that, across regulatory bodies, the provision of guidance to the applicant regarding how to demonstrate compliance with requirements is a key challenge.[126]

Knowing and attaining the level of proof for adequate protection is a challenge for both applicants and regulators alike, which can complicate engagements between the two. Back-and forth on complex, novel features is often the source of regulatory delays and rework.

It may also be difficult for staff to know when and how information should be shared between levels of NRC. On one hand, early and enhanced management and Commission involvement on complex policy issues can help increase timeliness, efficiency, and predictability for applicants.[127,128] On the other, Commission involvement on too many intermediate Staff decisions would inevitably cause additional delay and cost in completing the licensing process.[129]

Fee Structure

NRC's fee recovery model prevents technology innovation, regulatory innovation, and the development of institutional knowledge within NRC. Excluding certain activities, NEIMA mandates NRC to recover 100% of its budget from the fee base, including license holders and those utilizing NRC services.[130]

The fee structure i) restrains agency activities to what NRC will be compensated for, and ii) disincentivizes SMR applicants from completing robust engagements.

Fee Structure Impact on Regulatory Innovation, NRC

The cost-recovery model constrains the activities NRC can pursue, preventing the agency from taking proactive actions to update regulations and build institutional knowledge in SMRs.

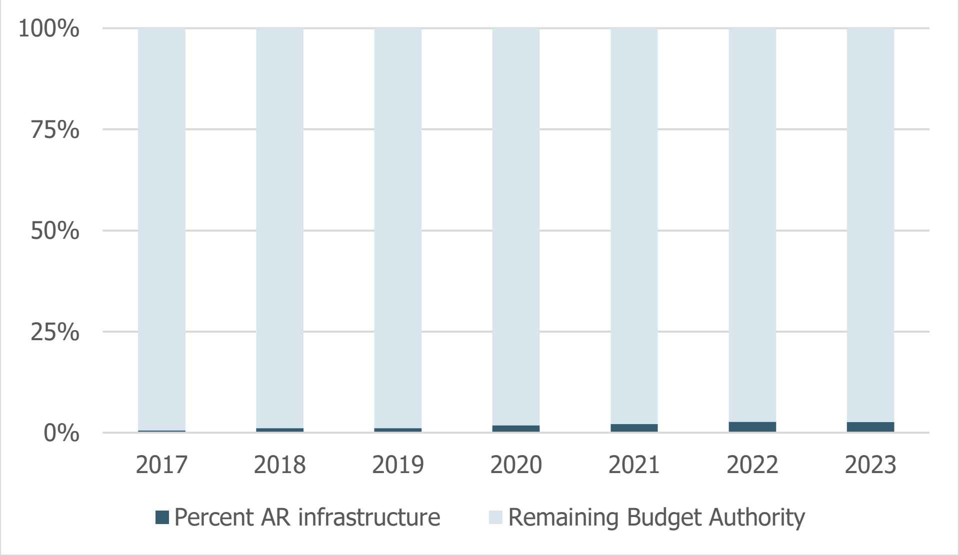
Fee recovery limits NRC flexibility and prevents capacity building on novel technologies. Congress, and, indirectly, industry, have substantial control over resource allocation and budgets at NRC. NRC activities are tied to certain categories depending on the fee class revenue comes from— for example, fees collected from the operating fleet are used for regulatory services that benefit the operating fleet. NRC cannot collect fees from the operating fleet to conduct broad, SMR research and rulemakings. Consequently, NRC's work in SMRs, particularly Gen IV, has been general and exploratory.[131] Even when NRC anticipates it will receive applications for new technologies, it cannot allocate resources accordingly unless the agency receives fees from a specific applicant.

This impacts the workforce capabilities within NRC, as the agency can only hire and train staff for activities it plans to recover fees from. Additionally, the fee structure prevents resolution of regulatory uncertainties associated with SMRs in advance of FOAK applications.

NEIMA made some improvements to the fee structure by excluding advanced reactor regulatory activities from the fee base. With these appropriations, the agency is able to work on general activities such as establishing offsite emergency planning requirements or new security and safeguards requirements for Gen III+ and Gen IV SMRs.[132] Still, NRC's activities to expand advanced reactor capacity are still dependent on congressional appropriations.

