CONCEPT PAPER

Regulation of Rapid High-Volume Deployable Reactors in Remote Applications

Prepared by the Nuclear Energy Institute
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Executive Summary

Rapid high-volume deployable reactors are designs that are expected to be able to be deployed in timescales of months (rather than years as is the case for large light-water reactors and other advanced reactors), and in volumes of hundreds to thousands with deployment rates measured in number per days (rather than number per years as is the case for large light-water reactors and other advanced reactors). These technologies are being considered by numerous companies for a range of traditional electricity generation applications and use in industrial applications that also require heat such as oil & gas production and development, mining and extraction, and chemical processing.

This paper describes a notional business model (Technology Capabilities, Concept of Deployment and Operations, and the Concept of Regulation) that is being considered for such a class of reactors. This business model focuses on remote locations, with a particular focus on industrial applications, which is a subset of potential uses and is selected to focus on a smaller set of regulatory topics, and is not a necessary condition for all uses of technologies that could otherwise achieve many of the conditions described in this paper The paper also discusses the set of regulatory topics that are expected to need to be addressed to enable the new business model (problem statement and desired outcomes – derived from the resolution plans). While other business models and permutations are possible, it is believed this construct will be broadly applicable to the range of technologies and commercial strategies under development.

There has been considerable work by the NRC to prepare and modernize the regulatory framework to more appropriately address the advanced reactor technologies being developed. Much of this work would benefit rapid high-volume deployable reactors. However, the existing regulatory framework, including on-going work to modernize the framework for advanced reactors, does not currently permit the business model on the required timeframe that would enable hard to abate industries from decarbonizing their energy sources.

In order to achieve the rapid high-volume deployment of advanced reactors to meet the potential demand from these markets and applications, the following business case requirements are of particular focus:

1. Deployment in less than 180 days (6 months) from the time that the site is identified to the time that operations and energy production begins; and

2. Regulatory costs are less than 1% of the total costs, as measured by total up-front capital costs, and annual on-going operations and maintenance (O&M) costs.

Rapid high-volume deployable reactors are unlike current operating nuclear plants or other advanced small modular reactors. In fact, these designs are much more similar – in terms of size and source term – to non-power reactors (also known as research and test reactors) than they are to commercial power reactors. Nuclear technologies that are very small in size and source term enable new business models in three main ways: (1) they will utilize a high degree of factory construction; (2) the customers for smaller reactors may wish to be only energy users, not energy sellers; and (3) the reduced costs of these reactors allow a vendor to build them before receiving customer orders. Smaller reactors will require little, if any, on-site construction, and in some cases may be transported in a fully assembled configuration.

The rapid high-volume deployment business model is expected to include five stages of reactor deployment to the location of operation after the site has been selected that will enable a schedule of 180 days or less from the point of site selection to operation. The concept of deployment is dependent upon several milestones in the NRC process for the site license. Currently the NRC licensing process is complex, including many steps and features that would not be necessary for a rapid high-volume deployable reactor.

The concept of operations focuses on the activities to operate and maintain the reactor, the NRC oversight and inspection, and the annual O&M costs and the corresponding NRC regulatory costs. There are two primary concepts for the operation and maintenance of the rapid high-volume deployable reactors: 1) operations with on-site staff, and 2) operations with off-site staff located at a remote operations center. A key feature being designed into rapid high-volume deployable reactors is the ability to leverage automatic normal power control and automatic off-normal safety control. Rapid high-volume deployable reactors are being designed with very few or no moving components, and very few operational parameters needed to monitor the condition of the reactor. They are being designed such that the human operators will have access to the real-time status of monitored conditions, and will be able to take actions according to their operating procedures.

The characteristics and safety basis of rapid high-volume deployable reactors are expected to be fundamentally different from those of larger commercial power reactors, even as compared to advanced small modular reactors. Therefore, it would be appropriate to fully consider these novel aspects with an understanding that a fundamentally different regulatory approach may be appropriate. Such an alternative regulatory approach for rapid high-volume deployable reactors could be more effective and efficient in protecting the public health and safety.

The regulatory approach for rapid high-volume deployable reactors should be flexible and accommodate multiple approaches that may be taken by applicants in the licensing process and to demonstrate the safety basis. The most effective way to achieve this is through a regulatory framework that is performance-based with requirements that define the acceptable outcomes in terms of public health and safety, and in ways that are as objectively measurable as possible. There are several methods to do this that have been used successfully for approaches in the NRC current set of regulations, such as consequence-oriented and risk-informed approaches. A graded approach to applying requirements is appropriate, since rapid high-volume deployable reactors may have variations in their safety characteristics, and the alternative regulatory approaches may have applicability to other technologies, and concepts of deployment and operations. While the details of the technology characteristics, and concept of deployment and operations, will be needed for the NRC to fully review and approve license applications, the information within this concept document is expected to be sufficient for the NRC to develop an alternative regulatory approach for rapid high-volume deployable reactors.

The technology and business models for these types of designs are rapidly maturing and the first applications are expected to be submitted to the U.S. Nuclear Regulatory Commission (NRC) as early as 2024. Lack of clarity on an efficient and effective alternative regulatory framework will impede the work of designers to develop their technologies, and the potential owners to develop their concepts of deployment and operations. Therefore, it is the intent of this paper to inform the NRC staff's planned paper to the Commission, and the Commission's consideration of the regulatory topics for rapid high-volume deployable reactor business. This paper is written to capture the emerging concepts that are being developed into a more detailed and actionable proposal paper that is expected to be submitted to the NRC around the end of July 2024.

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1 INTRODUCTION

This section describes the purpose of the document, the relationship to prior work in this area, and the applicability of the concepts contained within.

1.1 Purpose

The purpose of this document is to establish the concept for the regulation of "Rapid High-Volume Deployable Reactors." The paper will describe a notional business model (Technology Capabilities, Concept of Deployment and Operations, and the Concept of Regulation) that is being considered for such a class of reactors. The paper will also discuss the set of regulatory topics that are expected to need to be addressed to address the new business model (problem statement and desired outcomes – derived from the resolution plans). This business model focuses on remote locations, with a particular focus on industrial applications, which is a subset of potential uses and is selected to focus on a smaller set of regulatory topics, and is not a necessary condition for all uses of technologies that could otherwise achieve many of the conditions described in this paper. While other business models and permutations are possible, it is believed this construct will be broadly applicable to the range of technologies and commercial strategies under development.

Rapid high-volume deployable reactors are designs that are expected to be able to be deployed in timescales of months (rather than years as is the case for large light-water reactors and other advanced reactors), and in volumes of hundreds to thousands with deployment rates measured in number per days (rather than number per years as is the case for large light-water reactors and other advanced reactors). The technology and business models for these types of designs are rapidly maturing, with many design vendors engaged in preapplication reviews, and the first applications for major licensing actions are expected to be submitted to the U.S. Nuclear Regulatory Commission (NRC) as early as 2024. These technologies are being considered by numerous companies for a range of traditional electricity generation applications and use in industrial applications that also require heat such as oil and gas production and development, mining and extraction, and chemical processing.

Potential customers in the markets with needs for rapid high-volume deployable reactors have expressed that the NRC licensing processes and impacts of regulation are the chief risks to meeting the business requirements and being a viable alternative for power generation needs. If the NRC licensing and regulatory risks are adequately addressed, then nuclear energy will, for the first time, be a viable option for many new end use cases, in particular for remote industrial applications. Furthermore, in addressing these licensing and regulatory risks in a way that enables the business model for remote applications may also introduce alternative approaches that could help to make the NRC regulatory framework more effective and efficient for other types of designs and use cases.

The scope of this report is to outline current thinking on the concept of rapid high-volume deployable reactor business models, including the capabilities of the technology, the concept of deployment and operations, and the regulatory considerations. This paper discusses regulatory policy and technical topics that are expected to need alternative approaches to enable a viable business model, most of which have either not been identified to-date, or have not fully considered the concepts in this paper.

Given the urgency and scale at which the market's power needs must be addressed, potential customers in these markets need to obtain clarity that there is a reasonable pathway to modernize the regulatory framework for these technologies and applications in ways that meet the business case requirements (as described in Section 2.1). Specifically, Shepherd Power, a company exploring the option of using rapid high-volume deployable reactors, has expressed the need for “sufficient clarity by the end of 2024 on a licensing pathway supporting scale micro-rector deployment.” This clarity could be provided by an NRC plan to pursue alternative regulatory approaches that provide resolution of the topics described in this document and achieve the necessary conditions for regulatory effectiveness and efficiency that enables the business case.

It is the intent of this paper to inform on-going work by the NRC to address this class of reactors in developing options for alternative approaches to achieve the goals for regulatory clarity by the end of 2024, and establish these alternative regulatory approaches to enable the business model by 2026. This paper also provides a foundation for an industry proposal for the regulation of rapid high-volume deployable reactors, that the Nuclear Energy Institute (NEI) anticipates submitting to the NRC around the end of July. NEI anticipates that NRC public workshops to discuss these topics in more detail would foster mutual understanding and transparency to all stakeholders yielding more timely and well-considered alternative regulatory approaches.

1.2 Background

There has been considerable work by the NRC to prepare and modernize the regulatory framework to more appropriately address the advanced reactor technologies being developed. Much of this work would benefit rapid high-volume deployable reactors. Some of the more specifically applicable work has been associated with micro-reactors and manufacturing licenses. The following is a listing of some of the key documents from the NRC and NEI that help to address the regulatory needs of this new class of reactors – rapid high-volume deployable reactors.

- NRC SECY-24-0008, “Micro-Reactor Licensing and Deployment Considerations: Fuel Loading and Operational Testing at a Factory” (ML23207A252)
- NRC White Paper, “Micro-reactors licensing strategies” (ML21235A418)
- NEI 2021 Paper, “Manufacturing License Considerations” (ML21197A103)
- NRC SRM-SECY-23-0021, “Proposed Rule: Risk-Informed Technology-Inclusive Regulatory Framework for Advanced Reactors” (ML24064A039)
- NEI Comprehensive Comments on Part 53 (ML22243A257 – 8/31/22) and (ML21309A578 – 11/5/21)
- NRC SECY-20-0093, “Policy and Licensing Considerations Related to Micro-Reactors” (ML20254A363)
- NEI 2019 Paper, “Micro-Reactor Regulatory Issues” (ML19319C497)

This paper identifies a set of 31 regulatory topics that are expected to need alternative regulatory approaches for rapid high-volume deployable reactors in remote applications. Of the roughly 22 regulatory topics identified to date in the above key documents, about 16 are also included in the list of 31 topics. Thus, there are about 15 new topics that have not previously been identified as potentially needing alternative regulatory approaches. Furthermore, of the 16 previously identified topics that are included in this paper, most of those have not sufficiently considered the technology or concepts of deployment and operations for rapid high-volume deployable reactors. Therefore, there is significant scope of regulatory consideration, beyond what has previously been considered, that is needed to potentially enable these business models.

1.3 Applicability

This paper is focused on the use of rapid high-volume deployable reactors in remote applications, primarily in consideration of industrial applications. This is a subset of the types of advanced reactors being developed, and the intended use cases for the variety of nuclear technologies. Typically, nuclear technologies are categorized by size (e.g., large, small and micro), in terms of thermal power rating, land use, mass and volume dimensions of the reactor system, etc., or by moderator type (e.g., light-water reactors, and non-water cooled – including high temperature gas, liquid metal and molten salt). It is anticipated that rapid high-volume deployable reactors will be a subset of the advanced reactors that are small in size and source term. While many may call these micro-reactors, which the Idaho National Laboratory (INL) taxonomic guide[1] defines as less than 50 MWe in size, there may be some micro-reactors that are not capable of meeting the conditions for rapid high-volume deployment and there may be some designs that are not micro-reactors that could meet those conditions. Similarly, many types of reactors could be used for remote applications, and rapid high-volume reactors could be used for applications that are not in remote locations. Figure 1-1 is a simple depiction of the focused scope of this paper within the broader environment of nuclear reactors.

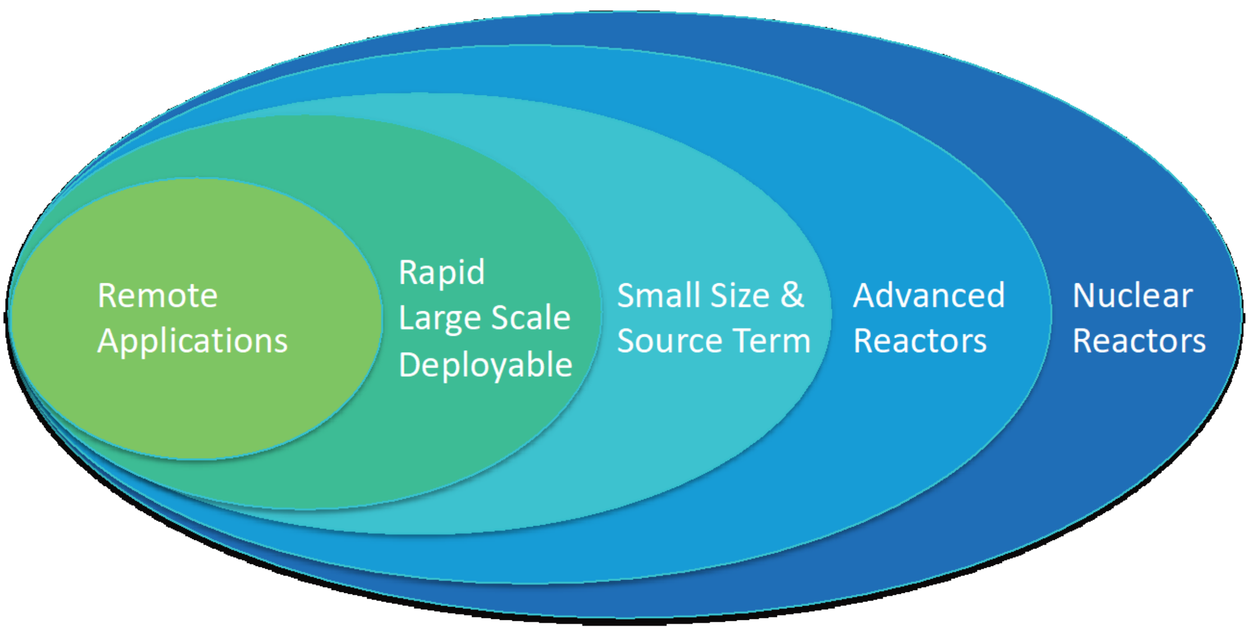

Figure 1-1: Applicability of the Regulatory Approaches for Rapid High-volume Deployable Reactors

The focused scope of rapid high-volume deployable reactors in remote applications is chosen in order to provide a focus for developing alternative regulatory approaches, since it has a well-defined business model, with concept of deployment and operations, that require technological capabilities that can be specified in sufficient detail. The resulting firm understanding of the business model enable the clarity needed to consider alternative regulatory approaches. However, it is important to recognize that these

[1] https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_64448.pdf

alternatives could be applicable beyond the specific business model discussed within this paper, and the broader applicability should be considered as alternative approaches are developed.

2 BUSINESS MODEL

This section discusses the business model for commercial deployment of this reactor class, which is established to meet the market and customer business case requirements. The business model includes three major components that are interrelated and must be developed in an integrated manner with the objective of achieving the business requirements. These three elements are: 1) the characteristics of the technology, 2) the concept of deployment and operations, and 3) the regulatory paradigm, which includes the regulatory framework and the statutory requirements that the regulatory framework is designed to implement.

The approaches discussed in this section reflect approaches that are being developed for a novel business model. It is noted that the current NRC regulatory framework does not currently enable this business model, and therefore Section 3 is included to discuss concepts for an alternative regulatory framework that would enable this business model.

2.1 Market and Customer Business Case Requirements

Many advanced reactors are being designed for rapid high-volume deployment that are well suited to serve the power needs for several markets that currently do not have access to clean, reliable, resilient and affordable energy. Many of these markets are in remote locations, such as oil and gas upstream operations, mining operations, and communities in the arctic and on islands. These locations are characterized by no or limited access to grid-based power supplies, distance from population centers, limited access to human and technical resources, and challenging logistic considerations for access to and from the end user's energy need.

These rapid high-volume deployable advanced reactors are also an option to power secure micro-grids for critical infrastructure such as defense installations and emergency response facilities, some of which may be in densely populated areas. This paper focuses remote applications, such that potential alternatives to population siting criteria, e.g., population density distance and population center distance, and considerations for integration with the electric grid, are not considered. Therefore, all of the proposed approaches are also applicable to non-remote applications, although non-remote applications may also have additional considerations such as population siting requirements. Industrial applications are also given special consideration in that the co-location of advanced reactors with industrial facilities that they serve creates new possibilities (e.g., potential to leverage the industrial facility's infrastructure and workforce). Where appropriate, the regulatory approaches discuss the special considerations of co-location with industrial applications. Co-location could either be reactor siting within the footprint of an existing industrial application or locating in a footprint directly adjacent to the application; both arrangements consider the possible impacts between facilities due to proximity. Furthermore, many of the proposed approaches could also be applicable to advanced reactors that follow the traditional deployment models and tend to be larger in size than the reactors that are rapid high-volume deployable, and for those regulatory topics this broader applicability is noted.

