Comments on the ADVANCE ACT implementation–ROP:

12/10/24 0930: NRC Public Meeting Ongoing Staff Efforts Under the ADVANCE Act

Ernie Kee, member of the public

Comment 1: Changing reporting standards

During the 12/10/24 NRC public meeting, the audio connection at my end was poor, but I believe I heard Dr. Lyman raise concerns about the possibility for confusion that could arise by modifying record-keeping practices for White findings.

An example from my experience highlights the risks of reporting changes:

I was once tasked with evaluating a design change proposal for a non-safety system involving repeated failures of ventilation dampers in the turbine building air-handling system. My initial cost-benefit analysis suggested no redesign was necessary, as recent data indicated improved performance when analyzed as cumulative failures over time–the figure (fig. 1) is a notional recreation of this trend. However, I later discovered that maintenance staff had stopped reporting failures due to a lack of action on prior requests. This reporting gap concealed the true extent of the problem, resulting in a misdiagnosis of cost-benefit.

Some of my prior comments on the ADVANCE Act and NEIMA addressed how the use of PRA in the NRC's ROP SDP process can compromise safety oversight. These comments emphasized that *theoretical proof* demonstrates that PRA, as currently practiced by licensees and the NRC, unavoidably produces optimistic estimates of accident risk. Despite practitioners' assertions to the contrary, there is no way to eliminate this optimistic bias with PRA in its present form. Given this inherent bias, the ROP should not rely on PRA for oversight decision-making.

While this example does not reflect actual NRC oversight practice on safety-related protections, it does underscore the unintended consequences of altering reporting practices which, if I understand his comment correctly, is central to Dr. Lyman's concern.

Comment 2: The ADVANCE Act, NEIMA, and the NRC Oversight Framework

I have significant and ongoing concerns about the potential for both the ADVANCE Act and NEIMA to compromise the effectiveness of NRC oversight of U.S. commercial nuclear power. These concerns extend beyond changes to the ROP.

The current NRC safety oversight framework is complex, comprehensive, and highly effective, having evolved through the application of sound safety engineering principles. However, Congress appears to believe that "risk-informed and performance-based" methodologies can serve as a theoretical foundation to replace well-established safety engineering practices. In my view, this approach is less a safety engineering principle and more a slogan that has yet to be rigorously tested.

Even if it were possible for significant changes to safety engineering practices to succeed, I believe experimenting with them on hazardous technological systems, such as commercial nuclear fission reactors, is unwise at best and reckless at worst. The report to Congress outlines a process that, in my opinion, systematically dismantles the NRC oversight framework. Viewing the NRC oversight framework as a collection of isolated processes is, in my view, fundamentally flawed.

There are very few opportunities to alter NRC oversight processes in ways that reduce workload while simultaneously maintaining or improving upon the current safety record of U.S. commercial nuclear power plants. I strongly urge the Commissioners to resist pressures that prioritize relaxing oversight standards over maintaining robust oversight. Instead, Congress should provide the NRC with the resources necessary to more rapidly perform its essential regulatory functions. By doing so, Congress can help the NRC continue to deliver an unparalleled safety record for U.S. nuclear power.

Further context

For further context, I have included as an addendum a document included with comments I submitted on October 9, 2024, related to concerns with the NRC "ADVANCE Act Congressional Report on Environmental Reviews of Nuclear Reactor Applications" as well as NEIMA.