Though appropriations for advanced reactor regulatory infrastructure have increased over time, funds dedicated to this business line are insufficient with the pace in which NRC must expand innovation activities. As shown in the figure below, AR infrastructure has grown from one to three percent of the agency's budget in the past six years.[133, 134, 135, 136, 137, 138, 139]

Figure 3: Advanced Reactor Infrastructure Appropriations, 2017-2023



Advanced Reactor Infrastructure includes work for GEN III+ and GEN IV designs. Data from: See first figure mention in text for sources

Fee Structure Impact on Technology Innovation, FOAK SMR applicants

The fee structure increases the cost of licensing for SMRs and disincentivizes pre-application engagement with NRC, a crucial step for successful, predictable licensing. Additionally, the costs associated with longer reviews discourage, rather than incentivize, technology innovation.

Disincentivizing Pre-Application Engagements

Rather than encourage early engagement, the fee structure disincentivizes developers from preapplication activities until their financing allows for these losses, perhaps after major design decisions have been made. This creates risk for rework due to eventual NRC feedback.

NRC and industry agree upon the importance of high-quality pre-application engagement as critical to predictable licensing for SMRs.[140] Preapplication activities increase regulatory certainty, provide early resolution of complex issues, and enable smoother engagements further down the licensing timeline.[141]

However, small developers may find it challenging to acquire the financing up front to initiate these regulatory activities, which may lengthen licensing activities later on. These engagements usually occur several years in advance of a licensing application, perhaps longer for FOAK SMR engagements to address the uncertainties raised by novel features. The timeline for pre-application engagement in particular contradicts investment timelines, as developers are early in the process with little-to-no regulatory certainty and perhaps minimal design completion.

Discouraging Technology Innovation

By imposing fees on FOAK developers whose licensing experiences are expected to be more burdensome, the fee structure discourages technology innovation.

The consequences of the fee structure fall to the “first movers,” as FOAK SMR applicants pay for NRC’s learning through longer, resource intensive reviews. First movers enhance staff knowledge and establish regulatory precedent on cross-cutting licensing uncertainties. These “lessons learned” will evolve the regulatory framework over time and improve the staff, management, and Commission’s ability to assess new reactors and resolve licensing uncertainties.

While reactor innovation can play a major role in deep decarbonization, imposing fees on novel technologies steepens FOAK obstacles. This additional burden dissuades customers and investors from advanced technologies. Indeed, one Gen III+ SMR said that light water technology provides a strategic regulatory advantage.

Culture

Safe operation of the country’s nuclear fleet is paramount, and NRC’s thorough reviews and questioning attitude are essential to maintaining public trust and upholding the current fleet’s high performance. The NRC’s high bar has and continues to set international standards.

However, some critics argue that NRC’s culture is perhaps *too* conservative, resulting in an agency that fails to adapt to innovation in a timely manner. A culture that is not receptive to SMR innovation may threaten the nation’s climate, reliability, and security goals.

In the past 20 years, NRC has consistently faced culture challenges. A 2000 Government Accountability Office (GAO) study found that only 23 percent of staff agreed or strongly agreed that senior management was receptive to suggestions for change made by the staff.[142] This echoes sentiments from a 1998 survey from NRC's Inspector General, which showed that NRC staff did not believe higher levels of management trusted their judgement.[143] Additionally, in 2014, an internal study of NRC's culture found that the agency's decision-making is hierarchical, and that innovation and agility were not valued.[144] Indeed, NASEM's 2023 analysis found that NRC has taken substantial time reviewing and accepting new technologies in currently operating plants, such as the transformation from analog instruments to digital instrumentation and control.[145]

A conservative culture may unnecessarily prolong timelines and engagements surrounding novel features, even when an adequate safety case with quality information is presented. Additionally, hierarchal decision making may contribute to inefficiencies in communication within NRC. As the 2023 NASEM report remarks, "cultural change could now be the biggest challenge which confronts NRC."[146]

6. A Path Forward: Strategies to Enable Efficient and Predictable Licensing for SMRs

Novel technologies, a fee structure that limits NRC flexibility and robust engagement, and a conservative agency culture creates major frictions in FOAK reviews. As such, policy, regulatory, and NRC administrative reforms are proposed in the near term to enable successful FOAK applications.