Rapid high-volume deployable advanced reactors operate at temperatures that can attractively produce both electricity and usable heat (cogeneration), or can be used exclusively to provide one or the other. The electricity or high-temperature heat from these reactors can also be used to desalinate and purify water, and to generate hydrogen. Heat can be used for industrial applications such as oil refining and chemical processing, and in colder climates, can be used for district heating of homes and businesses. The use of these reactors to produce heat for industrial processes or district heating can improve the utilization of the reactor in applications with variable demand for electricity, thus increasing the market potential for these reactors.

Rapid high-volume deployable advanced reactors are being designed to demonstrate resilience and protection against severe natural phenomena as well as man-made physical and cyber security threats, with the ability to operate in island-mode and to have black-start capabilities, which means they can initiate recovery from a loss of power to the site. These reactors can produce power on-demand, operate independent of weather conditions, and include the ability to automatically vary their power output to match changes in demand. Thus, these reactors are an ideal generation source for uses that need to operate independently from the electric grid to supply highly resilient power for critical loads under normal and emergency conditions.

The market potential for rapid high-volume deployable advanced reactors is very large. While a comprehensive market opportunity study has not been published, some estimate that the market size could be in the several hundreds to tens of thousands (multiple 10,000s) units operational by 2050. These markets and applications need rapid high-volume deployable advanced reactors in order to decarbonize their operations, while providing reliable, resilient, safe and affordable energy. These markets are looking for energy sources that are reliable, affordable and clean. In order to achieve the rapid high-volume deployment of advanced reactors to meet the potential demand from these markets and applications, the following business case requirements are of particular focus:

1. Deployment in less than 180 days (6 months) from the time that the site is identified to the time that operations and energy production begins; and

2. Regulatory costs are less than 1% of the total costs, as measured by total up-front capital costs, and annual on-going operations and maintenance (O&M) costs.

While other conditions may exist that enable such a deployment scenario, the business case requirements provide an initial bounding set of constraints within which business, logistic, regulatory, and operational activities must be accomplished.

2.2 Technology Description

Markets and customers that need rapid high-volume deployable energy generation sources have technology options. This section describes the rapid high-volume deployable reactors that and the other technologies that they are considering.

2.2.1 Rapid High-volume Deployable Nuclear Reactors

Rapid high-volume deployable reactors are likely to be very small, in comparison with other advanced reactors. For example, micro-reactors are typically in the 2 MW-thermal to 50 MW-thermal range with some designs being even larger or slightly smaller. This power output, a reflection on the potential source term, is 100 to 1,000 times smaller than a typical large light water reactor, and about 10 to 100 times smaller than advanced SMRs. Rapid deployable high-volume reactors are being designed to be small enough to fit on the back of a tractor trailer, potentially including not just the reactor itself, but also the power conversion system. When placed in the operating location, these reactors can be housed inside buildings with footprints measured in thousands of square feet.

Rapid high-volume deployable reactors have a unique combination of design attributes that make this class of reactors differentiated in their concept of deployment and operations. The following are typical characteristics of rapid high-volume deployable reactors, though it is noted that not all reactors have all of these characteristics:

- Lower power rating on the order of single or tens of MW thermal;
- Smaller physical dimensions and weights when assembled;
- Designed for transportability as an integrated system or packages of systems;
- Require minimal assembly at the end-user's operating site;
- Modularized systems and components that can be fabricated, assembled, and tested in factory settings at a high degree of standardization;
- Passive and inherent means of performing safety and protection functions;
- Reduced complexity and improved operability to enable reduced or no human interaction or interventions;
- Smaller site footprints and deployment/operational impacts on the environment;
- Resilience to external hazards that ensures higher reliability in operation and large margins to safety;
- Designed for progressive scale-up in deployments with multiple units at a site possible;
- Capable of delivery, emplacement, commissioning, and transition to operation on the order of weeks or less;
- Reduced or limited hazards that could affect workers, the public and the environment;
- Potential to fuel reactor modules at the factory; and
- Designed for removal of used systems at the end-of-life to reduce or eliminate the need for extended onsite storage.

Rapid high-volume deployable reactors are unlike current operating nuclear plants or other advanced small modular reactors. In fact, these designs are much more similar – in terms of size and source term – to non-power reactors (also known as research and test reactors) than they are to commercial power reactors. However, unlike the non-power reactors that operate safely today, this class of reactors is being designed with enhancements to further protect the public health and safety based on advancements in technology, and safety and security design approaches.

Nuclear technologies that are very small in size and source term enable new business models in three main ways: (1) they will utilize a high degree of factory construction; (2) the customers for smaller reactors may wish to be only energy users, not energy sellers; and (3) the reduced costs of these reactors allow a vendor to build them before receiving customer orders. Smaller reactors will require little, if any, on-site construction, and in some cases may be transported in a fully assembled configuration. For customers that wish to be only energy users, the advanced reactor developers also may be the reactor owners and operators, supplying energy under power purchase agreement. Having pre-fabricated reactors ready to ship as soon as an order is placed would significantly reduce time to market, a key consideration for many customers.

Micro-reactors can produce power on-demand and operate 24/7, 365 days a year. Micro-reactors are being designed to protect against severe natural phenomena as well as man-made physical and cyber security threats, and many are being designed with the ability to operate in island-mode and to have black-start capabilities, which means they can initiate recovery from a loss of power to the site. Thus, micro-reactors are an ideal generation source for uses that need to operate independently from the electric grid to supply highly resilient power for critical loads under normal and emergency conditions.

The operations and maintenance of micro-reactors are expected to be highly simplified through the use of automatic and/or remote operations/monitoring, the minimization of structures, systems and components (SSCs), and the maximization of the reliance on inherent and passive safety features. Micro-reactors can include the ability to vary their power output to match changes in demand. This attribute makes micro-reactors suitable to serve changing loads and compatible with intermittent sources of energy like renewables.

Micro-reactors are well suited to serve the power needs for several markets that currently do not have access to clean, reliable, resilient and affordable energy. Many of these markets are in remote areas, such as arctic communities, island communities, and mining operations. However, micro-reactors are also an option to power secure micro-grids for critical infrastructure such as defense installations and emergency response facilities, some of which may be in densely populated areas.

Micro-reactors that offer high reactor outlet temperatures can produce both electricity and heat, or can be used exclusively to provide one or the other. The electricity or high-temperature heat from a micro-reactor can also be used to desalinate and purify water, and to generate hydrogen. Heat can be used for industrial applications such as oil and gas extraction and mining, and in colder climates, can be used for district heating of homes and businesses. The use of micro-reactors to produce heat for industrial processes or district heating can improve the utilization of the micro-reactor in areas with variable demand for electricity, thus increasing the market demand for micro-reactors.

Rapid high-volume deployable reactors are being developed to achieve the following general objective:

> **Prospective Manufacture of Reactor Modules without a Customer Order** – In the past, some SMR developers have discussed manufacturing reactor modules prospectively and storing those modules until a specific customer (and hence a host site) is identified. The NRC's current Part 50/52 regulations permit such an approach under an ML, although we encourage the NRC to clarify its position regarding the ability of a DC or SDA holder to prospectively manufacture reactor modules prior to receiving an order from a customer either with a license or that has

applied for one (COL or CP).[2] Regardless, this paper discusses options for the Part 53 ML requirements to ensure that an ML is a possible pathway to prospectively manufacture reactor modules up to and including fully assembled reactors.

Fully Assemble an Operable Reactor at the Factory – Some advanced reactor developers, especially micro-reactor developers, will fully assemble the reactor at the factory. In this context, "fully assemble" means the assembly of all the structures, systems and components of an operable reactor module, excluding reactor fuel. If a particular reactor requires a significant amount of on-site construction before the reactor could operate, then it would not meet the definition of "fully assembled." Thus, the developer may become the ML holder and be responsible for the factory fabrication and assembly activities. Alternatively, the developer may contract with an appropriate manufacturer who will manufacture and assemble the reactor, i.e., "build to print." The details of which entity (developer or manufacturer) would be the ML holder would be addressed through contractual arrangements and application to the NRC for the ML. We emphasize that in this scenario, there would be no fuel loaded into the reactor and, in fact, there would not be any fuel at the factory.

This approach would allow the licensee to own or control (e.g., through subcontracts) all necessary facilities for the manufacture and testing (unfueled) of the reactor. (These facilities may or may not be co-located.) Assembly in a factory setting would support conducting ITAAC or ITAAC-like inspections and tests to ensure the reactor has been fabricated and assembled consistent with the license and applicable regulations. Security requirements for these facilities would be consistent with security for commercial manufacturing facilities supporting the nuclear industry. Fitness for duty requirements also would be consistent with those used in commercial manufacturing facilities.

Some designs are being developed with the capabilities to load, remove and reload fuel at the operations site. Designs that are not including the capability to load, remove and reload fuel at the operations site are being developed with the following capabilities.

Fuel a Fully-Assembled Reactor at the Factory – While not feasible for large reactors, fully assembling and fueling a reactor module at the factory is envisioned for a transportable reactor, e.g., a micro reactor, which eliminates onsite fueling. This activity can be performed under a Part 70 *possession license*, which may draw in other requirements, e.g., Parts 26, 30, 40, 70, 73, 74 and 75, etc., under which the primary function is to assure radiological safety and that the reactor is maintained subcritical at all times. Performing reactor fueling at the factory would be more efficient for reactors that are manufactured in large numbers and reduce the burden of doing these activities in numerous remote locations. This activity is separated from critical testing at the factory and transporting a fueled reactor to the operating site (separate activities described below).

Transporting a Fueled Reactor from the Factory – Some companies may wish to transport a fueled reactor to the site at which it will be operated. This will trigger other requirements, including those in 10 CFR Part 71. The developer may wish to transport the fueled reactor by barge, rail, truck, and possibly by air. The transport of a fueled reactor is intended to reduce field fueling activities and risks, and to eliminate or minimize the amount of testing and

[2] It is noted that the NRC's exception to ASME N-883 may prevent these activities even though they are permitted by regulation. See ML21208A44.

inspection required at the operating location to facilitate more rapid reactor deployment. For those situations where the ML holder also is the OL/COL holder, control of the reactor once it is at the approved site (including any storage before installation) would be consistent with the terms of the respective licenses. The OL/COL would govern any interim storage of the reactor on the approved operating site and related security requirements. If the ML holder and OL/COL holder are different entities, then provisions for transferring control of the reactor from the ML holder to the OL/COL holder would be addressed by contractual agreement. The ML holder would be required to ensure the safety and security of the reactor until control of the reactor is transitioned to the OL/COL holder. Any interim storage site, if different from the approved operating site, would require prior approval by the NRC based on relevant safety, security, and environmental considerations.

Defueling and Refurbishing Operated Reactor at a Factory – Some developers (especially those that pursue a multiple location approach) may want to return the reactor to a refurbishment center to enable fuel reloads and reuse of SSCs that have a design life greater than the fuel cycle and remain operable. For example, reactor modules that may be returned to the refurbishment center, refueled and returned to the original operating site or transported to a different operating site. This scenario could also contemplate reactor modules that are leased for use (e.g., for emergency response operations). This scenario raises regulatory issues associated with the transport of a reactor containing used fuel. The refurbishment center may or may not be the original factory at which the reactor was assembled. The refurbishment center likely would remove the used fuel and reload with new fuel. (Note that some designs have fuel that will last 10 to 20 years before refueling is required.) However, there may be some approaches that involve fuel unloading and loading at the operating location. The refurbishment center may also perform routine reactor maintenance, but doing so would be pursuant to the OL/COL, not an ML. For refurbishment centers that remove used fuel, interim storage of used fuel may be necessary, although this would be governed by a Part 72 license and not part of the ML. Finally, the refurbishment center might decommission the reactor. While the refurbishment center concept offers a number of advantages, some organizations may choose a more traditional approach, whereby the reactor would be defueled and decommissioned at the operating site, and the used fuel and defueled reactor would be transported offsite. These options should be available to the OL/COL holder.

Some designs are being developed with the capabilities to perform criticality and power ascension testing at operations site. Designs that are not including the capability to perform criticality and power ascension testing at operations site at the operations site are being developed with the following capabilities. Some designs are also being developed to be relocatable from site to site.

Testing a Fully-Assembled Reactor at the Factory – After fully assembling an operable reactor module at the factory, some developers may wish to perform critical (i.e., zero-power physics) and/or some degree of power ascension testing (also termed operational testing). We distinguish this activity from the above-described activities, which do not include control manipulation and criticality testing. Enabling this type of testing would clearly require significant changes from the existing regulatory framework and facilities, controls, and oversight. In fact, under the current regulatory framework, such activities generally require a utilization facility license, since the criticality prevention requirements for a Part 70 possession license (which governs the licensing of special nuclear material) would specifically preclude this type of testing. Thus, this activity would need the utilization license to either be included with the ML or obtained through a separate and limited Part 53 operating license. Fueling and testing a reactor involves a number of NRC regulations, which may include Parts 26, 30, 40, 55, 70, 73, 74 and 75. The benefit of performing fueled criticality tests at the factory is that such tests could be performed more efficiently for reactors that are manufactured in large numbers, thereby reducing the burden of doing these activities at numerous separate locations. Past precedent for these kinds of activities exists through the use of test reactor or critical experiment licenses.

Testing in a factory setting also would permit addressing ITAAC or ITAAC-like testing and inspection requirements. Performing these ITAAC or ITAAC-like tests and inspections, combined with those that would be conducted in fully assembling the reactor, would reduce the scope of on-site inspection and testing activities. These activities may be needed for the first unit, first several units, or for each unit to address an ITAAC or ITAAC-like testing or inspection requirement. This activity is separated from transporting a fueled reactor to a site (see discussion above), since some developers may wish to do fueled testing at the factory but not transport a fueled reactor (due to the desire to streamline transportation or to keep only a single set of fuel on-site that is used to test multiple reactors). Another option would be to fuel the reactor at the factory but not perform any criticality or power ascension testing, deferring that testing until after the reactor has been installed at the approved site.

Multiple Operating Locations – Developers of advanced reactors that require very little site infrastructure to operate may want the ability to move the reactor to an alternate site one or more times during the lifetime of the reactor: a mobile nuclear power plant versus a stationary power plant. For example, a micro-reactor that could be operated for 60 years might operate at mining site X for 30 years, and then be moved to mining site Y to operate for an additional 30 years. In another case, the micro-reactor might be moved to a new location every 5 years. This "Multiple Location" scenario would incorporate site-specific licensing actions and transportation between sites. Some scenarios that would envision using micro-reactors for multiple operating locations, like emergency response purposes, will likely need even shorter deployment timelines than those considered in this concept paper.

2.2.2 Alternative Technologies

The market and customers have other options beyond nuclear for electric power, heat generation, and overall reductions in their carbon footprints. These include:

Fossil Fuels – Diesel generators and natural gas plants have traditionally, and currently, been used to provide heat and electricity to remote applications. The challenge with these technologies is the increasing requirements to decarbonize the energy sources by the end-users, coupled with the difficulty and costs of making these sources zero carbon-emitting. Notably, there is some uncertainty regarding the total system costs and effectiveness of abatement technologies such as carbon capture, utilization, and storage. Thus, many of the remote applications are motivated to consider nuclear energy in response to plans to move away from fossil fuel generation. Many end users in the industrial application market have experience with the timeliness and schedule confidence associated with permitting requirements for fossil fuel-based generation sources (e.g., air or water use permits by state and/or federal authorities) that are different than those associated with nuclear power and informed the business requirements defined earlier in this paper.

Renewables – Wind and solar have become some of the lowest cost options in the market, but do not provide the reliability that is needed for remote applications. Adding battery backup (or other energy storage features) and overbuilding capacity to provide the desired levels of reliability appear to be cost prohibitive. Furthermore, the land use needed to achieve the needed reliability appear to also be unfeasible due to constraints on land availability and/or environmental impacts. Geothermal is a promising technology, but is still emerging, with unknown costs and reliability, and geographic limitations on where it could be deployed. While the permitting regime for renewables is different than for fossil fuel-based generation, there are elements of renewable deployment that informed the business requirements defined earlier and could make nuclear energy a more acceptable and attractive solution for their needs.

In comparison with these alternatives, nuclear energy meets more of the market and customer business requirements for be clean, reliable, resilient, safe, timely and cost-effective energy solution.