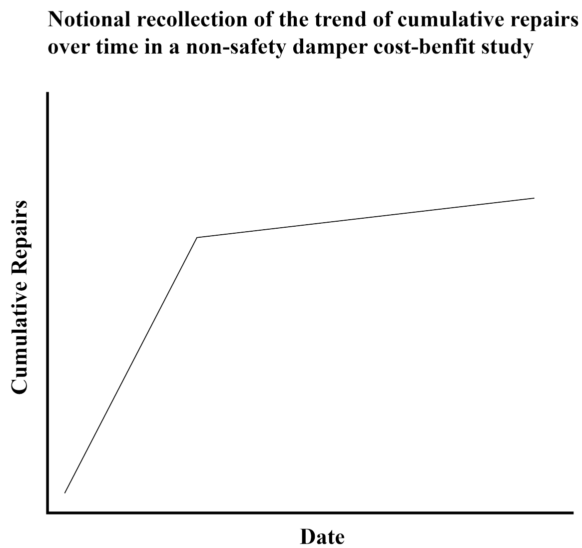

Figure 1: Changes in reporting standards can change decision-making outcomes

Addendum: Previous Comments on the ADVANCE Act and the NEIMA

The following addendum includes comments I previously submitted to Lance Rakovan, with copies to Sarah Lopez and Ted Smith. While there may be limited opportunities for adjustments, I believe the Commission should prioritize requesting additional funding and resources from Congress. With adequate support, NRC staff could provide timely responses to licensees in their oversight activities without compromising safety.

NRC oversight of licensee technical specifications, designed to ensure adequate protection, must remain prompt, especially if the nation seeks a more rapid expansion of nuclear power. However, this cannot come at the expense of the existing regulatory framework, which has proven its efficacy through its historical record. Congress should refrain from presuming it can dictate the technical support or oversight activities necessary to achieve adequate protection for commercial nuclear fission reactors.

Comments Regarding Recent Nuclear Power Legislation:

A Critical Review of the ADVANCE Act and NEIMA

Ernie Kee, member of the public

Summary

I believe that Commercial Nuclear Fission (CNF) is the best energy production technology available today for the environment, for protecting public health and safety, and for achieving environmental justice. It produces the least CO_2 per unit of energy generated, typically measured in megawatt-hours or exajoules (quads), and is arguably safer in terms of human sickness, injury, and death compared to all other existing alternatives. Its safety record is a direct result of the NRC's prescriptive regulatory framework on protections. In this document, I provide commentary on the following topical issues as they relate to Congressional legislation on Commercial Nuclear Fission Reactors (CNFRs):

- In the absence of extensive (and undesirable) CNFR accident data, attempts to quantify accident probabilities rely on flawed science, rendering such estimates irresponsible, misleading, and potentially dangerous.
- The cost of protections for CNF technology should be acknowledged and sufficiently funded to make the deployment of CNFRs attractive to investors.
- The costs incurred by the NRC for inspection and enforcement, which are necessary to maintain or enhance the CNF preference over other energy technologies, should be funded, on top of the existing industry support structure, through congressional action.
- The existing NRC regulatory framework has been highly successful and should be the standard for regulated protections on CNFRs.
- Offsetting atmospheric CO_2 entirely with CNF technology would require at least 1,000 CNFRs, a scale that is likely unfeasible in the short term without a national 'moon shot' effort.
- The NRC's prescriptive regulation of protections has effectively eliminated the moral hazard associated with CNFR operation, making CNFRs the top choice for achieving environmental justice in energy generation.

Relevant academic literature is cited where appropriate.

Acronyms

cdf Cumulative Distribution Function

pdf Probability Distribution Function

ADVANCE Accelerating Deployment of Versatile Advanced Nuclear for Clean Energy

AEA Atomic Energy Act of 1954

CNF Commercial Nuclear Fission

CNFR Commercial Nuclear Fission Reactor

FMEA Failure Modes and Effects Analysis

LER Licensee Event Report

NEIMA Nuclear Energy Innovation and Modernization Act

OIG Office of the Inspector General

PRA Probabilistic Risk Assessment

Introduction

The Accelerating Deployment of Versatile Advanced Nuclear for Clean Energy (ADVANCE) and Nuclear Energy Innovation and Modernization Act (NEIMA) Acts appear to direct NRC staff to lower costs and reduce schedule delays associated with licensing new CNFRs, with the goal of encouraging the widespread deployment of a large fleet of CNFRs. Congress may believe that the Atomic Energy Act of 1954's (AEA's) focus on ensuring 'adequate protection' through rigorous engineering reviews of CNFR technical specifications has hindered the expansion of CNF energy technology in the U.S.

The NRC's regulatory framework, which demands rigorous adherence to engineering principles for robust hazard protection, requires significant effort from both the regulator and the CNFR investor. This prescriptive regulatory framework is grounded in time-tested engineering principles, including safety margins and defense in depth–concepts that have been used since antiquity. To date, no better approach has been described for managing the risks associated with hazardous technological processes than those exemplified in the NRC CNFR regulatory framework.