After regulatory approval and successful build of the first unit of a design, sequential licensing experiences are expected to be much smoother and predictable given design standardization across sequential orders.[h] If industry projections actualize, though, the sheer volume of applications may be a challenge in it of itself, even if many designs are already standardized. Thus, recommendations are offered over the long term to ensure NRC can withstand a high quantity of applications while still fostering technology innovation.

Recommendations are proposed across four dimensions:

i) Enabling Strong Performance through Fee Reform

ii) Enabling an SMR Ecosystem through Innovation Capabilities

iii) Enabling Clear External Engagement, Internal Knowledge Management

iv) Enabling Efficiency through Cross-Cutting reforms

Dimension 1: Enabling Strong Performance through Fee Structure Reform

The current fee structure may be a sound model for an established industry, but attempting to stand up a new nuclear technologies while imposing fees is difficult.

Recommendation 1.A: Congress should move hourly service fees for FOAK SMRs off- fee base.

Timeline: Near Term

Rather than charging an applicant hourly service fees when a design is under review for the first time, Congress should move all hourly service fees off-fee base and supplement with additional

[h] Site specific issues, such as seismic risk or emergency preparedness, may require design changes. However, customers can also select designs that best fit according to site analysis to minimize risks of the need for changes during a review.

appropriations. After a given design has successfully completed one licensing pathway (either Part 50, 52, or 53), fees should once again apply to the design, as most complex issues will be resolved.

Successful SMR reviews from first movers will benefit a number of parties beyond the applicant— i) NRC, through the creation of institutional knowledge, ii) follow-on applicants, that benefit from new precedents regarding innovations, and iii) the public, through advancement of technologies that avoid carbon emissions.

Removing hourly service fees will enable success for FOAK SMR reviews by:

I) **Improving application and engagement quality**

Exemptions from fees can encourage early involvement by removing the cost burden associated with these actions. For a FOAK SMR, there are several notable benefits from pre-application engagement that improve the quality of an application, reduce risk of licensing days, smoothen application engagements, and improve internal communications:

- Clarification regarding the regulatory requirements that apply to the design
- Ability to obtain regulatory feedback, preliminary decisions, and resolve high areas of uncertainty though topical reports, technical reports, white papers
- Identification areas of review that may pose challenges, and potential early socialization with necessary levels of management or the ACRS
- Incremental reduction in regulatory uncertainty to increase developer and investor confidence through the completion of several engagements

Further, resources typically spent on review fees could instead be directed toward activities which enhance the quality of the application, such as hiring talent or the completing of testing.

II) **Enhancing NRC Workforce, Agency Preparedness**

For NRC's workforce to match the breadth of skill and expertise reflected in industry, the agency needs reliable foresight into how its workload will change in coming years. Fee exemptions can encourage activities that provide this signal.

Early involvement from applicants helps NRC identify the necessary core positions and competencies needed to support reviews, and an annual budget that accurately reflects the anticipated workload.[147,i]

Due to the skilled and specialized nature of some competencies, NRC conducts workforce planning five years in advance. For example, training for probabilistic-risk-assessment analysts takes three

[i] NRC faces additional challenges hiring skilled workers, such as competition from industry and keeping up with attrition due to higher rates of retirement. However, the Commission does have tools at its discretion to increase competitiveness, including direct hiring authority, contracting authority for specialized expertise, and incentives for staff. NRC must still utilize its direct hiring or contracting authority within the confines of its annual budget, emphasizing the importance of accurate requests.

years to complete.[148] Early awareness that such analysts will be needed is critical to ensures these positions can be filled when an applicant needs it.

NRC's fee structure, however, limits the hiring and training NRC can do if participation from applicants in advance is absent. NRC requests FTEs and resources based on specific business lines.[149] To not impose the costs of new reactor activities on the operating fleet, NRC will only request resources or staff for new reactors based on licensing activities NRC can expect to recover costs from.