2.3 Concept of Deployment

The concept of deployment focuses on the timeline for deployment and logistics activities that occur leading to site identification and the subsequent activities leading to commercial operations. This section describes the interfaces of the corresponding NRC licensing process, including the corresponding NRC regulatory costs and timelines.

2.3.1 Deployment Stages and Schedule

The deployment timeline for a rapid high-volume deployable reactor is expected to achieve the 180 day or less business case requirement.

<u>Prior to Site Selection</u>

The rapid high-volume deployment business model is expected to include four major features that will enable a schedule of 180 days or less from the point of site selection to operation. These are:

Fully Manufacturable Reactor – The reactor is capable of being fully manufactured prior to identification of the operating site and submittal of the site license applications. A fully manufactured reactor will utilize the NRC's Manufacturing License (ML) or Design Certification (DC) processes, and is enabled by designs for which the reactor and primary systems (i.e., nuclear island) are self-contained and able to be transported as a single unit to the site. Some designs may be fueled and made fully operational at the factory, while other designs may be able to be fueled and made operational at the site during the emplacement and commissioning activities. See Section 2.2.1 for more details on the technology description. It is presumed that any manufacturing, assembly, and integration activities to be executed in a factory setting will be completed within an acceptable timeframe to support the logistics for transport and emplacement at the operating site per schedule (i.e., hold points, approvals, etc., fit within or are not constrained by the 180-day deployment target).

Site Independence – The characteristics of these designs that enable rapid deployment are described in Section 2.2.1, and are expected to enable the NRC safety and environmental reviews to be completed prior to the selection of specific sites in a generic manner and to a broadly bounding site parameter envelope. In this way, the NRC review is a confirmation of a specific site utilizing the approved design focused on a verification that the site characteristics conform to the conditions of the approved design, without the introduction of any new or unreviewed safety or environmental considerations.

Use-Case Independence – The characteristics of the design are also expected to enable the NRC safety and environmental reviews to be completed prior to the identification of the specific use-case. A use-case is defined by the type of energy product(s) produced (e.g., electricity, heat, hydrogen, or a combination) and the specific use of those energy products (e.g., oil and gas extraction, mining operations, military installation resilient power). This approach will establish in the design approval the conditions for separating the safety and environmental impacts of the scope that requires NRC approval (i.e., nuclear island) from the scope that does not require NRC approval (i.e., energy island). In this way, the NRC review of the specific use-case in the site license application may be focused on a verification that the site conforms to the conditions of the approved design, without the introduction of any new or unreviewed safety or environmental considerations.

Site Selection Process – The site selection process for the rapid high-volume deployment model is expected to facilitate 1) the fabrication of the fully-manufacturable reactor prior to site selection, and 2) pre-application interactions with the NRC for the site license application. As an example for the oil and gas up-stream extraction use-case, there would be a down-selection from a wide range of potential sites to the specific site over several to many months prior to the site-selection decision. In this example, while it is known that generally there will be future deployments in the Permian Basin the site locations and timing of those locations are not known today. Approximately 18 to 24 months or more prior to site selection, the Sub-Basin (still a large area) will be selected for business operations and at this time the future need for power would be known, such that the ordering of long-lead materials may begin. At least 12 months before the site selection, the Field (a much smaller area) will be selected which will enable collection of site characterization information (e.g., core borings) leading up to a specific site being identified (exact footprint).

This concept of deployment can facilitate pre-application interactions with the NRC, if necessary (e.g., Owner or Field that has not previously been licensed by the NRC). For owners and/or general locations that have previously been licensed (i.e., site characteristics similar to those previously licensed for the design) it is expected that pre-application interactions can be limited to a notification of intent that informs the NRC of the plans for deployment, including the owner, general location, design and schedule so that the NRC can plan resources. Some owners may have a long term plan for rapid high-volume deployments of reactors that they will share with the NRC to facilitate even longer range planning of NRC resources to review multiple site licenses, or possibly even to approve a general area license for which the specific site can be identified and reported to the NRC later as part of a license condition.

Figure 2-1 shows the timelines for the site selection process, and the relationship with the NRC approval of the design and site.

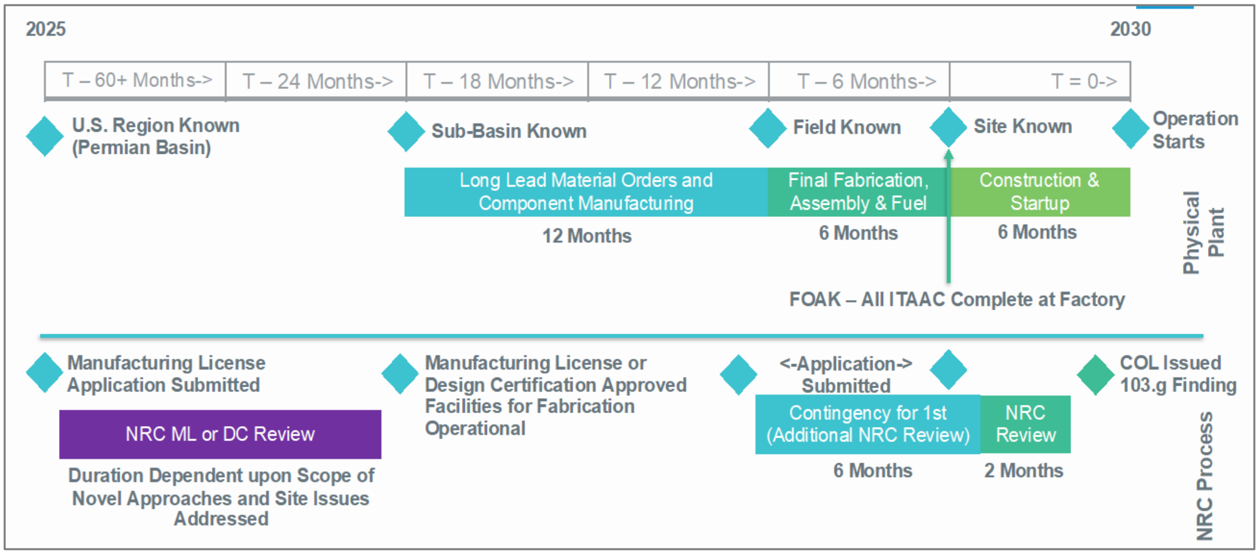

Figure 2-1: Reactor Manufacturing and Site Selection Process

<u>After Site Selection</u>

The rapid high-volume deployment business model is expected to include five stages of reactor deployment to the location of operation after the site has been selected that will enable a schedule of 180 days or less from the point of site selection to operation. These are:

Mobilization and Site Characterization (1 month) – Once the site has been selected the owner will immediately begin to mobilize site operations to execute local characterization activities for the site-specific design finalization, and to confirm that the site conditions are in conformance with the conditions of the approved design (ML or DC). Most site characterization data is expected to come from reliable generally and readily available data (e.g., USGS and NOAA) or from other specifically collected data from the site exploration activities that occurred during the site selection process. For industrial sites, such as oil and gas extraction, there may be a significant amount of data from geological investigations for the chosen site that were performed during exploration. Therefore, site characterization, which traditionally has taken 24 months or more, is expected to be possible in 1 month or less for rapid high-volume deployable reactors. The mobilization is also expected to bring equipment to the site that will be used to prepare the site for assembly of the structures.

Site Preparation (1 month) – Site preparation includes any site grading and earth works to prepare the site for the assembly of the site structures. This work would not require NRC prior-approval to perform since it would not have any impact to the NRC safety and environmental considerations in the design approval (ML or DC). Site preparation would include preparing a site assembly lay-down area and the pre-staging of the structural modules and other materials used for the site structures, some of which may be safety-related. This scope is intended to be within the existing definitions of preconstruction.

Site Assembly (2 months) – There are expected to be very few site structures (e.g., concrete pads and buildings) which are also expected to be very simply and modular in nature, such that they could be assembled in 2 months or less. It is expected that the approved design (ML or DC) would have a safety design such that much of the structures would not be safety-related. It is also expected that the NRC approval of the design would approve safety-related site assembly, and delivery and emplacement of the reactor at the site (e.g., a general Limited Work Authorization). In this way, the NRC approved design (ML or DC) would include conditions that the applicant would demonstrate in the site license application, the NRC would verify during the application acceptance review, and the NRC would grant a specific LWA for the site when the application is accepted and docketed.

Delivery and Emplacement (1 month) – After the site structures are assembled, the reactor will be delivered to the site and emplaced in its location. Emplacement includes the separate and integrated systems testing that enables transfer of control from "construction to operations," and the pre-operational testing (hot functional test), which verify that the reactor has been installed correctly and are able to operate according to the NRC design approval (ML or DC). There may be considerable variability in how designs establish their structures and the emplacement of the reactor. Some designs may have an above-ground building with the reactor delivered on a skid that is bolted on a concrete pad, other designs may emplace the reactor below-grade on a pedestal, other designs may deliver a reactor that will remain in the ISO-container in which it was shipped without a surrounding building, and there could be many other variations in the design of the site structures. All designs are expected to deliver the reactor; that includes all systems and components included in the nuclear island in a single truck shipment. Some designs may include the energy island (energy conversion system) and control and monitoring system on the same truck that delivers the reactor, while other designs may have separate modules that are delivered on multiple trucks. While there is room for considerable design variations, in all cases, it is expected that the delivery and emplacement of the reactor will be simple and quick, requiring very little site infrastructure to support lifting, moving and emplacement activities.

Commission and Startup (1 month) – Once the NRC gives final approval and authorization to operate the reactor, the licensee may begin the commissioning and startup of the reactor. These activities focus on fuel loading and start-up testing. Some designs will be delivered with the reactors fueled, and other designs will fuel the reactor on site after emplacement. For designs delivered with fuel loaded, the commissioning activities will include the removal of any components that were installed at the factory to prevent criticality. For designs that are to be fueled at the site, the commissioning activities will include fuel loading. The start-up testing is focused on the testing for nuclear physics and power output, such as criticality, low power and power levels greater than 5% of total rated power. The commissioning will test the operation of the controls (including automatic, and remote monitoring and operation) and protection equipment to verify that they operate consistent with the approved design. Commissioning will also obtain any data needed to calibrate the instrumentation and control system, and verify operations withing the technical specifications. Once the commissioning and startup tests are complete, the reactor may be used for full operations and delivery of the energy products for the intended use-case. While the commissioning and startup traditionally has taken around 6 months, it is expected that rapid high-volume deployable reactors can perform these activities in less than 1 month due to their small size and simplicity.

Figure 2-2 shows the timelines from the point of site selection to operations, and the relationship with the NRC approval of the design and site.

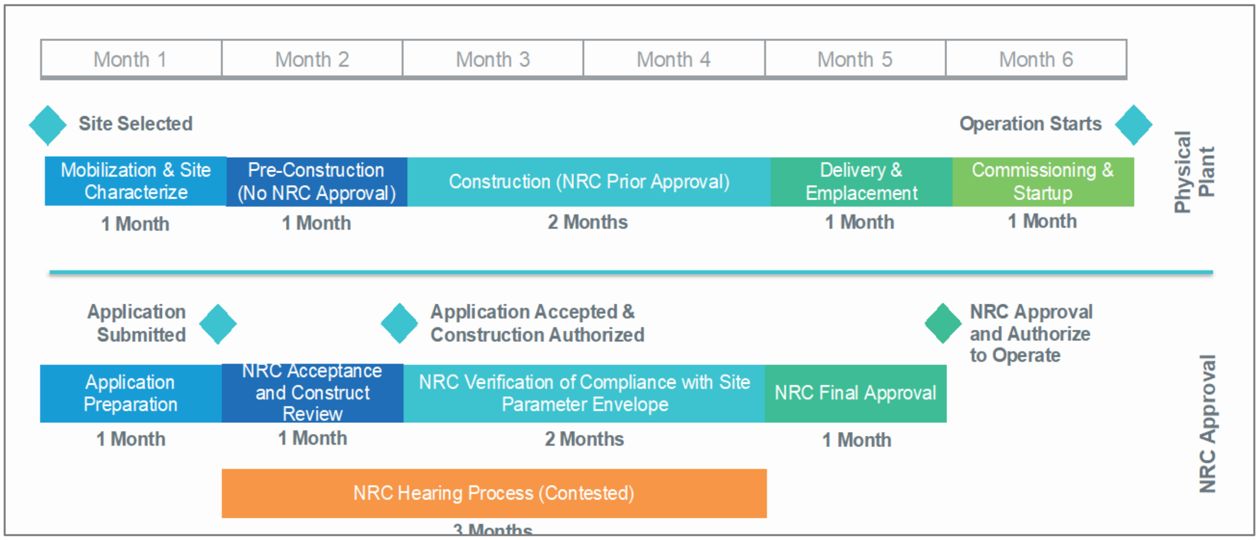

Figure 2-2: Site Selection and Deployment Process

2.3.2 NRC Licensing

The concept of deployment is dependent upon several milestones in the NRC process for the site license. Currently the NRC licensing process is complex, including many steps and features that would not be necessary for a rapid high-volume deployable reactor. The following are the major considerations of a licensing process for this business model, with the details of the simplification of the NRC licensing process described in Section 3, and several of the identified Regulatory Topics. The following illustrates the licensing process that is expected to be enabled by rapid high-volume deployable reactors, and which will be needed for reactors that could be deployed in the 100s per year, in order to ensure that the NRC reviews are effective and efficient, in that they provide reasonable assurance of adequate protection of the public health and safety while applying resources to the most safety significant activities regulated by the NRC. As technology continues to improve, there is a potential that the use of AI could enable the applicant and NRC to more effectively and efficiently prepare, review and approve applications.

Application Preparation and Pre-Application Engagement (1 month) – The preparation of the application has traditionally taken 12 to 24 months, and is expected to take 1 month or less for rapid high-volume deployable reactors. The major factor for the schedule reduction is that the design approval (ML or DC) is expected to address the safety and environmental considerations, establishing a site parameter envelope for the conditions that must be met by the site. In this manner, the design approval would have already performed the safety and environmental analyses necessary for a site that conforms to the site parameter envelope. Furthermore, these analyses depend on site specific characterization data (such as 2 years of weather data) in order to be completed. Thus, it is the site characterization, and site-specific safety and environmental analyses that require most of the traditional 12 to 24 months. Moving almost all of these activities into the design approval greatly reduces the scope and volume of information in the site-specific application. Most site characterization data is expected to come from reliable generally available data (e.g., USGS and NOAA) or from other specifically collected data from the site exploration activities that occurred during the site selection process. A site license application that focuses on the verification of conformance to the already established site parameter envelope in the design approval will avoid the need for additional site specific safety and environmental analyses. It is expected that pre-application engagement could be completed within this month to facilitate the 4 months or less (possibly as little as 2 months) for the NRC to perform the acceptance review, verification review and issuance of the license. Therefore, the application preparation for rapid high-volume deployable reactors can be completed in less than a month.

NRC Acceptance Review (1 month) – The NRC has established a target for a 3 month application acceptance review, which begins upon NRC receipt of the application and concludes with the NRC acceptance and docketing of the application, and is expected to take 1 month or less (possibly as little as 15 days for applications for a licensee or site previously approved by the NRC) for rapid high-volume deployable reactors.[3] An application for a site license for a rapid high-volume deployable reactor is expected to be focused on the verification of conformance to the site parameter envelope in the design approval. Therefore, it is expected to deviate from the traditional site-specific license applications for which the NRC has established a 3 month schedule, since a site license application for a rapid high-volume deployable reactor will 1) have had the safety and environmental considerations previously reviewed and approved by the NRC as part of the design approval (ML or DC), 2) not introduce any new or unreviewed safety or environmental considerations, and (therefore) 3) likely be less than 100 pages, whereas typical applications are 6,000 to over 10,000 pages. The NRC receipt of the application would also initiate the NRC Contested Hearing Process, which given the nature of verification of conformance to the safety and environmental considerations included in the previously approved design, can be expedited and simplified, to enable it to be completed at the same time, or within 7 days after, the NRC Verification Review is completed. As noted above, the applicant will be performing site preparation (not requiring NRC prior approval) during this phase, and the NRC acceptance and docketing of the application will include authorization to perform safety-related assembly, delivery and emplacement (e.g., through a generic Limited Work Authorization included in the design approval).