While this approach results in relatively high costs and extended build schedules, it also produces significantly safer outcomes compared to other, less desirable energy technologies. If Congress perceives this regulatory framework as an obstacle to expanding CNF technology and directs the NRC to deviate from rigorous reviews, then it risks making a grave mistake that will inevitably endanger the citizens it represents and the environment it intends to protect.

Despite these challenges, I believe Congress understands the value that well-designed and well-managed CNFRs offer in advancing national goals for reducing the environmental impact of energy production. If Congress holds this view, leveraging CNF technology to offset national energy production could be highly beneficial–so long as it is pursued both rapidly and safely. However, while CNF can significantly mitigate climate change, it also poses serious risks to human health and the environment if critical protections are not rigorously engineered.

The comments and discussion that follow are motivated by my concern that recent Congressional Acts redirecting the NRC licensing framework could lead to, or even encourage, poor engineering practices in critical protections–practices that the NRC licensing process, originally developed under the AEA, has successfully prevented. In the following sections, I briefly summarize key concerns regarding specific aspects of the proposed legislation. Further clarifications with relevant references are provided in Appendices A to C.

On improper probability quantification

In recent legislation, Congress has blurred the distinction between risk quantification and the design of protections. Engineering principles, which rely on the laws of physics, guide the design of protections. In contrast, risk quantification is performed only after the engineering design is complete and significant operational data have been collected–typically on identical systems or subsystems. Reliable probability estimates, such as those used for automobile accidents or human life expectancy, depend on large, statistically meaningful data sets. Fortunately, no such data sets yet exist for either current or obviously new CNFR designs, making CNFR accident risk quantification speculative at best.

The current NRC licensing process accounts for unexpected events. Such consideration is essential because, despite CNFRs operating for many years, new and unforeseen events still occur. To prevent the recurrence of these events, which are inevitable due to design uncertainty, thorough root cause analysis and prompt corrective actions are required–steps often undertaken only due to regulatory oversight. The NRC mandates that such events be reported in their Licensee Event Report (LER) system.[1] The occurrence and management of these events through regulation illustrate why probability quantification is unhelpful for engineers focused on reducing protection failures. Probability quantification is inherently 'backward looking,' as it reflects only past events that have already been addressed, while future events remain part of an ongoing learning process. While these future events must be considered in probability estimates, their unknown nature prevents them from being included.

Careful study shows that, because unexpected events occur during the operational lifetime of CNFRs, probability quantification often leads to overconfidence in safety. Quantification methodologies that attempt to estimate accident probabilities often lack the necessary data support and have been shown to be overly optimistic and theoretically flawed, as noted in the works of (Kee and Wortman, 2023b; Hansson, 2009; Doorn and Hansson, 2011; Kee and Wortman, 2023a, for example). This holds true despite the assertions made by Kaplan and Garrick in Section 6 of their work. Probabilistic Risk Assessments (PRAs)

[1] Licensee event report system, 10 CFR §50.73.

of modern CNFRs estimate accident frequencies at approximately 0.0001 per year or lower, misleading the public to an overly optimistic perception of safety.[2] The false sense of safety fostered by PRAs, which follow the practices first developed by Rasmussen, is revealed by the operating records preceding the most recent accidents:[3]

1. The actual accident frequency for Three Mile Island Unit 2 is 1 per year.

2. The actual accident frequency for Chernobyl Unit 4 is approximately 0.5 per year.

3. The lowest actual accident frequency among the three Fukushima Units (1, 2, and 3) is 0.025 per year.

Ha-Duong and Journé comprehensively review accident experience to reach a conclusion that shows CNFR accident frequency in the worldwide CNFR fleet, based on available accident experience, is much higher than quantitative risk assessment would indicate.

It is my understanding that Congress has been informed by many experts from regulatory bodies, academia, industry, and the public in developing the ADVANCE Act and the NEIMA. These experts advise using risk-informed and performance-based regulation by the NRC to expedite the licensing process. However, it is unclear whether Congress has been fully informed about the distinct difference between regulatory requirements for properly designed protections (as outlined in CNFR technical specifications) and the inspection and enforcement of those protection requirements. Currently, the NRC employs risk-informed and performance-based methodologies to optimize the allocation of its limited inspection and enforcement resources to ensure CNFR operators and investors are in compliance with protections required by NRC regulations. However, with limited resources, the NRC must prioritize its inspection and enforcement efforts instead of ensuring full compliance with all protection requirements detailed in CNFR technical specifications. When CNFR investors are asked whether protection requirements are being met, the response should be definitive–there should be no room for 'probably' or 'maybe.' For further background see Appendices A and B.