With strong, reliable foresight from industry, NRC can gauge the right quantity and expertise needed to foster efficiency and strong workforce performance. Historically, influxes of applications have led to delays across licensing applications due to limited bandwidth and expertise.[150,151] Strong, reliable foresight also reduces unexpected workload shifts, which can be detrimental to agency performance.[152,153]

Congress acknowledges the fee structure's impact on SMR commercialization. The Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2023 (ADVANCE) would make prizes available for the FOAK that demonstrates success in each of the licensing pathways (50,52, or 53) or demonstrates novel nuclear applications, such as industrial facility co-location or spent fuel re-use.

The ADVANCE act rightly recognizes the need to support FOAK SMRs across different applications. However, a prize program reimburses applicants at the end of the licensing process, rather than when the financial support is needed most. Prize programs often entail transaction costs that can reduce the effectiveness of the grant.[154]

Almost every SMR design NRC is reviewing has novel features of some kind. Thus, an exemption to all first-of-a-design SMRs within a certain timeframe, or until a critical mass has successfully passed through the entire process, can enhance application quality and hiring and training efforts within NRC. Additionally, learnings from one design, even if ultimately unsuccessful in progressing through a review, may spill over to and enable success in other designs.

NRC has measures in place to ensure application materials are of sufficient quality to initiate a review. For example, in submitting a topical report, NRC recommends applicants meet with NRC Project Managers and schedules a pre-submittal meeting three to six months prior to ensure the report meets criteria and staff are familiar with the topics. In accepting pre-application or application documents, NRC only accepts for official review if the quality is sufficient.

Recommendation 1.B: the cost of licensing standardized designs is better understood, Congress should consider fixed application fees for licensing activities.

Timeline: Long Term

As licensing costs for standardized designs are better understood, Congress should consider fixed licensing costs to provide certainty and transparency to applicants.

After FOAK exemptions sunset, future technology developers that hope to innovate may be in a similar position to vendors today — longer, more costly licensing reviews. Though expansion of different nuclear technologies and new regulations may better equip NRC to be agile, new advancements will likely still face exhaustive reviews. Fixed fees can foster technological innovation and provide more certainty for applicants regarding the price of reviews, even when the exact licensing schedule is less clear.

The ADVANCE Act aims to provide cost relief over the long term by reducing the professional staff rate for all advanced reactor activities; however, this does not address uncertainty surrounding what the total cost of a licensing review will be.[j]

A fixed licensing fee, similar to the U.S. Food and Drug Administration (FDA), has been raised as an alternative to provide applicants with certainty.[155,156,157] The FDA and industry negotiate agreements on user fees every five years, leading to settled fixed prices for application reviews in exchange for commitments from the FDA to meet certain performance goals.[158] The tables below compare the FDA's application rates versus NRC's fee estimates.

Table 7

FDA Prescription Drug User Fee Act FY 2023, FY 2024 User Fee Rates

User Fee Type	FY2023	FY2024
Application Fee- Clinical Data Required	$3,242,026	$4,048,695
Application Fee- No Clinical Data Required	$1,621,013	$2,024,348
Program Fee	$393,933	$416,734

U.S. Food and Drug Administration, 2023[159]

[j] ADVANCE would reduce licensing costs by altering the calculation of the professional staff rate. Currently, NRC's professional staff rate is derived by adding budgeted resources for 1) mission-direct program salaries and benefits, 2) mission-indirect program support, and 3) agency support. ADVANCE would exclude the costs of mission-indirect programs and agency support.

Table 8
NRC New Reactor Business Line Fee Estimates, January 2023

	Staff Costs			Contractor Costs		
	Low Level of Effort	High Level of Effort	Average Level of Effort	Low Level of Effort	High Level of Effort	Average Level of Effort
License Amendment	$9,630	$583,899	$84,423	N/A	N/A	N/A
Combined License	$14,210,349	$57,189,360	$28,652,781	$2,760,000	$8,880,000	$5,020,000
Early Site Permit	$4,694,946	$20,845,740	$9,342,384	$1,870,000	$5,110,000	$2,760,000
Design Certification	$34,668,000	$82,530,384	$57,585,795	N/A	N/A	N/A
Topical Report*	$642,000	$1,284,000	$963,000	N/A	N/A	N/A

U.S Nuclear Regulatory Commission, 2023[160]

Though NRC provides application specific estimates in addition to the estimates shown in table 5, applicants do not know the true cost until a review is complete. It is unclear what NRC considers “high” versus “low” levels of effort. One may assume that a low level of effort corresponds with robust pre-application engagements.[161] However, NuScale, engaged with NRC for nine years before submitting the DC application, yet still had fees that ranged in the high level of effort. [162]

While NRC cannot yet make accurate estimates given the few complete licensing activities, firmer estimates may be better understood as multiple SMR reviews are completed. Given the hopes that each SMR will receive several orders, potentially with multiple licensing reviews, pinpointing a fixed price for an application review will improve with time.