NRC Verification Review (2 months) – The NRC has established a Generic Review Schedule[4] of 30 months for a Combined Operating License (Part 52), and 36 to 42 months for an Operating License (Part 52). Recently, the NRC completed the Kairos Power Hermes construction permit review (safety and environmental) in 14 months. However, it is expected that the NRC review can be performed in 2 months or less (possibly as little as 20 days for applications for a licensee or site previously approved by the NRC) for site license application that meets the above expectations for a rapid high-volume deployable reactor. This is because the NRC review will not be a traditional safety and environmental review, since those considerations would have been completed with the design approval, but rather the site license review would be a verification that the site conforms to the conditions of the design approval (i.e., the site parameter envelope), the generic environmental approvals (e.g., a Categorical Exclusion or a Generic Environmental Impact Statement), and prior NRC approvals (e.g., in a prior license approval or in Topical Reports) for the licensee qualifications and programs (e.g., Financial Qualification, Quality Assurance Program). It is noted that the applicant will be performing safety-related site assembly, delivery and emplacement of the reactor during the NRC verification review, and the

[3] The NRC may also extend the application acceptance review if supplemental information is needed to perform the review, or reject the application if it is does not meet the acceptance criteria. However, for the purposes of describing the NRC licensing process, it is assumed that the application is complete and meets the NRC's criteria for acceptance.
[4] https://www.nrc.gov/about-nrc/generic-schedules.html

NRC will be providing oversight and inspection of these activities, commensurate with their safety significance.

NRC Final Approval (1 month) – The NRC Final Approval is the approval by the Commission, and the administrative activities, to issue the license. Traditionally this has taken 4 to 6 months, though in some cases it has taken longer. It is expected that a site license application that verified conformance to a prior approved design, such that the site license did not include any additional or new safety and environmental considerations, and would be 10% or less of the volume of a traditional site license application can be performed in 1 month or less (possibly as little as 15 days). It is noted that the issuance of the license 1 month prior to operations will allow sufficient time for the commissioning and startup.

2.3.3 Deployment Costs

The April 2019 NEI report, "Cost Competitiveness of Micro-Reactors for Remote Markets,"[5] establishes a basis for the costs of designs that are expected to be rapid and high-volume deployable. It is noted that an update to that report is on-going to reflect a greater maturity in the technology and other factors (e.g., inflation and recently enacted tax credits) that could show expected costs today are lower than those projected in 2019. Thus, the following discussion on costs is expected to provide a reasonable basis for understanding the business need for regulatory costs less than 1% of total costs. In this manner, costs are separated into two categories:

1. Up-Front Capital Costs

2. Annual Operations and Maintenance Costs

<u>Up-Front Capital Costs</u>

Up-Front Capital Costs are the costs associated with the deployment project from project initiation through to completion of construction and initiation of operations, and for which there are associated regulatory costs. These are a one-time cost that are financed through debt and equity and amortized over a portion of the life of the plant. The majority of the capital costs are associated with the manufacturing of the reactor, site assembly, delivery and emplacement of the reactor, and the NRC licensing costs. These are the only costs considered in the referenced 2019 NEI paper, i.e., there could be future capital costs associated with plant modifications or upgrades that are not included because they are negligible in comparison to the up-front capital costs.

The 2019 NEI report provides a simple metric for the up-front capital costs in the form of an overnight capital cost. While this does not include financing costs, it is a reasonable metric to which to compare the expected NRC licensing costs. These costs for the first-of-a-kind are shown as a nominal, with a range between $10,000/kWe and $20,000/kWe, where the kWe is the rated capacity of the reactor. However, costs are expected to reduce rapidly through multiple deployments for a Nth-of-a-kind (NOAK) to as low as $4,000/kWe. Rapid high-volume deployable reactors are expected to come in a variety of sizes, and while this paper does not define a specific size range (since the defining factors are simplicity

[5] https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/Report-Cost-Competitiveness-of-Micro-Reactors-for-Remote-Markets.pdf

and safety performance, which cannot be specifically tied to size); however, this paper uses a range of 5 MWe to 30 MWe to estimate costs for illustrative purposes.

The regulatory costs include the direct NRC fees for performing the review, collecting the site data, and preparing the site license application. Based on historical experience, it is expected that the direct NRC fees for performing the review are about 25% to 33% of the total regulatory costs to obtain a site license for a rapid high-volume deployable reactor. Table 2-1 identifies the NRC review costs that would enable the business case for various sizes of rapid high-volume deployable reactors, as measured by the total facility capacity.

Table 2-1: NRC Review Costs that would Enable the Business Model

	5 MWe Facility	15 MWe Facility	30 MWe Facility
Total Up-Front Capital Costs for NOAK	Less than $20,000,000 to up to $75,000,000	Less than $60,000,000 to up to $225,000,000	Less than $120,000,000 to up to $450,000,000
NRC Review Costs that Enable the Business Model	Less than $50,000 to up to $187,000	Less than $150,000 to up to $560,000	Less than $300,000 to up to $1,120,000

This is not to imply that the NRC must conform to these regulatory costs, since we do not wish the NRC to compromise on reasonable assurance of adequate protection of the public health and safety. However, for clarity purposes, it is helpful to have this information in order to assess whether a potential NRC review process for rapid high-volume deployment reactors could meet the business model, in part or in whole. This enables the market and potential customers to determine whether nuclear technologies could meet their needs.

2.4 Concept of Operations

The concept of operations focuses on the activities to operate and maintain the reactor, the NRC oversight and inspection, and the annual O&M costs and the corresponding NRC regulatory costs.

2.4.1 Reactor Operations and Maintenance

There are two primary concepts for the operation and maintenance of the rapid high-volume deployable reactors: 1) operations with on-site staff, and 2) operations with off-site staff located at a remote operations center. For the purposes of this paper, it is assumed that the on-site staff operations model is primarily used by licensees with small fleets of rapid high-volume deployable reactors, with a fleet size of 10 or fewer sites being the example considered in this paper. Similarly, this paper assumes that the operations with off-site staff located at a remote operations center model is primarily used by licensees with large fleets of rapid high-volume deployable reactors, with a fleet size of 100 or more sites being the example considered in this paper.

In reality, the decision by the owner to pursue an on-site or off-site operations model is much more complex than just the number of sites where they are operating rapid high-volume deployable reactors. The decision will also factor in 1) how many reactors are at one site, 2) what is the size of the reactor, which influences 3) the required staffing size to operate the reactor based on a human factors analysis. There may also be other hybrid approaches where there is a mix of on-site and off-site monitoring and control of the reactor, which are not considered here due to the broad variability that these other approaches may take, and because the two approaches discussed here are expected bound of all the potential regulatory considerations.

Therefore, the purpose of the description of the two operations models, on-site or off-site control and monitoring, is to provide a basis for understanding the scope of regulatory topics that need to be addressed for rapid high-volume deployable reactors, and for developing the regulatory approaches for these reactors. The purpose is not to be a guide to an owner for developing a specific operations plan, nor for the NRC to review the operations plan for a specific application.

Automatic and Autonomous Operations

A key feature being designed into rapid high-volume deployable reactors is the ability to leverage automatic normal power control and automatic off-normal safety control. During routine operations, these reactors would control power automatically based on signals from the load center, such that changes in power level will be performed by the reactor's automatic control system. During off-normal events, these reactors would have reactor safety control systems that would return the reactor to a normal operating condition, and when necessary completely shutdown the reactor and place it in a long term steady-state safe configuration. The reactor would be designed to do all of these operational functions automatically, without reliance on the operator to perform any of these functions.

In this case, automatic operations is defined as the reactor responding to changes in externally monitored conditions according to a pre-programmed algorithm. While some designs may seek to incorporate non-human controls that are more similar to autonomous operations, i.e., the reactor could predict future conditions and take actions that are not pre-programmed, such features are not necessary to the rapid high-volume deployable reactor business model.

Role of the Human Operator

Rapid high-volume deployable reactors are being designed with very few or no moving components, and very few operational parameters needed to monitor the condition of the reactor. They are being designed such that the human operators will have access to the real-time status of monitored conditions, and will be able to take actions according to their operating procedures.

It is expected that all designs will have a manual trip function that an operator could quickly activate, although such a feature is expected to provide an additional layer of defense, and is not expected to be essential to demonstrating the safety of the design. Some vendors may design the reactor to have controls that the human operator could use to control the power of the reactor, while other designs may exclude power operation controls.

As these designs will have very little to no reliance on the operator to maintain safety, these operators will not require much training, and the licensing of these operators will be much simpler than it is for today's operating commercial reactor. Furthermore, these operators will be capable of performing other collateral duties (in the case of on-site staffing model), and monitoring a very large number of reactors (in the case of off-site staff at a remote operations center).

Operations of these reactors (either in the on-site or off-site operational models) might have five (5) shifts covering operations 24/7/365. The five (5) shift approach is typical for many of today's operating reactors allowing for 12-hour shifts, with sufficient rotations for time off. However, the five (5) shift model include a rotation about every six (6) weeks for the operations crew (typically 10 to 20 people including Shift Manager, Senior Reactor Operators, Reactor Operators and Non-licensed operators) to attend training. It is expected that due to the simplicity and safety profile of rapid high-volume deployable reactors, including the incorporation of automatic operations features and very little to no reliance on the operator to maintain safety, that operators would not need to be trained every six (6) weeks, but rather once per year. This could enable fewer shifts of a single operator, as each operator is able to spend more of their time at the reactor rather than in training.

Type 1 Operations: With On-Site Staff

Each applicant will need to propose an operations plan with an organization staffing that considers the human factors analysis for controlling and monitoring plant, and performing other required functions to protect the public health and safety. To-date, there have not been any applications for rapid high-volume deployable reactors submitted to the NRC that have articulated the concept of operations for these types of reactors. The following description is an example of the operations plan that some designs are expected to be able to achieve, subject to demonstrating reasonable assurance of adequate protection and being approved by the NRC.

In the on-site staffing operations model, all operations control is performed at the site. This model could include total or partial on-site monitoring, supplemented by remote off-site monitoring. It is anticipated that some designs will be able to demonstrate that all NRC required functions are capable of being performed by one (1) individual during routine operations and in the case of an off-normal event (e.g., anticipated operational occurrence, accident scenario). This may be supplemented by additional staff during pre-planned non-routine operations, such as a major maintenance activity or in modifications to the facility.

The role of the single on-site operator will enable them to perform collateral duties, such as minor plant maintenance, and security functions. Many designs are being developed for which the single on-site operator would be able to perform all functions regulated by the NRC. These operators might be supplemented by a "home office" staff that performs functions that are not directly related to the operations and maintenance of the facility. The "home office" staff would perform general business functions, such as procurement, accounting, IT and regulatory affairs, and may be sent to specific sites periodically to assist in the non-routine operations that require more than one (1) individual to perform (e.g., major maintenance activity).

Type 2 Operations: With Off-Site Staff Located at a Remote Operations Center

Each applicant will need to propose an operations plan with an organization that considers the human factors analysis for controlling and monitoring plant, and performing other required functions to protect the public health and safety. To-date, there have not been any applications for rapid high-volume deployable reactors submitted to the NRC that have articulated the operations plan for these types of reactors. The following description is an example of the operations plan that some designs are expected to be able to achieve, subject to demonstrating reasonable assurance of adequate protection and being approved by the NRC.

In the off-site staffing operations model, all control and monitoring functions are performed at a remote operations center. Other plant functions, both those required by the NRC such as security and emergency preparedness, and those that are not required by the NRC may also be performed or managed from the remote operations center. As noted below, for some co-located facilities, it is possible that on-site resources from the co-located facility could be leveraged to support these functions (e.g., plant security, fire brigades). Each design will need to establish the exact number of operators at the controls (at the remote operations center). However, as a representative number, most designs are being developed so that a crew of about four (4) people could operate a large fleet of reactors from a remote operations facility. This crew might be comprised of two operators at the controls, one shift manager and one flexible position.

The remote operations center would also include staff that work routine business hours, 8 hours a day 5 days a week, or 10 hours a day 4 days per week. These daytime positions would be responsible for maintaining and administering the NRC required programs, such as QA, Training, Emergency Preparedness, Security and Environmental Monitoring. The daytime positions would also include the licensee's organizational leadership, business functions, such as accounting, engineering, regulatory affairs and other support functions.

Rapid high-volume deployable designs are being developed so that there will not be a need for a human to be stationed on-site. These designs are expected to need a human to visit the site periodically, and to establish Field Technicians as part of their staffing organization. The Field Technicians would provide periodic visual confirmation for the remote monitoring center and periodic tasks that can only be performed on-site. Walk down procedures would define the areas, equipment, controls and monitored parameters that would need to be observed and confirmed. The procedures would also identify any routine or compensatory actions that the Field Technician may need to take, for example testing of certain equipment or cleaning out debris. Each design will also need to establish and obtain NRC approval on the frequency of the site walk-downs, for example whether they would occur in the range of once per week or once per month, which may be dependent upon the simplicity of the design and the extent to which the plant is fully observable from the remote operations center. The field technicians would have the capability to perform non-routine activities as necessary, such as major maintenance on a component. These field technicians could also be sent to visit sites in between the routine walk downs in response to anomalies observed by the remote operations center, for example birds nesting or after a thunderstorm.

Each design will need to establish and obtain NRC approval for a specific organization and staffing plan; however, it is expected that most designs would have an organization size of 80 to 150 FTE for a fleet of around 100 reactors. This would be organized into around 50 to 90 FTE at the remote operations center, and around 30 to 60 FTE Field Technicians.

<u>Co-Located Facilities</u>

Rapid high-volume deployable reactors are expected to be co-located with the end-use applications for which they will provide heat or electricity. Many of these co-located end-use facilities, especially in the case of industrial applications, will have their own infrastructure and staffing. In some cases, the owner of the rapid high-volume deployable reactor will also own the co-located end-use facility, and in other cases there will be a different owner of the co-located end-use facility. In both cases, it may be possible that the infrastructure and the staffing from the co-located end-use facility could be used to support the operations and maintenance of the rapid high-volume deployable reactor (in the case of different owners this could be through a sharing agreement). This is especially true in the case of industrial facilities that have a significant infrastructure and staffing organization.

A simple option for the end-use facility infrastructure and staffing to be used to supplement the rapid high-volume deployable reactor infrastructure and staffing is in the general business functions (see the on-site staffing model). In models where the end-use facility infrastructure and staffing are used to fulfill NRC requirements (e.g., security fencing, security guards, fire and emergency response), these plans will need to be reviewed and approved by the NRC. They may also require that the end-use facility infrastructure and staffing have some level of NRC oversight.

The details of using end-use facility infrastructure and staffing are beyond the scope of this paper; however, these possibilities are mentioned for regulatory topics where there is a greater potential to credit the end-use facility to meet NRC requirements.

2.4.2 NRC Oversight and Inspection

NRC oversight and inspection of rapid high-volume deployable reactors will cover 1) manufacturing of the reactor, 2) delivery, assembly and emplacement of the reactor at the site, and 3) operations of the reactor. Just as rapid high-volume deployable reactors are very different from currently operation large light-water reactors and other advanced reactors in development, it is also expected that NRC oversight and inspection will be very different for these types of reactors.

<u>Manufacturing and Site Activities</u>

The rapid high-volume deployable reactor is expected to be entirely fabricated and assembled in a manufacturing facility with minimal on-site activities, which are focused on assembly and emplacement. Some licensees will also have a remote operations facility that will need to be constructed; however, the construction of the remote operations center is outside the scope of this paper. NRC's oversight and inspection is expected to be focused at the locations of these activities and at a level of oversight commensurate with the safety related activities being performed.

For high deployment rates, for example 10 reactors manufactured, the NRC may determine that the resources needed to provide oversight and inspections would justify having a full-time inspector located at the reactor manufacturing facility. Similarly, for deployment model for which there is safety-related activities at the site occurring over 4 months, the NRC may determine that an inspector would need to visit the site multiple times to observe these activities. If there are 10 reactors being brought on-line per month (thus 40 reactors in the phase of safety-related site activities) and they are in close proximity to one another, then the NRC may determine that a handful of inspectors could move from site to site to effectively and efficiently provide oversight. If there is a slower deployment rate with locations that are very far from each other, then the NRC may determine that there are not enough economies of scale to have multiple inspectors that move from site to site.

<u>Operations of the Reactor</u>

The NRC currently places resident inspectors at operating reactors to provide oversight. This is for reactors that are very large, with numerous components to control and parameters to monitor, and with significant day to day site activities related to safety. In contrast, the NRC does not utilize resident on-site inspectors for non-power reactors, but inspects them on a periodic basis.

It is expected that rapid high-volume deployable reactors will not need on-site resident inspectors, and that the NRC would periodically inspect sites, and such inspections could be on a sampling basis for a licensee that has a large fleet of sites. The NRC will establish the appropriate frequency for these inspections; however, it is expected that some designs and fleet sizes could justify an NRC inspection frequency of as little as once per year. For licensees that utilize a remote operations center, the NRC is also expected to provide oversight and inspection of the remote operations center. The NRC might determine that an inspector would need to be located at the remote operations center full-time, and that this would reduce the need for site inspections, achieving a more efficient oversight and inspection program.