On implications of PRA applied to engineered protections

The Office of the Inspector General (OIG) has concluded that PRA is valuable for revealing potential weaknesses in CNFR's designs, especially when such weaknesses may have been overlooked in the CNFR technical specifications (Commission et al., 2006). The OIG's

[2]Note that the single parameter distribution produced from PRAs ignores hazard intensity. That is, an accident is much more likely when for example, a hurricane or earthquake arrives than at other times.

[3]The PRA intends to state the ratio of the number of accidents that occur in a CNFR over the total time they occur. This ratio is misleading as a measure of accident frequency, not only due to insufficient data but also because experience shows that CNFR operations are often curtailed following the first severe accident.

review of the NRC PRA policy statement quotes Rogovin, who notes that 'the frequency estimated for severe core-damage accidents is usually low (on the order of once in 10,000 reactor-years).' He adds, however, that it is 'not possible to validate the results directly because sufficient data does (sic) not exist.' The PRA logic structure provides the engineer with a comprehensive view of protection support in accident progressions. This comprehensive view is valuable for assessing the effectiveness of the design's protections.

The language in both the ADVANCE Act and NEIMA fails to recognize that risk-informed and performance-based methodologies are meant to complement the existing deterministic regulatory framework. It is my understanding that Congress intends for the current well-established prescriptive regulations to remain in place and be enhanced with PRA, not circumvented by it. However, the language in the Acts implies that these changes will reduce costs and expedite deployment schedules for new CNFRs, which is illogical–adding a review designed to reveal weaknesses in the deterministically designed protection specifications would naturally require additional effort and resources. If my understanding is correct, Congress should allocate additional inspection and enforcement resources to the NRC in future legislation to offset the burden of reviews that incorporate risk-informed and performance-based elements on top of the existing licensing framework. By doing so, Congress would enable the NRC to complete their technical specification reviews more quickly than can be done with existing resources. For further background see Appendices A and B.

On accident implications displacing fossil fuels

Congress should consider that replacing fossil fuels as the primary energy source with CNFRs would require a substantial increase in the number of reactors. Consider the annual energy consumption of the US, approximately 93 quads or about 29,000,000,000 MWh.[4] A large, modern, and efficiently managed CNFR typically generates about 1,500 MWe and operates at about 95% capacity throughout the year–amounting to about 12,500,000 MWh. Completely offsetting U.S. fossil fuel consumption with large CNFRs would require approximately 2,000 reactors. There are currently about 100 CNFRs operating in the US, though not all are as large as 1,500 MWe. Naturally, offsetting U.S. energy consumption with smaller reactors would require a proportional increase in the number of reactors–750 MWe would need around 4,000 CNFRs, while 300 MWe would require approximately 10,000 CNFRs, and so on. Operating a large fleet of reactors would demand highly reliable protective system designs to prevent accidents. Preserving the U.S. CNFR fleet's excellent safety record would require great care in the design of protections, especially when considering a fleet that could be one to two orders of magnitude larger than the current fleet.

[4] U.S. energy facts explained

On social and environmental justice

It is essential to recognize that risk quantification through utilitarian approaches can overlook the impact on individuals, especially those most vulnerable to accident consequences (see Appendix C for a detailed discussion). Unlike other current energy technologies, CNF stands out as the one least likely to expose citizens and the environment to harm, prioritizing public welfare over profits. With densely regulated and historically robust protections mandated by the NRC, CNF ensures that both people and the environment are safeguarded from either accidents or pollution. Other energy technologies have been associated with significantly higher rates of death, injury, and illness.[5]

CNF technology is also exceptionally efficient in terms of environmental impact, producing only around 10 kg of CO_2 per megawatt-hour–an order of magnitude less than fossil fuels, on par with wind turbines, and three times less than solar power. In addition to its low carbon footprint, CNF technology, especially when incorporating nuclear fuel recycling, has an insignificant environmental footprint compared to other energy sources.