Providing certainty with fixed fees does not force NRC to meet a fixed timeline, maintaining the agency’s ability to make decisions when, and only when, an applicant demonstrates compliance with safety regulations. For example, while FDA aims to review in the timelines established by user fee agreements, the timeline does not force FDA to decide on a product’s application before the agency’s work is complete.[163] Similar to NRC, FDA's decisions are made based on science and are consistent with the legal and regulatory standards that govern the agency.[164]

Upon official acceptance of a review, NRC certifies that an application is of sufficient quality to be reviewed by NRC, within an estimated time frame and cost. If NRC requires additional time to review an application due to unforeseen challenges, that cost should not be borne on the applicant and should rather be supplemented with Congressional appropriations.

Dimension 2: Enabling an SMR Ecosystem through Innovation Capabilities

DOE plays an important role in smoothening the review process for FOAK and enabling scaleup.

DOE's financial support and laboratory capacity, in terms of testing capabilities and staff expertise, are effective mechanisms to transfer knowledge to NRC and create regulatory infrastructure.

Recommendation 2.A: Congress should appropriate funds for a microreactor demonstration program via a public-private partnership.

Timeline: Long Term

A microreactor demonstration program restricted to designs <20 MWth would help create a regulatory foundation that reduces the testing burden on applicants, enables higher quality applications and engagements, and equips NRC with more knowledge. The reduced size and smaller power output i) reduce the necessary materials and capital required to build the plants, and ii) reduce the likelihood of significant impacts and land footprint required for demonstration, both of which can allow this program to move quickly.[165] Similar to the AEC's demonstration program and the Office of Nuclear Energy programs, industry should be responsible for bringing their technology to DOE designated sites, which provide the laboratory capabilities, site, and staff.

Nuclear experts agree that there is a need for expedited, noncommercial demonstrations to further knowledge, data, and experience with innovative technologies.[166,167] Microreactor demonstration will improve understanding of how technologies or components behave and enhance NRC's ability to assess risk and regulate over time. Though not entirely applicable, these learnings can spillover to larger reactors.

Two DOE programs provide industry with access to lab capabilities, i) Gateway for Accelerated Innovation in Nuclear (GAIN), which provides access to experimental, computational, and land use for specific projects, and ii) National Reactor Innovation Center (NRIC), which enables testing, construction, and demonstration of reactor concepts.[168,169] One NRIC capability is the Demonstration of Microreactor Experiments (DOME), a space dedicated to demonstrating nuclear reactor concepts less than 10MWth.

Industry expressed significant interest in DOME. A visit to the DOME revealed that the space is constrained, given several civilian and defense microreactor demonstrations competing for access. In speaking with senior officials at INL, a separate microreactor demonstration program, in addition to the ongoing advanced reactor demonstration program would benefit deployment.

Scaleup will rely on improved operational performance of technologies currently in development and the introduction of new technologies that do not yet exist. Support from Congress to facilitate additional demonstrations low-risk environments, such as laboratories or unpopulated federal reserve land, can support this scaleup and innovation.