2.4.3 Operating Costs

The April 2019 NEI report, "Cost Competitiveness of Micro-Reactors for Remote Markets,"[6] establishes a basis for the costs of designs that are expected to be rapid and high-volume deployable. It is noted that an update to that report is on-going to reflect a greater maturity in the technology and other factors (e.g., inflation and recently enacted tax credits) that could show expected costs today are lower than those projected in 2019. Thus, the following discussion on costs is expected to provide a reasonable basis for understanding the business need for regulatory costs less than 1% of total costs. In this manner, costs are separated into two categories:

1. Up-Front Capital Costs

2. Annual Operations and Maintenance (O&M) Costs

Annual Operations and Maintenance Costs

Annual O&M are the costs associated with the operation of the reactor after it is constructed and operations begin, and for which there are associated regulatory costs. These are recurring costs every year, and for which the costs are expected to increase in the future with inflation. Annual O&M costs include property taxes, purchasing of consumables and replacement equipment, general and administrative, personnel and NRC regulatory costs. Staffing is expected to be a small portion of the annual O&M costs. For the purposes of this report, fuel (including used fuel management) and decommissioning funding, which are provided for on an annual basis, are included in the annual O&M costs.

The 2019 NEI report provides a simple metric for the NOAK fixed operations and maintenance costs with a range between $250/kWe and $450/kWe, where the kWe is the rated capacity of the reactor. Fuel and decommissioning costs are reports in $/MWh, and refueling costs are reported in total costs. These costs are combined to form a total annual O&M cost. Rapid high-volume deployable reactors are expected to come in a variety of sizes, and owners may have a variety of sizes of fleets; however, this paper uses a range of 5 MWe to 30 MWe in facility size, and a small fleet that would use the on-site staffing concept and a large fleet that would use a remote operations center.

[6] https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/Report-Cost-Competitiveness-of-Micro-Reactors-for-Remote-Markets.pdf

The regulatory costs include the direct NRC fees for performing oversight and inspections, the NRC annual fee, and licensee support for NRC regulatory engagement. Based on historical experience, it is expected that the NRC fees for regulatory oversight and inspection are to be around 25% to 33%, and NRC annual fees also around 25% to 33% of the total regulatory costs. Table 2-2 identifies the fees (annual and direct for oversight) that the licensee would pay to the NRC that would enable the business case for various sizes of rapid high-volume deployable reactors, as measured by the total facility capacity, and number of reactors in a fleet.

Table 2-2: NRC Review Costs that would Enable the Business Model

	Small Fleet On-site Staff Model (e.g., less than 10 sites)	**Large Fleet Remote Operations Model (e.g., More than 100 sites)**
Example Fleet Size	150 GWe	1,500 GWe
Annual O&M Costs for NOAK	Less than $90,000,000 to up to $120,000,000	Less than $600,000,000 to up to $850,000,000
Anticipated Staffing Size	3 to 5 FTE per site 30 to 50 FTE Total	0 FTE per site 100 to 200 FTE Total
NRC Annual Fees that Enable the Business Model	Less than $30,000 to up to $40,000 per site	Less than $20,000 to up to $30,000 per site
NRC Direct Oversight and Inspection that Enable the Business Model	0.5 to 1 FTE	3 to 5 FTE

This is not to imply that the NRC must conform to these regulatory costs, since we do not wish the NRC to compromise on reasonable assurance of adequate protection of the public health and safety. However, for clarity purposes, it is helpful to have this information in order to assess whether the potential NRC annual fees, and oversight and inspection process for rapid high-volume deployment reactors could meet the business model, in part or in whole. This enables the market and potential customers to determine whether nuclear technologies could meet their needs.

2.5 Total Lifecycle Management

Rapid high-volume deployable reactors are expected to have a novel approach to total lifecycle management. This includes the following:

Manufacturing – The reactor is expected to be fully fabricated at a manufacturing facility with minimal on-site assembly (see Section 2.2.1 on Technology Description).

Refueling – There are multiple concepts of refueling, which align with the concepts of initial fueling during deployment. For designs delivered with the reactor already fueled, they are also being designed to fully replace the reactor and fuel with a replacement reactor that is also fueled. For designs that are fueled on-site, there would be a refueling operations on-site.

Used Fuel Management – Under both scenarios, the reactor is being replaced or there is a refueling operation on-site, the used fuel would be stored on site for a pre-determined time to achieve lower dose and heat rates before being shipped to a used fuel storage location. For reactors that are being replaced without removing the fuel on-site, the used fuel storage location could be co-located with the refurbishment and refueling center.

Decommissioning – The small size of the rapid high-volume deployable reactor enables more streamlined decommissioning of the site. It is expected that the majority, if not all, of the decommissioning will be related to the reactor itself. Since the reactor can be transported by truck or rail, it is expected that it would be packaged and shipped to a decommissioning facility. For reactors that are being replaced without removing the fuel on-site, decommissioning facility could be co-located with the refurbishment and refueling center.

3 REGULATORY CONSIDERATIONS

This section discusses the regulatory considerations for rapid high-volume deployable reactors for remote applications. This includes the rationale for why an alternative regulatory framework is needed, a concept for an alternative regulatory approach, and a discussion of the regulatory topics that may need to be addressed.

3.1 Rationale for An Alternative Regulatory Approach

As discussed earlier, the technology characteristics, concept of deployment and operations, and regulatory framework are interrelated. Thus, the regulatory framework needs to be informed by the capabilities of the design and the activities associated with the deployment and operations for the intended applications. Similarly, the development of the technology capabilities, and the concept of deployment and operation will be informed by the development of the alternative regulatory approach. This interrelationship of technology, business model and regulatory framework are shown in Figure 3-1. As these technologies and concepts are being developed now, there is an urgent need to understand whether the regulatory framework will enable the business model.

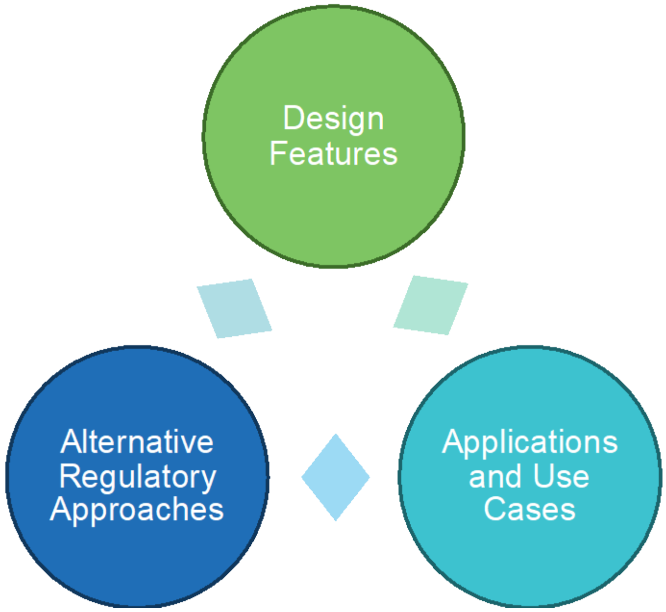

Figure 3-1: Interrelationship of Technology, Business Model and Regulatory Framework

3.1.1 Need for An Alternative Regulatory Approach

The characteristics and safety basis of rapid high-volume deployable reactors are expected to be fundamentally different from those of commercial power reactors, even as compared to advanced small modular reactors. These business models are so new that the current statutes and regulatory requirements, including changes and alternatives that are in process, have not fully considered the technology capabilities or the concepts of deployment and operations. Therefore, it would be appropriate to fully consider these novel aspects with an understanding that a fundamentally different regulatory approach may be appropriate. Such an alternative regulatory approach for rapid high-volume deployable reactors could more effective and efficient in protecting the public health and safety.

The key features of rapid high-volume deployable reactors are their very small inventory of fission products and simplicity, as compared to other advanced reactors. They are expected to come in a variety of designs and while there is not a standard set of safety features, the following are some of the more common safety enhancements that are expected to be incorporated into the designs (note: not all of these features are applicable to all designs):

- Fail-safe to shut down automatically
- Decay heat removal provided entirely by passive and inherent features (e.g., long term passive cooling with natural forces to sufficiently transfer decay heat indefinitely with the loss of any fission product barriers)
- Accident and proliferation resistant fuel with enrichments below 20% U-235
- High fission product retention
- Operator actions are not needed to assure safety of the reactor

- Operational simplicity with very few active SSCs, instruments or controls

The NRC has made great strides in modernizing its regulatory framework to recognize that the existing frameworks are ill-suited for today's new reactor technology. However, the existing regulatory framework, including on-going work to modernize the framework for advanced reactors, does not currently permit the business model on the required timeframe that would enable hard to abate industries from decarbonizing their energy sources.

The NRC should consider alternative approaches for rapid high-volume deployable reactors that can demonstrate that the potential consequences of accidents, even for the worst-case scenarios in which there are multiple failures of fuel fission product barriers and other systems, structures and components, would not lead to a significant adverse impact on the health or safety of the public.

As discussed in Section 1.2, the NRC has been working to modernize the regulatory framework for advanced reactors, including specific work related to micro-reactor and manufacturing license topics that are relevant to rapid high-volume deployable reactors for remote applications. Also discussed in this paper is the basis for concluding that this prior work, while valuable to this technology, is not sufficiently complete to enable the business model. For rapid high-volume deployable reactors, the existing regulations and proposed rule changes to address advanced reactors, in many cases, would result in excessive regulatory burden that is not necessary to protect the public health and safety. The safety features, and the corresponding simplicity of rapid high-volume deployable reactors, are expected to result in designs with very low potential consequences, which could justify the use of alternative approaches to existing regulations.

3.1.2 Consistent with National Priorities

There is widespread recognition that the U.S. needs more nuclear energy to achieve our climate, energy, environmental, economic, and national security goals.

President Biden's December 2021 Executive Order articulates the need and urgency for accelerating the deployment of advanced nuclear technologies to decarbonize the energy sector. In it, "President Biden has set an ambitious U.S. goal of achieving a carbon pollution-free power sector by 2035 and net zero emissions economy by no later than 2050. As a result of the historic investments in the Inflation Reduction Act and Bipartisan Infrastructure Law as well as other actions the Administration is taking, the United States is on a clear path to achieve this goal, while reducing costs for consumers, lowering harmful pollutants, mitigating climate change, and creating new economic opportunities."[7] Advanced reactors, including rapid high-volume deployable reactors, are needed to decarbonize difficult to abate sectors and use-cases.

In the March 22, 2024, letter to the Secretary of the Department of Defense (DoD),[8] the Senate Select Committee on Intelligence identified the need to bolster the resilience of our critical infrastructure. The letter identified the importance of civil nuclear technology for critical mission demands and increased resilience for U.S. bases. Advanced reactor technologies, including rapid high-volume deployable reactors, are well suited, and perhaps the only technology that can provide the level of resilience needed for defense and commercial critical infrastructure, such as remote industrial or data centers. The

[7] White House Press Release: https://www.whitehouse.gov/briefing-room/statements-releases/2023/04/20/fact-sheet-president-biden-to-catalyze-global-climate-action-through-the-major-economies-forum-on-energy-and-climate/

[8] https://www.warner.senate.gov/public/index.cfm/2024/3/intel-chair-warner-vice-chair-rubio-colleagues-urge-department-of-defense-to-boost-energy-security-of-critical-infrastructure

Committee stressed that "It is critical that the United States lead in the development and deployment of advance nuclear reactors to secure our own critical infrastructure with resilient, continuous power, especially for DoD mission critical operations in remote and austere environments." As DoD is pursuing the use of commercial technology, they are dependent upon this technology being enabled by alternative regulatory approaches that protect the public health and safety more effectively and efficiently.

In the recent DOE Liftoff report for Advanced Nuclear,[9] the Department emphasized that, (2) "This group [capital providers] considers nuclear to be outside of their risk appetite due to perceived technology and regulatory risk…" emphasis added. Furthermore, the DOE Liftoff report identified the following challenge, "The NRC would need to scale its license-application capacity from 0.5 GW per year to 13 GW per year to meet projected demand," and the following potential solution, "The NRC's capacity is determined both by actions taken by the NRC to improve efficiency and increase resources and by activities from applicants to improve and expedite applications interactions."

The industry's recent Advanced Reactor Roadmap[10] reached similar conclusions and recommendations, stating that, "The market need for advanced reactors to enable the United States … to meet their decarbonization goals will result in … a volume of licensing applications that far exceeds the NRC's … current capacity." The Roadmap also identified the following key enabler to regulatory efficiency: "Regulatory reform … would establish regulatory frameworks to facilitate the efficient and timely approval and licensing of innovative and safe designs, … support deployment of the first advanced reactors and fast followers and set the foundation for large-scale deployment in the early 2030s."

The concepts included in this paper are aimed at achieving the outcomes identified by the DOE liftoff and industry Roadmap reports that would enable nuclear technologies to help the nation meet its climate, energy, environmental, economic, and national security goals. This paper supports the resolution of the priority issues identified in NEI's February 12, 2024, letter to the NRC, "NEI Input on Regulatory Priorities for New and Advanced Reactors" (ML24043A249).

3.1.3 Consistent with NRC's Mission and Principles of Good Regulation

Pursuit of more effective and efficient regulation of new classes of reactors, like rapid high-volume deployable reactors, is consistent with the NRC's Mission and Principles of Good Regulation. The Atomic Energy Act established the NRC to regulate radiological hazards to protect the public health and safety in pursuit of the overall goal of the Act to "make the maximum contribution to the general welfare" … "to the maximum extent consistent with the common defense and security and with the health and safety of the public." This establishes a dual-factored mission for the NRC – safety and efficiency. The NRC's Principles of Good Regulation and numerous Policy Statements have reflected the dual mandate of safety and efficiency.

The NRC's Principles of Good Regulation for Efficiency states, "where several effective alternatives are available, the option which minimizes the use of resources should be adopted." In the application of this principle to advanced reactors, the safety requirements for advanced reactors should be focused on ensuring that advanced reactors meet the underlying intent of the regulations to provide reasonable assurance of adequate protection of the public health and safety. As a result, rapid high-volume deployable reactors would likely not need to meet all of the existing detailed and prescriptive

9 https://liftoff.energy.gov/wp-content/uploads/2023/05/20230320-Liftoff-Advanced-Nuclear-vPUB-0329-Update.pdf
10 https://publicdownload.epri.com/PublicAttachmentDownload.svc/AttachmentId=83812

requirements that were developed based on the potential consequences of larger power reactors to ensure public health and safety.

The NRC's Advanced Reactor Policy states that its goal is to encourage advanced reactor designers to consider safety and security in the early stages of design in order to identify potential design features and/or mitigative measures that provide a more robust and effective security posture with less reliance on operational programs. Industry has responded to this goal by developing innovative advanced reactor technologies.

In the Advanced Reactor Policy Statement[11] the Commission stated that it "*expects that advanced reactors will provide enhanced margins of safety and/or use simplified, inherent, passive, or other innovative means to accomplish their safety and security functions*" and includes a list of over 10 specific features that would enhance safety of advanced reactors. Incorporating even some of those features would result in designs for which many of the NRC's existing regulations would no longer be applicable, because the existing requirements were developed with large LWRs in mind. The Commission recognized this fact and in the Policy Statement stated, "*Incorporating the above attributes may promote more efficient and effective design reviews*" … "*Indeed, the number and nature of the regulatory requirements may depend on the extent to which an individual advanced reactor design incorporates general attributes such as those listed previously*." While the NRC has several on-going regulatory initiatives related to advanced reactors, few of these initiatives have fully contemplated the design features and concept of deployment and operations identified in this paper.

3.1.4 Consistent with Congressional Direction

Congress has passed legislation aimed to enable the NRC to modernize the regulatory framework for advanced reactors and enable business models for these technologies. The Nuclear Energy Innovation and Modernization Act (NEIMA) authorized the NRC to develop a technology-inclusive performance-based and risk-informed alternative regulatory framework. There is also legislation that is currently introduced in the House and Senate, that if passed into law would further enable the business models for rapid high-volume deployable reactors. The ADVANCE Act includes sections specifically related to micro-reactors and the NRC licensing process, and many of the elements of the concept for an alternative regulatory approach discussed in this paper would be options to implement those provision if they become law. There are many other examples of legislation that have been enacted or are being contemplated by Congress, the analysis and discussion of which is beyond the scope of this current paper. However, the key point is that legislation from Congress has directed the NRC to modernize the regulatory framework for advanced reactors, and future legislation may further enable the business models for rapid high-volume deployable and other reactors.