For example, wind farms require between 90 to 240 acres per megawatt produced (30 - 80 acres per megawatt of installed capacity), while hydroelectric production typically requires between 10 - 50 acres per megawatt of installed capacity, though this can double when considering capacity factors. In comparison, a CNFR requires only between 1 - 4 acres per megawatt, even accounting for capacity factors–U.S. nuclear plants currently operate with capacity factors around 90%. Moreover, CNF's centralized nature and stringent safety regulations mean fewer environmental and social burdens are placed on nearby communities, making it a top choice for promoting environmental justice.

Conclusion

Congress should be skeptical of claims that new CNFRs are 'inherently safe,' and therefore their technical specifications require less scrutiny by the NRC staff to ensure adequate protection of public health and safety as required by the AEA. There are at least two significant problems with this assertion. Radiation release hazards are not limited to the inability to remove decay heat, though this deserves proper focus (for example Mårtensson, 1992, focuses on decay heat). A prompt criticality excursion immediately vaporizes much of the reactor core and its radioactive inventory in CNF applications. Most prompt criticality accidents have occurred in experimental or fuel processing facilities (McLaughlin et al., 2000). There have been prompt criticality accidents in the US. While some may assure Congress that 'An accident like Chernobyl could not happen in the US,' this overlooks the N reactor at Hanford, which operated for years with a modest 'confinement building,' sharing this design flaw with Chernobyl (Toffer, 1989). Citizens understand assertions that a CNFR is 'safe' lack meaning and foundation–safety is only properly measured against

[5] See for example, Death rates per unit of electricity production.

alternatives for example, 'A is safer than B' (Hansson, 2012). Making an assertion that a CNFR is safe, especially when it is based on a 'number' erodes the public trust.

Congress should continue providing support to the NRC so that the current, highly successful prescriptive regulatory framework on protections can prevent accidents. Rather than relaxing regulations using questionable risk quantification, Congress should prioritize providing incentives to CNFR investors to ensure they can comply with regulations and still earn a profit. By supporting strong regulatory oversight and incentivizing compliance, Congress can ensure the safe expansion of CNFRs, positioning this technology as the top choice for sustainable and equitable energy production in the fight against climate change and preservation of the environment.

To achieve this, Congress must commit to robust funding for NRC oversight, maintaining strict regulatory standards, and creating incentives that would help ensure investor compliance with protective regulations, fostering responsible growth of CNFRs as a cornerstone of clean energy.

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A Probability and design of protections

Some engineering parameters are dimensionless. A common example is material strain, expressed in mm/mm or inch/inch. Although it is also dimensionless, probability is not an engineering property. As such, probability is not a design property. Instead, probability represents the ratio of the occurrences of a specific event to the total number of possible events. When designing a new device, this ratio is unavailable.

In a formal mathematical context, probability is defined within the framework of a Kolmogorov probability space, which provides a rigorous foundation for understanding random events. A probability space is a triple $(\Omega, \mathcal{F}, P)$, where:

- Ω is the sample space, representing all possible outcomes of an experiment or process.
- $\mathcal{F}$ is a σ-algebra, a collection of events (subsets of Ω) for which probability can be assigned.
- P is the probability measure, a function that assigns a probability to each event in $\mathcal{F}$, such that $P(\Omega) = 1$ and $P(A) \geq 0$ for all $A \in \mathcal{F}$.

In this classic framework, probability quantifies the likelihood of an event A and is defined as $P(A)$, the ratio of favorable outcomes to total outcomes, in the limit as the number of trials approaches infinity. However, when designing a new device, the underlying event space and the probability measure are not typically available, as the behavior of the system is often not fully understood a priori. The absence of sufficient data during the design phase underscores why probability is not an inherent design property but rather an empirical measure, which emerges only through observation and data collection over time. The need for large data sets for probability reckoning has been understood for centuries. The evolution over time can be modeled in the Kolmogorov probability space as $(\Omega, \mathcal{F}, \mathcal{F}_t, P)$, where $\mathcal{F}_t$ represents potential unforeseen future events. This distinction between theoretical probability and practical engineering analysis is particularly critical when designing protections for essential systems.