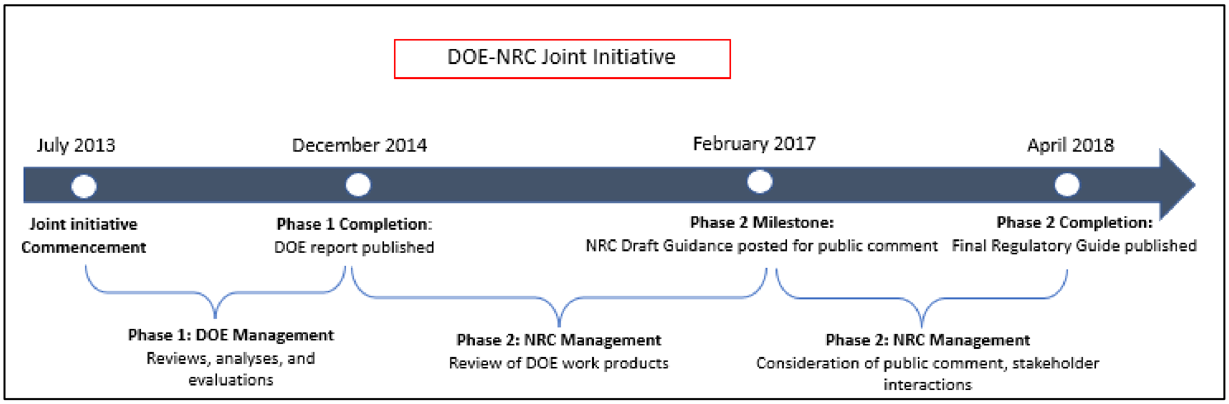
Recommendation 2.B: DOE and NRC should pursue the joint-initiative model to create regulatory infrastructure and capacity via official reviews on cross-cutting technical uncertainties.

Timeline: Long Term

DOE and the National Laboratory System, including the laboratories' staff, testing, and modelling capabilities, can help close gaps in regulatory infrastructure and transfer knowledge to NRC staff. The laboratories and NRC frequently collaborate on a number of issues; however, one model that is easily replicable is the DOE-NRC Joint Initiative Model.

This model builds regulatory infrastructure by mimicking real licensing experiences on cross-cutting issues. Starting in 2013, DOE and NRC established a joint initiative to develop guidance on developing principal design criteria (PDC) for non-LWR SMRs.[170] The program had two phases: phase 1, in which DOE put together a draft guidance, and phase 2, in which NRC reviewed DOE materials and issued a final regulatory guidance from the review. Both phases allowed for industry and public involvement through workshops and public comment.[171,172] The timeline of the joint initiative is shown below.

Figure 4: DOE-NRC Joint Initiative



Not only did this program effectively transfer knowledge from DOE to NRC, but it also provided staff with real experience evaluating novel designs and applying novel characteristics to NRC regulations. This benefits workforce capacity through learning-by-doing and results in strong, well-informed guidance. The usability of the PDC guidance is demonstrated by ongoing use from Kairos, Terrapower, and X-Energy in licensing activities.[173, 174, 175]

DOE and NRC should complete joint initiatives to create guidance on cross-cutting technical matters that impact a number of SMR designs. The initiative should be focused on critical gaps, in both staff expertise and regulatory infrastructure. For example, an initiative could focus on ATFs, advanced manufacturing, or Part 53 implementation. These efforts take about five years; thus, can be used to address both current gaps and as they are discovered in the future.

Dimension 3: Enabling Clear External Engagement, Internal Knowledge Management

To foster more effective, clearer engagement, as well as improve communication pathways internally, proposed reforms aim to alleviate areas which cause delays and/ or rework, from the side of the applicant or the regulator.

Recommendation 3.A: National Laboratories and NRC should collaborate through a "Sherpa" program to assist applicants during reviews.

Timeline: Near Term

While NRC has conducted a number of activities to improve RAIs for new reactor licensing, such as revising the RAI process, updating guidance, and providing refresher trainings, RAIs remain a source of frustration for applicants. [176,177,178] Given the likelihood of delays during this process, applicants and NRC may benefit from a third party to help facilitate communication. A laboratory "sherpa" that aids interpreting NRC requests may alleviate communication shortfalls and ensure the right information is presented at the right time.

There are several examples in which DOE assists applicants to ensure smoother application reviews. DOE's Loan Programs Office (LPO) Outreach and Business Development (OBD) staff meet with potential applicants and provide step-by-step assistance to navigate the application process.[179] DOE also funds the American-Made Power Connectors program, in which DOE prize recipients can access a network of more than 250 organizations that provide technical assistance, access to laboratory space, and assistance regarding program execution.[180]

A similar program for NRC has been proposed in the past. An MOU between GAIN and NRC signed in 2017, directs the DOE to establish a process under which prospective new or advanced reactor technology applicants can request information or ask questions about NRC's regulatory requirements and activities.[181] It is unclear if this process was ever created.