In considering the regulatory framework for rapid high-volume deployable reactors, there may also be statutory requirements identified that would prevent the NRC from implementing a more effective and efficient alternative regulatory approach for this business model. Just as the regulatory framework has not fully considered the technology capabilities, and concept of deployment and operations, so also the statutes, including the Atomic Energy Act, have not fully considered this business model. Therefore, it would not be unreasonable to expect that the statutes, though developed to be flexible and not overly prescriptive to the technology or business model, would not have been able to envision future technology capabilities, and concepts of deployment and operations, that are as fundamentally different

[11] ML082750370

from the technology and business models at the time of the enactment of those statutes, and thus may not have provided sufficient flexibility to enable these novel business models.

3.2 Concept for an Alternative Regulatory Approach

The regulatory approach for rapid high-volume deployable reactors should be flexible and accommodate multiple approaches that may be taken by applicants in the licensing process and to demonstrate the safety basis. The most effective way to achieve this is through a regulatory framework that is performance-based with requirements that define the acceptable outcomes in terms of public health and safety, and in ways that are as objectively measurable as possible. There are several methods to do this that have been used successfully for approaches in the NRC current set of regulations, such as consequence-oriented and risk-informed approaches. A graded approach to applying requirements is appropriate, since rapid high-volume deployable reactors may have variations in their safety characteristics, and the alternative regulatory approaches may have applicability to other technologies and concepts of deployment and operations. While the details of the technology characteristics, and concept of deployment and operations, will be needed for the NRC to fully review and approve license applications, the information within this concept document is expected to be sufficient for the NRC to develop an alternative regulatory approach for rapid high-volume deployable reactors.

3.2.1 Insights from the Regulation of Other Low Risk Technologies

The technology characteristics and concept of deployment and operations are so fundamentally different from other power reactors that it may be difficult to enable the business model by adapting the current regulatory framework for power reactors and the on-going work related to modernizing the framework for advanced reactors. In fact, the potential consequences and risks to the public health and safety, and the environmental impacts are much more similar to other low risk technologies that the NRC regulates than they are to other power reactors, including even advanced small modular reactors.

Micro-reactors are expected to have source terms that are 100 to 1,000 times smaller than large light-water reactors which are the basis for the current regulatory framework. Micro-reactors are also expected to have source terms that are 20 to 100 times smaller than dry storage casks and other advanced SMRs, which are the basis for most of the NRC regulatory modernization for advanced reactors. The potential consequences of advanced reactors will be similar to those for RTRs rather than to those of large LWRs for which the existing regulations were developed. Figure 3-2 provides a representative comparison of the magnitude of the source terms for these nuclear technologies.

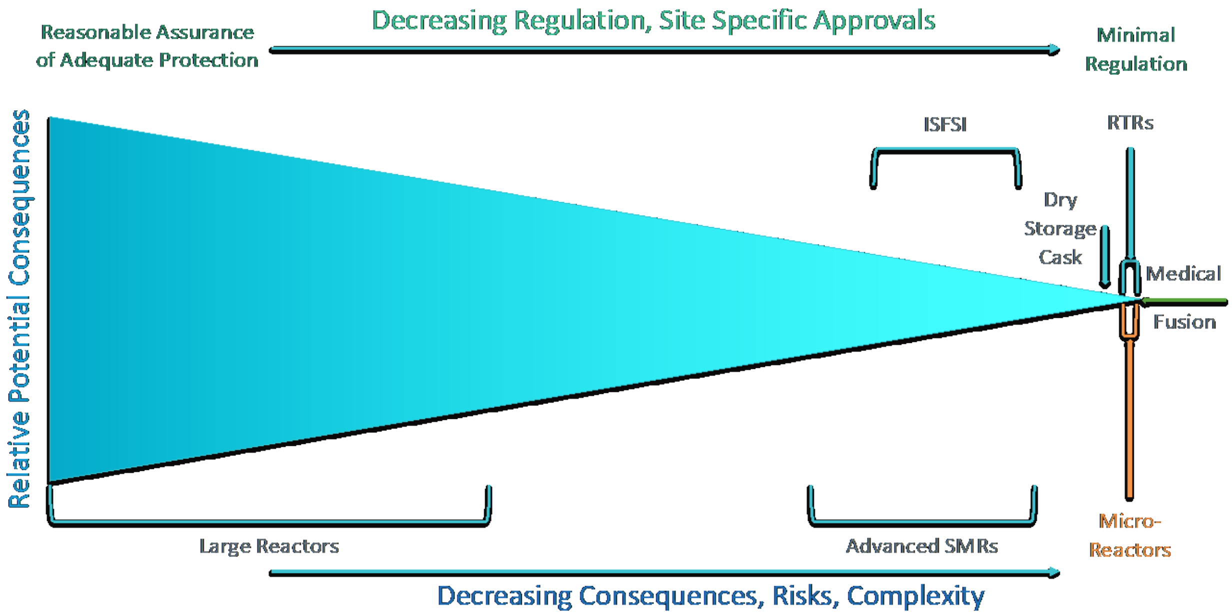

Figure 3-2: Relative Comparison of Potential Consequences for Selected Nuclear Technologies

<u>Insights from Non-Power Regulation</u>

The size, simplicity, and potential consequences of rapid high-volume deployable reactors are very similar to non-power reactors, also called research and test reactors (RTRs). The regulation of non-power reactors is carried out in accordance with Section 104 of the AEA, using the requirements in 10 CFR 50 (and other parts) and implementing guidance, such as NUREG-1537.

While there are similarities between the potential impact to public health and safety, and environmental impacts between rapid high-volume deployable reactors and RTRs, there are also notable differences between how power reactors and non-power reactors are regulated. Most fundamental is that RTRs are regulated under Section 104 of the AEA, which directs the NRC to "*impose the minimum amount of regulation consistent with its obligations under this Act to promote the common defense and security and to protect the health and safety of the public.*" In contrast the AEA directs the NRC to license reactors for industrial and commercial purposes under Section 103 (except as provide by Section 102), which provides a standard of "*reasonable assurance of adequate protection of the public health and safety.*" While there are differences between these two standards of protecting the public health and safety, those differences are very small in comparison to the differences between micro-reactors (and other advanced reactor designs with similar safety profiles) and the large LWRs for which the current regulatory framework was developed. In addition, the similarities between RTRs and micro-reactors are much greater than the similarities between micro-reactors (and other advanced reactor designs with similar safety profiles), and the large LWRs for which the current regulatory framework was developed.

There are several important factors when considering the applicability of the regulatory framework for RTRs to micro-reactors (and other advanced reactor designs with similar safety profiles) that provide insight into how the different public protection standards in Sections 103 and 104 are applied, and how the regulatory framework could be adapted to micro-reactors. These include:

1. **Acceptable Doses** – Both RTRs and advanced reactors must meet Part 20 occupational and public dose limits for normal operations. Advanced reactors must also meet Part 100 dose limits for postulated fission product releases. However, Part 100 dose limits do not apply to RTRs in the same manner, as NUREG-1537 states "*If the facility conforms to the definition of a test reactor, the doses should be compared with 10 CFR Part 100. As discussed in the footnotes to 10 CFR 100.11, the doses given in 10 CFR Part 100 are reference values. Any further references to 10 CFR Part 100 in this document apply to test reactors only*."

2. **Safety Features** – Advanced reactors are being designed to include safety features that are not typically included in RTRs. These safety features are typically included to limit doses during accident scenarios, and thus are related to meeting the Part 100 dose limits. While micro-reactors (and other advanced reactor designs with similar safety profiles) have similar power levels and quantities of radiological material, the use of additional safety features could result in lower source terms and lower potential off-site doses. Advanced reactors plan to use more inherent and automatic safety features that will result in less reliance on human actions for safety, as compared to RTRs.

3. **Operations** – Most advanced reactors are closed systems that do not perform tests and experiments, while RTRs range from open pool to pressurized light-water systems with power ranges of less than 1 MWt to 20 MWt. The GE Vallecitos test reactor was 50 MWt (ML23047A392). RTRs also have varying duty cycles from infrequent to nearly continuous operation and also typically perform tests and experiments (i.e., frequently perform non-routine operations). Continuous full-power operations of advanced reactors creates more operational experience that is useful in improving the safety of operations. Furthermore, high-volume deployment of standardized advanced reactor designs means that the operating experience from all the plants can be shared, increasing the rates of learning and improving operational performance, which is directly related to safety.

This paper is not suggesting that micro-reactors be regulated *as* RTRs, but rather that the NRC regulations and guidance that are commensurate with the safety profile and risks be adapted. However, insights from the underlying safety bases of RTR regulations are useful starting points for alternative approaches for rapid high-volume deployable reactors. For example, many of the underlying bases for RTR requirements are based upon the very low potential consequences to the public. It is also noted that some approaches taken by RTRs may not be appropriate for advanced reactors.

The NRC has already acknowledged that commercial reactors that are similar to non-power reactors should be regulated in a similar manner. In NUREG-1537, the NRC stated:

> "*The licensed thermal power levels of non-power reactors are several orders of magnitude lower than current power reactors [large LWRs]. Therefore, the accumulated inventory of radioactive fission products in the fuel (in core) of nonpower reactors is proportionally less and requires less stringent and less prescriptive measures to give equivalent protection to the health and safety of the public. Thus, even though many of the regulations of Title 10 apply to both power and non-power reactors, the regulations will be implemented in a different way for each category of reactor consistent with protecting the health and safety of the public, workers, and the*

environment. Because the potential hazards may also vary widely among non-power reactors, regulations also may be implemented in a different way within the non-power reactor category."

Therefore, it is anticipated that the regulation of advanced reactors, like rapid high-volume deployable reactors, that are around the same order of magnitude lower in potential consequences would be regulated in a proportionally similar manner, with flexibility in the implementation of regulations since designs may vary widely. The only major difference in the concept of an alternative regulatory framework in this paper, and the NRC statement in NUREG-1537, is that this paper does not propose to identify similarities in potential consequences to the public health and safety in terms of thermal power and radiological inventories, which are rough proxies for the potential consequences and risks, but rather to use more directly related measures to the protection of public health and safety, such as the source term and risks.

3.2.2 General Principles for an Alternative Approach

As the potential alternative regulatory framework for rapid high-volume deployable reactors at remote applications is being considered, it is helpful to formulate general principles under which such an alternative regulatory framework would operate and be well suited for the technology capabilities, and the concept of deployment and operations. In particular, the following general principles are considered in this paper: 1) Specific and General Applicability, 2) Performance-Based Acceptance Criteria, and 3) Fundamentals of the Licensing Approach.

<u>Specific and General Applicability</u>

This concept paper is written for a very specific business model that has recently emerged for rapid high-volume deployable reactors. However, while the combination of all of the technology capabilities and concepts of deployment and operations is unique, most of the individual pieces of these technology capabilities, and concepts of deployment and operations have existed for a while, and in some cases they have existed for decades. Therefore, it is important to understand the specific applicability and the general applicability of the business model discussed in this paper, in this way:

> **Specific Applicability** – This means that it is only designs with a combination of all of the enabling technological capabilities, and concepts of deployment and operations, that would be able to fully benefit from the concepts of an alternative regulatory framework discussed in this paper. For this purpose, these designs have been called "rapid high-volume deployable reactors" in this paper.
>
> **General Applicability** – This means that any single feature of the concept for an alternative regulatory framework discussed in this paper is not dependent upon a design having all of the enabling technological capabilities, and concepts of deployment and operations discussed in this paper. As such, pieces of the concept for an alternative regulatory framework that is specifically developed for rapid high-volume deployable reactors may also be applicable to other advanced reactors.

There is a natural tension between developing a concept around a very specific business model, like rapid high-volume deployable reactors, that has both specific applicability and general applicability. There is a need to be specific in order to fully understand how to develop an effective and efficient alternative regulatory framework for that business model. There is also a need to be general so that the alternative regulatory framework is business-model-inclusive. When the variability among designs is low the tension between the specific and general applicability is not very noticeable, but when variability is high, this tension is apparent. This has been the case for micro-reactors that have found that, even in the development of technology-inclusive Part 53 requirements, those proposed requirements were either not achieving the desired levels of being effective and efficient, or were resulting in the creation of optional requirements that could be more effective and efficient for those designs.

The other two General Principles are also considered in this paper, in part, for their ability to minimize the tension between specific and general applicability for the concept of an alternative regulatory framework for rapid high-volume deployable reactors.

Performance-Based Acceptance Criteria

Performance-based requirements, that have outcome-based acceptance criteria, that do not prescribe the methods or features of the solution are essential to creating a technology-inclusive regulatory framework. This paper considers that there are several cross-cutting technical acceptance criteria that generally establish the safety performance for advanced reactors that would be able to use a majority of the concept of an alternative regulatory framework discussed in this paper. This paper further considers that it is possible to develop performance-based acceptance criteria that have a graded approach to safety. In that sense, when possible, identifying different levels of outcomes safety levels or risk-informed terms will increase their general applicability.

This paper recognizes that not all of these cross-cutting acceptance criteria are applicable to every specific regulatory topic area, and as these topic areas are developed it will be helpful for them to identify which of these cross-cutting technical acceptance criteria are applicable to that topic area. This paper also recognizes that as alternative approaches are developed for specific regulatory topic areas (e.g., siting, environmental, security) some of those topics may identify additional issue-specific technical acceptance criteria. Similar to the cross-cutting technical acceptance criteria, performance-based acceptance criteria that have a graded approach to safety will enable them to be more generically applicable.

Potential cross-cutting technical acceptance criteria (performance-based and graded to safety when possible) could be:

- **Off-site doses are small** – Use of a graded approach of acceptance criteria based upon different levels of potential off-site doses would enable this criterion to be broadly applicable. Small off-site doses are expected to be achieved through the use of passive and inherent systems, simplicity and other features that result in higher safety margins and lower risks. Examples of various levels of potential impacts to the public are: [12]
    - **Small Doses** - Site boundary Emergency Planning Zone (EPZ) (Doses are less than the Environmental Protection Agency's Protection Action Guides limits, e.g., 1 rem, at the site boundary). Note that this would result in a site boundary dose of less than 10% of

[12] Reactors that could meet the criteria for Extremely Small Doses could enable business models and alternative regulatory approaches that go beyond those described in this paper. The AEA identifies in Section 103.f that for reactors where an accident would not result in an unplanned release of quantities of fission products in excess of allowable limits for normal operations, then the NRC is not required to include a condition in the license for immediate notification of the Commission. Note that normal off-site dose release to the public is less than 0.1 rem, which is less than 1% of the accident off-site dose limit of 25 rem dose limit, and a small fraction of the average annual dose of the U.S. public of 620 millirem.

the current requirements of 25 rem upon which the current regulatory framework is established.

- **Very Small Doses** – Site boundary EPZs that are less than a few hundred meters. Note a site boundary EPZ could be as small as 1% the distance of a 10-mile EPZ for LLWRs upon which the currently regulatory framework was established.

- **Impacts to Land, Water and Atmosphere are small** – Use of a graded approach of acceptance criteria based upon different levels of potential environmental impacts would enable this criterion to be broadly applicable. Examples of various levels of potential impacts to the public are:
  - **Small Impacts** – Physical footprints, water usage and air releases that are on the order of 10% of existing large LWRs. This may be possible for advanced reactors with site boundaries that cover 30 acres or less of land.
  - **Very Small Impacts** – Physical footprints, water usage and air releases that are on the order of 1% of existing large LWRs. This may be possible for advanced reactors with site boundaries that cover 1 acre or less of land.

- **Independence of Site Conditions** –Use of a graded approach of acceptance criteria based upon different levels of impacts of the site-specific conditions to the safety and environmental reviews would enable this criterion to be broadly applicable. Examples of various levels of potential impacts to the public are:
  - **Small Dependence on Site Conditions** – Bounding analyses with large margins in the safety and environmental conclusions for geotechnical, meteorological, flooding and other external hazards. Bounding analyses would avoid the need for additional analyses using site-specific data for most sites.
  - **Very Small Dependence on Site Conditions** – Use of features to establish a design that is not sensitive to the site-specific characteristics. For example, seismic isolations could create independence between the structure and soil. Similarly, an intermediate loop, between the reactor and the energy supply system, could create independence from the balance of plant such that regardless of what energy production system is connected to the reactor (e.g., electric generator, steam supply, hydrogen) it would be bounded by the safety and environmental conclusions for the design.

This paper makes two assumptions that are not in themselves acceptance criteria for the concept of an alternative regulatory framework, but were made to reduce the scope of regulatory topics that would need to be considered. These are: 1) the site is not located near a population center or densely populated areas (i.e., remote), and 2) there are considerations made for using the reactor for industrial applications (e.g., potential to leverage the industrial facility’s infrastructure and workforce).

Fundamentals of the Licensing Approach

The NRC’s current licensing process will take an applicant approximately 58 months from the time of site identification to operations of the reactor, of which the duration from application submittal to final approval and authorization by the NRC is 34 months.[13] This is more than 10 times the schedule that is needed to enable a business model that depends on a schedule of 6 months from site identification to operations. Within that 6 months, the regulatory process will need to be no more than 5 months, of which the duration from submittal of the application to the NRC to the final approval and authorization by the NRC must be completed in 4 months or less.