Although the mathematical foundation for probability provides a logical framework for assessing potential failures, engineers must depend on systematic approaches to address uncertainties during the design phase, such as those proposed by Tribus. Before finalizing a protection design, careful engineers with detailed knowledge of the system conduct a Failure Modes and Effects Analysis (FMEA). This process systematically asks, for each design element, "How can this element fail, and what would be the consequence of its failure on the performance of the protection system?" If, during the FMEA process, it is determined that an element's failure would result in the failure of the entire protection system, the design is revised to eliminate that failure mode. The FMEA is subsequently updated to reflect the new design. The final FMEA serves as a solid foundation for developing fault trees and event trees, both of which are crucial in forming the basis for the PRA of the design.

B Accident timing (Hazard Intensity)

Accidents in CNFRs are most likely to happen when triggered by an event arrival such as earthquake, high winds, flooding, terrorist attack, improper operation, and so forth. When such events arrive, the increased accident likelihood is termed "hazard intensity" and is assessed with the hazard function.

The hazard function describes the instantaneous rate of failure at any given time, provided that the system has survived up to that time. Mathematically, the hazard function $h(t)$ is expressed as:

$$h(t) = \frac{f(t)}{1 - F(t)},$$

where:

- $f(t)$ is the Probability Distribution Function (*pdf*) of the time until failure,
- $F(t)$ is the Cumulative Distribution Function (*cdf*) of the time until failure, defined as $F(t) = \int_0^t f(u)\,du$, and
- $1-F(t)$ is the survival function, representing the probability that the system survives beyond time t.

The hazard function is sometimes written as:

$$h(t) = \frac{f(t)}{S(t)},$$

where $S(t) = 1 - F(t)$ is the survival function.

The hazard function provides information on the instantaneous rate of an accident occurring at time t, given that no accident has occurred up to time t. It captures the time-varying nature of accident risks, which can be influenced by various external factors, such as environmental conditions or operational states.

The PRA methodology typically models event arrivals as Poisson processes, assuming a constant rate of occurrence over time. However, this approach may overlook significant temporal variations or clustering in event triggers, such as seasonal or environmental factors. For instance, certain events, like hurricanes, follow seasonal patterns, increasing the likelihood of accidents during specific times of the year. Similarly, seismic events are often accompanied by foreshocks and aftershocks around the mainshock. This necessitates CNFR operators to implement seasonal protective measures to mitigate accident risks related to hurricane events. It highlights as well the dynamic nature of accident risk in nuclear power plants, where certain periods or conditions may necessitate heightened readiness and protective measures to manage elevated hazard intensities.

C Disregard for the individual's exposure to harms

A primary concern is that risk quantification, when approached through a utilitarian lens, can overlook the moral hazards posed to individuals who may be exposed to the consequences of CNFR accidents. If regulations on protections are relaxed in legislation, Congress risks failing to account for the impacts on vulnerable individuals. If we deviate from or relax the prescriptive regulations on protections that can be argued to concern Congress and prompt legislative action, we risk ignoring the moral hazard posed to individuals who may be exposed to CNFR accident consequences. Moral hazard applies to a heterogeneous citizenry, c, indexed by individuals i. Each citizen may have varying susceptibilities to harm, depending on the nature of the hazards $h \in s$ and personal factors like proximity to the hazard, wealth, or health. That is, each individual may have one or more susceptibilities to harm such as investment in property, health effects from exposure to pollutants, chronic medical support, mobility, support from family, monetary wealth, proximity to the source of hazard, and so forth. With this in mind, consider implementing a level of protection, L, fairly to each citizen over the lifetime of a deployed CNFR,

$$\begin{aligned} &H(c_{i,h\in s(i)}, t) = L, \\ &0 \le t \le T, \end{aligned} \tag{1}$$

where t is time and T is the time horizon for the system operation that begins at $t = 0$. Ignoring the citizenry at large, a population center exposed to risk of harm from a particular hazardous technological system may contain from 1,000 to 50,000 citizens or more at various times, each having one or more susceptibilities. In a more complex but realistic setting, there may be more than one hazard source from a typical deployed technological system, such as particulate plus chemical species, and so forth. Realistically, dependencies often exist between different hazards and an individual's susceptibility, influenced by factors such as proximity to the hazard source and individual health conditions.

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