DOE should implement a similar process as the one described in the MOU with a stronger focus on providing support during the RAI process for first movers.

Recommendation 3.B: The Government Accountability Office should complete a study on NRC's management practices, with a focus on improving staff performance during reviews

Timeline: Near Term

An independent study from GAO can shed light on NRC's management successes and challenges. This should include varying levels of NRC management, from project managers up to the Commission. Discoveries regarding higher levels of senior management may reveal critical components regarding the agency's incentive structure and how that impacts culture.

Many of the challenges applicants have experienced with NRC staff can be attributed to management. Effective management and oversight of technical staff, particularly those with less experience, is essential to ensure RAIs are focused, procedures are executed properly, and reviewers make timely decisions. According to former NRC Commissioners, current cultural challenges may be attributed to incentive structure created by higher levels of senior management, including the Commission.[182]

Recommendation 3.C: The Office of Inspector General should complete its audit of NRC's Knowledge Management Program.

Timeline: Long Term

NRC should reprioritize and conduct an audit on knowledge management to improve knowledge transfer between staff and different levels of management.

In FY2018, NRC's Office of Inspector General (OIG) identified knowledge management as a challenge in the annual *Most Serious Management and Performance Challenges Facing NRC* for FY2019.[183] OIG planned to conduct an audit in FY2019 on the knowledge management program to reduce the risk of regulatory inconsistency and inefficiency.[184] The status of the audit on knowledge management is unclear. OIG planned to initiate the audit in 2019, 2020, and 2021.[185, 186,187] After the annual OIG report for FY2021; however, the audit for knowledge management was no longer mentioned.

OIG must reprioritize this audit to pinpoint current challenges regarding knowledge transfer between staff as well as between different levels of NRC management. This audit can shed light on and hopefully improve knowledge transfer, communication, and internal alignment within NRC for licensing reviews.

Recommendation 3.D: Congress should provide the Commission with a refreshed direction as to how NRC fits within the climate, security, and reliability goals

Timeline: Long Term

NRC is an agency under the auspices of Congress. If national security and decarbonization are national imperatives for Congress, as reflected by recent laws such as the Infrastructure, Investment, and Jobs Act and the Inflation Reduction Act, then these remits must be reflected to NRC. Public support for nuclear has grown in recent years, also reflecting a growing change in the nation's priorities; 43% of adults supported nuclear in 2016 in comparison to 57% percent in 2023.[188]

While the overall NRC mission should remain the same, Congress should provide direction as to how NRC fits into a larger national narrative. This could start to create an incentive structure that more equitably balances expediency, safety, and other dimensions.

Cultural changes can have a number of positive impacts on challenges outlined in this paper. For example, effective knowledge sharing. In comparison to structural changes, the International Atomic Energy Agency (IAEA) outlines cultural changes as more effective measures to enhance knowledge sharing within a regulatory organization.[189]

While several NGOs and industry groups suggest altering the agency's mission as a means for cultural change, NRC must also maintain public trust.[190,191,192] As demonstrated in the era of the AEC, public trust in the regulator is a necessary ingredient to ensure the continued success of the industry at large. Though climate change and energy security create urgency for SMR deployment, industry must recognize that meeting decarbonization and security ambitions requires successful licensing across several decades. This is only possible with sustained public trust in the regulator.

Dimension 4: Enabling Efficiency through Cross-Cutting Reforms

Statutory and procedural reforms aim to reduce resource use, lower construction risk, and institutionalize lessons learned to enable faster licensing.

Recommendation 4.A: Congress Should Remove the Mandatory Uncontested Hearing Requirement.