It is clear, it is not possible to achieve a 96% reduction in the current NRC licensing process (a 23-month reduction in the applicant's site characterization and application preparation – going from 24 to 1 month, and a 30-month reduction in the NRC review process – going from 34 to 5 months). More radical thinking, and likely a new process for approving and authorizing the operations are needed to enable the business model for rapid high-volume deployable reactors.

The central concept around rapid efficient licensing (ReLic) for rapid high-volume deployment (RHDRA) is to minimize the scope, content and purpose of the site-specific reviews. This is not suggesting the NRC cut corners, since it is recognized that these reviews must also be effective at providing reasonable assurance of adequate protection of the public health and safety. The concept is in when, who and how the reviews are performed and assembled together as part of demonstrating that the use of an advanced reactor at a particular site provides reasonable assurance of adequate protection of the public health and safety. This new type of site-specific review is enabled by:

1. completing all, or as much as possible, of the safety and environmental reviews and public engagement processes as possible one-time prior to the identification of a specific site, and

2. performing a site license review that only needs to verify that the site characteristics conform to the minimum set of site parameters in the envelope established in the one-time up-front reviews.

Potential cross-cutting fundamental elements (performance-based and graded to safety when possible) of the licensing approach could be:

- **NRC generic approvals on a technology-inclusive basis** – Use of a design that meets the performance-based acceptance criteria established for generic NRC approvals will significantly reduce the scope of the site license review. The NRC has several processes to make generic approvals on a technology-inclusive basis that will be applicable to many designs. While rulemakings are by far the most effective at achieving rapid efficient licensing, they are not the only process available to the NRC. Rulemaking can be used to codify generic decisions, bringing with them the public engagement process, such as the NRC is in the process of doing with the Advanced Nuclear Reactor Generic Environmental Impact Statement. Rulemakings can also be used to establish alternative regulatory approaches, or even eliminate requirements that are not necessary to provide reasonable assurance of adequate protection.

- **NRC approvals with a standardized design** – Use of a standardized design that has been approved by the NRC will significantly reduce the scope of the site license review. The NRC has several processes to approve a standardized design, such as the Standard Design Approval, Design Certification, Manufacturing License, and Part 50 Appendix N. These offer different levels

[13] This is using the NRC's recent review schedule of 26 months – from docketing to issuance – for the Kairos Hermes, which is about half the time of the NRC's Generic Review Schedules. Note that the NRC review of Kairos Hermes was for a construction permit, and the 34 months for NRC approval and authorization assumes the same schedule for a COL followed immediately by the process to issue a 103.g finding.

of NRC approvals in terms of scope of the design and finality in the NRC decision. These licensing processes offer graded approaches, in that the more scope and content that is included in these applications, especially for site-characteristics that bound future potential sites, the greater these licensing actions will enable schedule reductions for the site license, and cost reductions for deployment at a high-volume of sites.

- **NRC pre-approvals for a Licensee** – Use of NRC processes to pre-approve a licensee prior to the selection of the site would address matters that are not specific to a site. The NRC must review applications to determine that an applicant is qualified and capable of owning and operating a nuclear reactor. The NRC must also review certain programs in association with the applications to verify compliance with NRC regulations. The more of this non-site-specific site-license information that applicants are able to submit to the NRC, and the more the NRC can review and approve such information ahead of time, the less information that will need to be included in the site-specific review.

- **Use of Pre-Existing Reliable Site Data** – Use of reliable generally available data that already exists will significantly reduce the time it will take to collect site-specific data. The NRC requires several types (e.g., soil, weather, flora and fauna) of site characterization data that must be verified that the site conforms to the conclusions of the safety and environmental analyses. Traditionally, the NRC has required that this data be collected over long periods of time after the site has been selected, typically requiring at least two (2) years from the time the site is selected until the application could be submitted. Clearly a 2-year process, from the point of site selection, that only gets to the point of submitting an application will never enable a business model that requires a 6-month schedule between those two points – even if the NRC's licensing process could be reduced from 34 to 4 months. Reliable data for U.S. sites already exists that could be used in any advanced reactor site license application, review and approval, and for on-going operations when that data may be so required. For example, the National Oceanic and Atmospheric Administration has meteorological data, and the U.S. Geological Survey of the Department of Interior has seismic hazard data and a process to evaluate seismic hazards that is similar to the NRC-endorsed SSHAC process, both of which have this data for sites across the U.S. These are federal agencies directed by Congress to collect and administer this information for use by other federal agencies and others for the benefit of the general public. The NRC has also, in the case of National Metrology Institutes (NMIs) not just in the U.S. but also international, recognized the ability to use their data for safety-related applications and without the need for them to meet Appendix B or be audited by purchasers, because those NMIs are government institutions with proven abilities and disciplines. (ML15111A477)

The common theme to each of these fundamental elements to rapid efficient licensing (ReLic) for rapid high-volume deployment (RHDRA) is to move the scope and content of information that has traditionally been in the site license application into licensing processes that can occur one-time prior to the site license application. In doing so, these one-time up-front approvals will establish the minimum set of bounding site parameters that are necessary and sufficient to verify that the site complies to these prior NRC approvals. This enables the NRC's review of the site license application to be a verification of compliance with the site parameter envelope, ensuring that the site license conforms with all the NRC conclusions from prior safety and environmental reviews, along with their commensurate public engagement processes. Figure 3-3 provides a simplified perspective of how a rapid efficient licensing (ReLic) for rapid high-volume deployment (RHDRA) could enable a business model that requires a 6-

month schedule from the point of site selection to operations. Figure 3-4 provides a more specific example of how NRC licensing processes could be used to create the ReLic process.

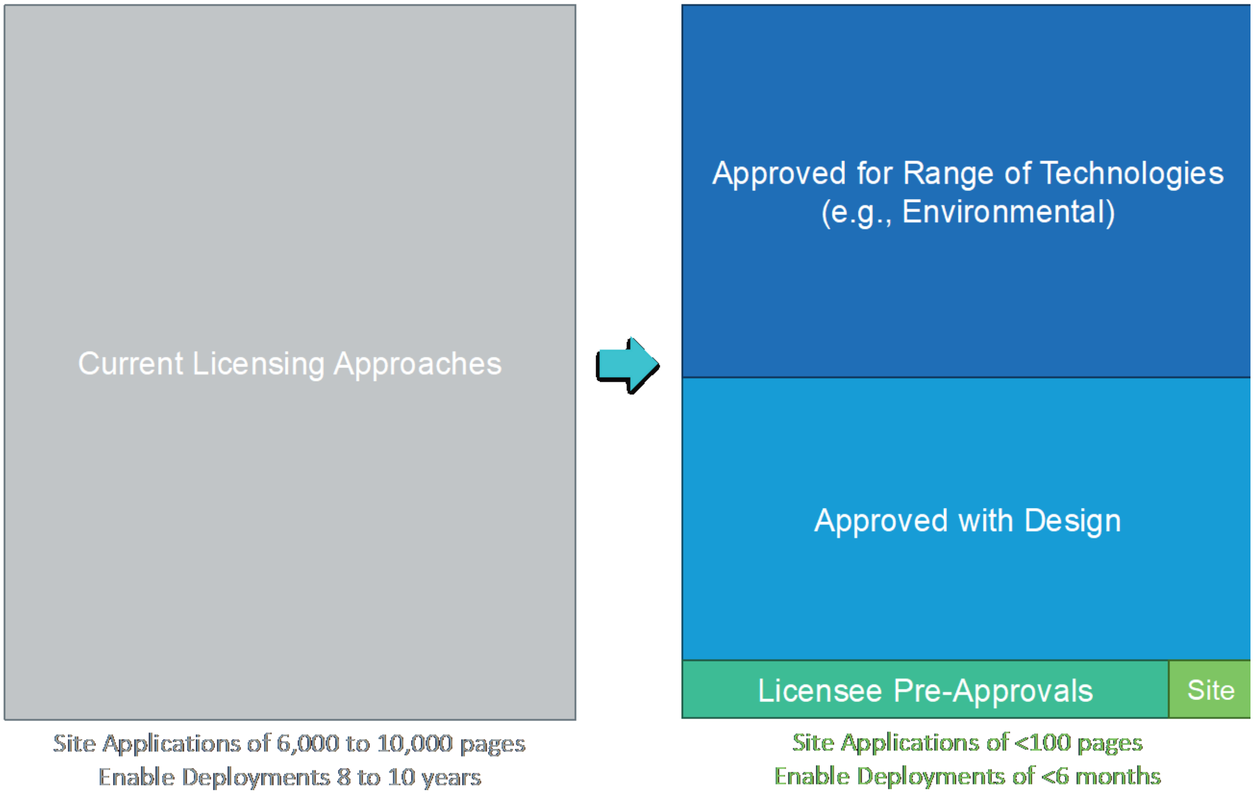

Figure 3-3: Concept for Using Multiple NRC Processes for Rapid Efficient Site Licensing

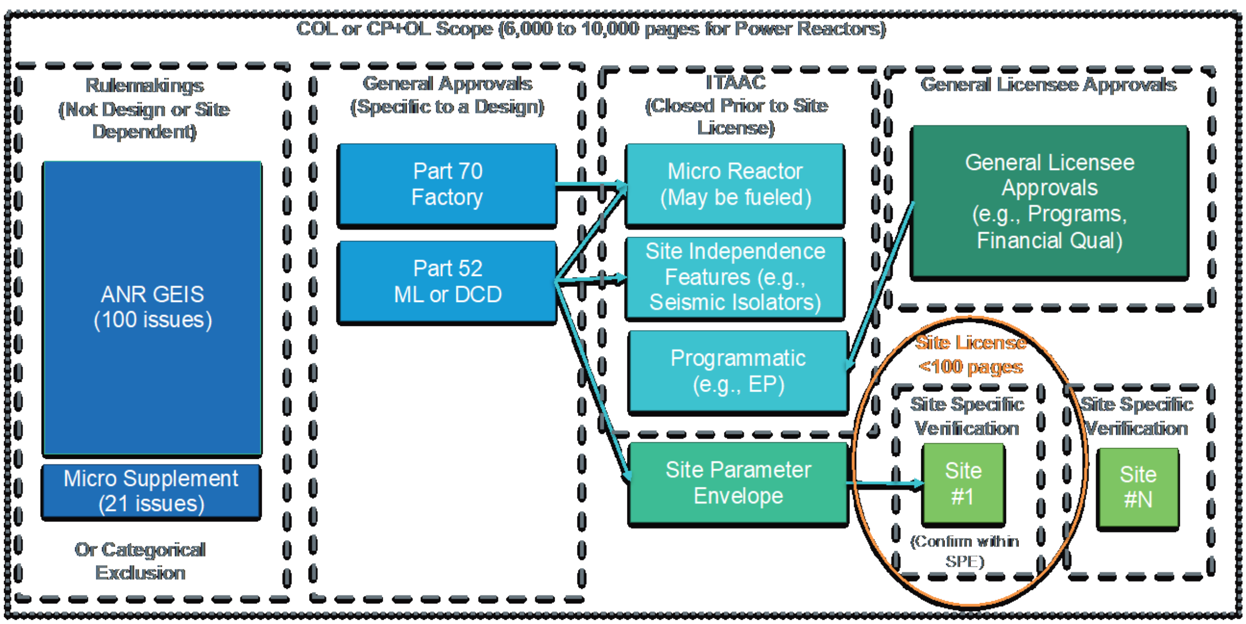

Figure 3-4: Example of NRC Processes that Could Enable Rapid Efficient Licensing of Sites

3.2.3 Goals for Regulatory Clarity

The technology and business models for these types of designs are rapidly maturing and the first applications are expected to be submitted to the U.S. Nuclear Regulatory Commission (NRC) as early as 2024. Lack of clarity on an efficient and effective alternative regulatory framework will impede the work of designers to develop their technologies, and the potential owners to develop their concepts of deployment and operations.

Given the revolutionary changes that are needed to enable a business mode that can achieve a 6-month schedule from site identification to operations, and regulatory costs that are less than 1% of total costs (capital and O&M), these companies have few good choices. They can either develop approaches around the existing regulatory framework, including the in-progress alternatives being developed, or they can develop approaches that are fundamentally different from what the NRC has previously approved or is considering. In the former, they are likely to develop approaches that cannot meet the business requirements and will need to seek alternative technologies, abandoning the potential for these hard to abate industries to reliably and affordably decarbonize their operations. In the latter, they will have to spend tens (10s) of millions of dollars and spend the next few years to develop approaches that they do not know whether the NRC will ever approve.

The difficulty between these two choices is expressed by Shepherd Power that said in the May 14, 2024, NRC public meeting that "*Industrial Customers see licensing & regulatory uncertainty as chief risks,*" so much so that it is "*Impossible to have price and delivery conversations [with customers] based on the current state of regulation.*"

This stresses the clear urgency to provide what Shepherd and others in the market for advanced reactors need, specifically "*sufficient clarity by the end of 2024 on a licensing pathway supporting scale micro-rector deployment*." This clarity could be provided by an NRC plan to pursue alternative regulatory approaches that provide resolution of the topics described in this document and achieve the necessary conditions for regulatory effectiveness and efficiency that enables the business case. To this end, the NRC in the May 14, 2024, public meeting stated that they have plans to develop a paper addressing the regulatory topics related to the rapid high-volume deployable reactor business model later this year for the Commission's approval.

It is the intent of this paper to inform the NRC staff's paper to the Commission, and the Commission's consideration of the regulatory topics for rapid high-volume deployable reactor business. This paper is written to capture the emerging concepts that are being developed into a more detailed and actionable proposal paper that is expected to be submitted to the NRC around the end of July 2024.

As discussed in this paper, there are revolutionary changes that would need to be undertaken in an alternative regulatory framework to enable this business model, and our work to date indicates that this can be done in a way that provides reasonable assurance of adequate protection of the public health and safety. Shepherd, BWXT and NEI presented an overview of the concepts that are described in detail in this paper. The NRC also agreed with the assessment of achieving the concepts presented in the meeting, saying that it may be hard, but it does not seem untenable.

It is also the intent of this paper to inform other on-going NRC work to prepare the regulatory framework for advanced reactors. As discussed in this paper, many of the concepts can be applied more broadly to other advanced reactors, sometimes directly and sometimes in a graded approach. On-going rulemakings such as Part 53 to create a technology-inclusive, performance-based and risk-informed alternative rule for advanced reactors, according to the requirements of NEIMA, would benefit from considering these emerging concepts for technology capabilities, deployment and operations, and an alternative regulatory framework. Other activities such as the considerations of topics in SECY 24-0008 for micro-reactors would also equally benefit from being informed by these concepts. NRC prompt action in addressing the needs for rapid high-volume deployable reactors will enable market participants to pursue their business goals in the 2026/2027 timeframe.

This paper provides input to the on-going work by the NRC to address this class of reactors in developing options for alternative approaches to achieve the goals for regulatory clarity by the end of 2024, and establish these alternative regulatory approaches to enable the business model by 2026. This paper also provides a foundation for an industry proposal for the regulation of rapid high-volume deployable reactors, that the Nuclear Energy Institute (NEI) anticipates submitting to the NRC around the end of July. NEI anticipates that NRC public workshops to discuss these topics in more detail would foster mutual understanding and transparency to all stakeholders, yielding more timely and well-considered alternative regulatory approaches.

3.3 Regulatory Topic Areas

This section describes the topics that are expected to need alternative regulatory approaches for rapid high-volume deployable reactors. There are currently 31 topics that have been identified. While some of these topics have previously been addressed by the NRC in work related to micro-reactors and manufacturing licenses, these topics have not fully considered the unique and significantly different aspects of the business model for rapid high-volume deployable reactors. Therefore, a fresh regulatory analysis and development of options for alternative approaches is warranted for all of these topics.

As part of this paper's goal to describe the concept for the rapid high-volume deployable reactors, the following information is provided for each topic area:

1. **Topic Description** – This includes a description of the unique features of the technology capabilities, and concept of deployment and operations that merit consideration for the topic area. This also includes a discussion on the flexibility of the current regulatory framework to enable, and the limitations of the current regulatory framework that would prevent, the business model for rapid high-volume deployable reactors.

2. **Desired Outcome** – This includes the vision for an alternative regulatory approach that enables the business model. This is not intended to include a description of the regulatory changes that may be necessary, but rather it is intended to describe the feature-based end-state for the alternative regulatory approach.

3. **Potential Priority** – This indicates the potential priority for achieving regulatory clarity based upon how significant the topic is to enabling the business model, and the amount of effort that is expected in order implement an alternative regulatory approach. This paper uses a five-level priority ranking from High, Medium-High, Medium, Medium-Low and Low.