Timeline: Near Term

The mandatory uncontested hearing requirement unnecessarily lengthens licensing reviews. The Atomic Energy Act requires NRC to hold a mandatory hearing for any action (both optional and required) under Part 50 and 52, including CPs, LWAs, ESPs and COLs. The uncontested hearing process typically adds an additional 4-7 months before an applicant receives a license, as the process does not begin until NRC staff completes its review. [193]

Mandatory hearings in recent years typically reach the same conclusion from NRC staff on findings to support licensing action. [194] INL did a recent survey of mandatory hearings held in the past 15 years and found that all reached the same findings as NRC staff. This is unsurprising, as hearings often cover application information that has undergone thousands of hours of review by hundreds of NRC staff reviewers and many months of meetings with NRC staff and ACRS.

Importantly, removing the uncontested hearing requirement does not impede the public's ability to provide input in public meetings or comment or pursue a contested, Commission-granted hearing. By removing the requirement, Congress can enable NRC to have faster reviews while still ensuring the public can pursue options to raise issue in the review if desired.

Recommendation 4.B: NRC should develop an expedited process for reviewing licensing actions during construction

Timeline: Near Term

An expedited process for reviewing licensing actions during construction should be considered to reduce risk for FOAK projects. In a lessons learned exercise on Part 52 implementation, Southern Company advocated for a pilot approach in resolving changes for the first licensee of a design as unintended challenges are identified, particularly if issues are of minimal safety significance. [195]

An expedited review process can also mitigate risk if regulatory changes occur during construction, entirely outside the applicant's control. For example, changes during the Three Mile Island accident had detrimental impacts on cost and schedule for reactors during construction.[196] An expedited process can cushion new projects from said risk.

Recommendation 4.C: The Commission should revisit key challenges with Part 53 to ensure the rule is performance-based.

Timeline: Long Term

A technology neutral licensing pathway is essential to enable scale and foster nuclear technology innovation over time. In creating this rule, the Commission must fulfill the requirements of NEIMA— a rule that is risk-informed and performance-based.[197]

NRC's understanding of new technologies and how they should be regulated will evolve. NRC has many tools at its disposal to address operational issues as they emerge— not all issues can be solved with licensing. The Commission can create Part 53 such that technologies demonstrate safety through performance-based outcomes, with knowledge that changes can be made with learnings from operational experience. NRC regulates technologies across the continuum of plant operations and decommissioning.

Of course, the rule must contain sufficient infrastructure that enables staff to make safety finding, in some cases being prescriptive. However, the rule should prescribe performance-based goals or outcomes that allow applicants to comply in a way that makes sense for their technology.

Recommendation 4.D: NRC should complete a lessons learned activity following each FOAK licensing review.

Timeline: Long Term

Given the plethora of new reactor technologies, applications, and sizes that are to be demonstrated in the next decade, NRC should conduct regular lessons learned activities and incorporate those findings into a set of standard review plans (SRPs).

NRC conducts lessons learned activities at an irregular cadence. The agency may conduct collective exercises across a variety of reviews, in response to industry lessons learned, or conduct a lessons learned based on one experience. Regular activities, on the other hand, can help ensure retainment of positive and negative lessons learned from each review.

Institutionalizing lessons learned into a Standard Review Plan (SRP) for a given reactor technology will help ensure best practices are utilized and create a more uniform review process.[198] SRPs are guidance for staff in performing reviews of proposed licensing actions, with the goal of assuring quality and uniformity of safety reviews. Lessons learned from LWR licensing have been used to improve the SRP guidance. For example, a lessons learned activity identified 11 key technical areas related to seismic analysis and structural designs that could be improved in the SRP.[199]

As DOE is supporting many vendors through licensing with some form of subsidy, information sharing to benefit future applicants and technical staff should be a priority.

7. Conclusion

SMR commercialization can accomplish decarbonization, energy security, and reliability goals. At present, licensing is a barrier for deployment. Fee structure reform is necessary to enhance NRC's flexibility and reduce the cost burden on first movers. Strategic use of DOE and the national laboratory system can help close regulatory gaps and improve agency understanding of novel technologies. Strengthening NRC management and internal processes will also improve review efficiency, predictability, and perhaps agency culture. Finally, cross-cutting reforms can reduce resource use, lower construction risk, and institutionalize lessons learned.

Licensing is a shared challenge. Implementation of reforms can enhance each party's ability to execute effectively, from application development to license to operate. This will not only allow successful deployment of an orderbook, but also to enable throughput of licensing necessary to reach scale by 2050.

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