The set of 31 topic areas is organized into four groupings of similar topics based upon the business model. Specifically: 1) Licensing Process, 2) Concept of Deployment, 3) Concept of Operations and 4) Total Lifecyle. The set of the 31 topic areas and their groupings is listed in Table 3-1.

It is noted that the work to identify these topic areas has resulted in a comprehensive list of regulatory topics, although the work is not exhaustive and is still on-going. While it is not expected that there will be significant changes to the set of topics identified in this paper, it is possible that additional topics may be identified, and some of the topics described in this section may later be determined to not be expected to need alternative regulatory approaches. The finalization of this list will benefit from NRC public workshops with all stakeholders. NEI plans to submit to the NRC more complete regulatory analyses, and options for changes, for an exhaustive set of topics in the proposed regulatory approach for rapid high-volume deployable reactors paper that is anticipated around the end of July 2024.

Table 3-1: List and Groupings of Regulatory Topic Areas

Group 1 (Licensing Process)		Group 2 (Concept of Deployment)		Group 3 (Concept of Operations)		Group 4 (Total Lifecycle)	
Topic Area	Potential Priority	Topic Area	Potential Priority	Topic Area	Potential Priority	Topic Area	Potential Priority
Approvals Prior to Site License		Design Considerations		14) On-Site Staffing	Medium	Pre-Operational	
1) Generically Resolved Environmental Considerations	High	9) Aircraft Impact Considerations	Medium	15) Automatic and Autonomous Operations	Medium	25) Use of Contractors By Manufacturing Licensees	Medium
2) Design Approval Scope and Authorizations	Medium			16) Remote monitoring	Medium	26) Loading Fuel at Factory	Medium
Approvals with Site License		Site Characterization		17) Remote operations	Medium	27) Testing at the Factory	Med-High
3) Construction Authorization Upon Docketing	High	10) Meteorology and Weather Data	High	18) Cyber security	Medium	28) Features to Preclude Criticality	Medium
4) Inspections, Tests, Analyses and Acceptance Criteria	High	11) Geologic and Geotechnical	High	19) Physical Security	Medium	29) Transport of Fueled Reactor	Med-High
5) Site License Scope and Purpose	Med-High	12) Flooding	Med-Low	20) Emergency preparedness	Low	Post-Operations	
6) Streamlined Contested Hearing	High	13) Other External Hazards	Low	21) FFD/Access Authorization	Medium	30) Replace Modules at Site	Med-Low
7) Elimination of Mandatory Hearing	Med-High			22) Radiation Protection	Med-Low	31) Storing Used Fuel at Site	Med-Low
8) Licensing Review Resources and Costs	High			23) NRC Oversight	Med-High		
				24) Annual Fees	High		

3.3.1 Licensing Process Topics

The topics in this section relate to the process for obtaining a license to approve and fully authorize the operation of a rapid high-volume deployable reactor. The focus of these topics is to structure a process for the NRC to review all safety and environmental considerations in a way that provides finality through generic and design specific licensing actions, resulting in a site license review process that does not introduce any new safety or environmental considerations, and only needs to verify conformance to prior NRC approved conditions. There are 8 interrelated topics arranged to illustrate how they enable the business case for time and costs.

Approvals Prior to Site Licensing

1. Generically Resolved Environmental Considerations

Topic Description

NRC's NEPA regulations in 10 CFR Part 51 require the agency to prepare an EIS for specific categories of actions, including permits/licenses to construct and operate any nuclear power reactor. The EIS process involves multiple stages, including scoping, development of a draft EIS for public comment and EPA review, numerous public meetings, inter-agency consultations, and preparation of responses to public comments for inclusion in the final EIS. Environmental issues also may be the subject of contentions and Commission inquiries as part of the contested and mandatory hearing processes, respectively. As such, NRC NEPA reviews for new reactors are likely to require at least two years to complete (and, historically, have averaged three to four years). This review timeline is not compatible with the business model needed for a licensing pathway that takes no more than 180 days from the date a precise location is identified to the time it begins operations.

Desired Outcome

The NRC satisfies all NEPA requirements either on a class of reactor basis, e.g., micro-reactors, or on a design specific basis, so that the site license application and NRC review does not need to include any environmental review or hearing scope. The NRC has several options such as issuing a categorical exclusion for micro-reactors, completing a generic EIS that resolves all environmental topics (i.e., the ANR GEIS scope plus the 21 topics not addressed generically), or performing a full EIS with the design approval. Any of these options would need to be completed prior to the identification of the site, and may need to rely on generic, bounding analyses (e.g., the ANR GEIS and a potential supplement thereto), tiering, incorporation by reference, and environmental assessments (possibly including associated exemptions, a rule of particular applicability, and application of non-power reactor environmental review guidance to microreactors). NRC approach would also need to satisfy the AEA's contested hearing opportunity requirement.

Potential Priority

High

2. Design Approval Scope and Authorizations

Topic Description

The existing Part 52, Subpart F, and proposed Part 53 requirements, do not address all the topics necessary to enable manufacturing license (ML) closing all ML ITAAC at the factory, fueling the reactor in the factory, operational testing of the reactor in the factory, transportation of a fueled reactor to the deployment site, and emplacement of the reactor at the final operation location prior to the NRC issuance of a site-specific license (either a concurrent Part 50 CP+OL or a concurrent Part 52 COL+103.g finding. The NRC regulations also do not provide similar (though not necessarily needing to be the same) flexibility for other NRC processes to approve standardized designs (e.g., design certifications – DC – and standard design approvals – SDAs). Furthermore, the NRC regulatory framework for these one-time up-front approvals of standardized designs does not enable providing finality on all NRC safety and environmental considerations (either directly in the design approval or by incorporating generic approvals on a technology-inclusive basis) that would be needed for NRC review and approval of a site license (e.g., Part 50 CP+OL or Part 52 COL+103.g finding).

Desired Outcome

NRC establishes a regulatory framework with process(es) to approve standardized designs so that future site licenses incorporating the NRC approved standardized design would not need to review any new or additional safety and environment considerations, but could rather be focused solely on the verification that the site conforms the design's site parameter envelope. As a fundamental element of a new NRC rapid efficient licensing (ReLic) process, the NRC approval of the standardized design, together with generic approvals on a technology-inclusive basis and licensee pre-approvals enable a site license process (review and approval, scope, content and purpose) that results in site license applications that are 10s of pages and enable an NRC timeline from site license application submittal to approval and authorization to operate in less than 5 months. It is recognized that as more of the scope and content of the NRC review is moved from the site license application to the application for the standardized design, the NRC process for approving standardized designs may not be significantly shorter for smaller simpler reactor designs than the current NRC Generic Review Schedule of 30 to 42 months that has been established for larger more complex non-LWR and LWR designs.

These NRC approvals of standardized designs would need to be sufficiently comprehensive to enable closing all design and site related ITAAC, fueling the reactor in the factory, operational testing of the reactor in the factory, transportation of a fueled reactor to the operating site, and emplacement of the reactor at the final operation location prior to the NRC issuance of a site-specific license, so that the NRC approval and authorization of the site license (either a concurrent Part 50 CP+OL or a concurrent Part 52 COL+103.g finding) would permit immediate operation of the reactor.

The NRC process for resolving safety and environmental considerations in the design review, and using the site license to verify conformance to the site parameter envelope, should also include considerations of potential future design changes that require a change to the NRC issues ML, DC or SDA. These potential design changes could come from operating experience, NRC orders that impose new requirements, or design enhancements. The NRC process should be effective and efficient in permitting innovation, while avoiding burden on site licensees that reference the NRC approved design.

Potential Priority

Medium

Approvals with Site Licensing

3. Construction Authorization Upon Docketing

Topic Description

Existing NRC processes for authorizing construction and operation, whether under the Part 50 CP/OL or the PART 52 COL regulations, will not permit a schedule of 6 months from site identification to operation. The business model would require construction, which requires prior NRC approval, to begin within two months of site identification, which is about the time when the NRC accepts and dockets the application. This does not allow the NRC time to review (beyond the acceptance timeline) the application to make a decision to allow construction prior to final approval (either through a Limited Work Authorization – LWA – or Commission discretion).

Desired Outcome

The NRC establishes a process that would authorize construction activities, which today require the issuance of a site-specific construction permit, COL or LWA, concurrent with or prior to the acceptance and docketing of the site license application. This construction includes site preparation, concrete pad, any buildings, and installation. This would not include startup testing and commissioning (which can occur starting in month 5 after identifying the site). This process would need to not trigger any additional safety assessment, environmental review or opportunities for public hearings.

Potential Priority

High

4. Inspections, Tests, Analyses and Acceptance Criteria (ITAAC)

Topic Description

According to SECY-24-0008, the ITAAC closure process could take at least 6 months. If ITAAC cannot be closed until after the reactor is fully emplaced at the site, this will require at least 11 months from site identification to operation (assuming that the site license process can be completed in the needed maximum of 5 months). Thus, all ITAAC must be closed sufficiently before the reactor is emplaced at site in order to enable the 6 month schedule from site identification to operations. However, the NRC does not have a process to enable all ITAAC to be closed prior to having the reactor emplaced at the final site of operations. The NRC also has not contemplated issuance of the 52.103(g) finding at the same time as the COL is issued.

Desired Outcome

Closure of ITAAC as part of the Manufacturing License, or other process to approve the standardized design (e.g., at the manufacturing facility) and as part of the licensee pre-approvals (e.g., Emergency Preparedness program), and the minimization of ITAAC in the COL, all of which can be closed during the licensing review finding so that the NRC can make the 103.g finding concurrent with the issuance of the COL.

Potential Priority

High

5. Site License Scope and Purpose

Topic Description

The current site-specific approach to safety and environmental reviews and issuing either an Operating License under Part 50 or a Combined Operating License concurrently with the 103.g finding under Part 52 will not support either the 6-month deployment schedule nor the <1% cost target.

Desired Outcome

NRC establishes a rapid efficient licensing (ReLic) process that enables the scope and content of the site license to be minimized by moving as much as possible from what has traditionally been in the site license application into licensing processes that can occur one-time prior to the site license application (e.g., generic technology-inclusive approvals, approvals with the design, and licensee pre-approvals), and the purpose of the site license to be a verification of conformance to the site parameter envelope established by those prior approvals. The process would enable the concurrent issuance of a construction permit and operating license under Part 50, or a COL under Part 52, within 5 months from application submittal to issuance.

Potential Priority

Medium-High

6. Streamlined Contested Hearing

Topic Description

Section 189.a. of the Atomic Energy Act requires the NRC to "grant a hearing upon the request of any person whose interests may be affected" by any proceeding for the granting, suspending, revoking, or amending of any license of construction permit; applications to transfer a license; or issuance or modification of rules or regulations dealing with the activities of licensees. In the licensing context, these are known as "contested hearings." The NRC currently uses a trial-type process for contested licensing hearings that takes many months and, in some cases, years to complete.

Desired Outcome

Significant reduction in the complexity and timeline for the conduct of contested licensing hearings to complete the contested hearing within a few weeks to up to three (3) months to enable the business model for a 180 day or less timeline from the point of site identification to operations.

Potential Priority

High

7. Elimination of Mandatory Hearing

Topic Description

The Atomic Energy Act (AEA) requires that the NRC conduct mandatory hearings on reactor applications for combined licenses, construction permits, limited work authorizations, and early site permits. These mandatory hearings occur after issuance of the final safety evaluation report and final environmental impacts statement by the NRC staff. Historically, mandatory hearings have added approximately 4-7 months to the process for issuing licenses and permits. Recent recommendations by the NRC’s Office of the General Counsel (OGC) to reform the mandatory hearing process recommend changes that would reduce this time frame to 8-10 weeks (from issuance of the FSER/FEIS or EA to final decision). These reforms could be made without changes to the AEA or the NRC’s regulations. Even if these reforms are approved by the Commission, the mandatory hearing would consume at least 1/3 of a 6-month deployment timeline, and nearly ¼ of a 9-month deployment timeline.

Desired Outcome

An amendment to the AEA, like the one proposed in the “Efficient Nuclear Licensing Hearings Act,” eliminates the mandatory hearing requirement.

Potential Priority

Medium-High

8. Licensing Review Resources and Costs

Topic Description

NRC reviews for site license applications have typically been about 75,000 person-hours ($25 million) for applications that are around 6,000 to 10,000 pages. NRC reviews for site license applications will have to be less than 500 person-hours ($150,000) for applications that are a few 10s of pages in order to enable the business model and meet the business case requirement that the regulatory costs are less than 1% of the total capital costs.

Desired Outcome

Achieving the desired outcomes for the other licensing process topics (e.g., site license scope and purpose, approvals with site licensing, generically resolved environmental considerations).

It is expected that if the NRC establishes a rapid efficient licensing (ReLic) process that this will enable site licenses that are a few 10s of pages and NRC reviews that are less than 500 person-hours. The ReLic process would enable the scope and content of the site license to be minimized by moving as much as possible from what has traditionally been in the site license application into licensing processes that can occur one-time prior to the site license application (e.g., generic technology-inclusive approvals, approvals with the design, and licensee pre-approvals), and the purpose of the site license to be a verification of conformance to the site parameter envelope established by those prior approvals. The process would enable the concurrent issuance of a construction permit and operating license under Part 50, or a COL and 103.g finding under Part 52, within 5 months from application submittal to issuance.

Potential Priority

High

3.3.2 Concept of Deployment Topics

The topics in this section relate to the technical topics that provide a basis for enabling the licensing process of a rapid high-volume deployable reactor. The focus of these topics is to enable all safety and environmental considerations to achieve finality through generic and design specific licensing actions, and enabling a rapid collection of site characterization data that will be used to verify conformance to prior NRC approved conditions. There are 5 interrelated topics arranged in two categories – Design Considerations and Site Considerations – to illustrate how they enable the business case for time and costs.

Design Considerations

9. Aircraft Impact Considerations

Topic Description

The 10 CFR Part 50.150-Aircraft Impact Assessment (AIA) Rule requires applicants to perform a design-specific assessment of the effects on the facility of the impact of a large, commercial aircraft. Using realistic analyses, applicants should identify and incorporate into the design those design features and functional capabilities to show that, with reduced use of operator actions: 1) The reactor core remains cooled, or the containment remains intact; and 2) Spent fuel cooling or spent fuel pool integrity is maintained. A primary driver for the current approaches to designing nuclear reactors to withstand an aircraft impact is the fact that the consequences of such an impact could pose a hazard to the public health and safety. For micro-reactors that are very small, such that it is highly unlikely that an aircraft could impact the micro-reactor building or result in damage to the fuel, and which have such low radionuclide inventories that a potential aircraft impact is unlikely to pose a substantial hazard to the public health and safety, it is expected that the unmitigated consequences of an aircraft impact on a micro-reactor would not lead to a significant adverse impact on the health or safety of the public. For these micro-reactors, the existing regulations on aircraft impact would result in unnecessary regulatory burden.

Desired Outcome

NRC generic rulemaking to establish that a class of reactors that are very small, such that it is highly unlikely that an aircraft could impact the micro-reactor building or result in damage to the fuel, and which have such low radionuclide inventories that a potential aircraft impact is unlikely to pose a substantial hazard to the public health and safety (as the NRC may define in a performance-based acceptance criteria related to source term, radiological inventory or thermal power level) would meet the intent of 10 CFR Part 50.150 to adequately protect the public health and safety from the consequences of an aircraft impact without the need for other means of defense-in-depth. The NRC's determination could be made in part on the basis that these designs would likely not need to meet the acceptance criteria of 10 CFR Part 50.150 (i.e., the reactor core does not need to remain cooled or the containment remain intact and the spent fuel cooling or spent fuel pool integrity is not needed to be maintained in order to meet NRC dose requirement in 10 CFR 50.34) in order to adequately protect the public health and safety. The rulemaking would also determine that it is unnecessary for a micro-reactor to perform a realistic analysis of an aircraft impact, if such an impact could not pose a substantial hazard to the public health and safety.

Potential Priority

Medium

Site Characterization

10. Meteorology and Weather Data

Topic Description

Regulatory Guide (RG) 1.23 is the sole NRC-endorsed methodology for meteorological data collection, and it requires 2 years (preferably 3 per the RG) of site-specific data (i.e., locally sampled) on wind speed, wind direction, temperature, humidity and precipitation. This data supports dispersion calculations for Main Control Room (MCR) dose (GDC 19), offsite dose (10 CFR 20, 50, 52), occupational dose (10 CFR 20), as well as design basis hazard characterization (10 CFR 50, 52) and emergency planning (10 CFR 50.47). A requirement for a met tower as described in RG 1.23 is codified in 10 CFR 50 Appendix E for emergency preparedness to accurately describe radionuclide dispersion during accident conditions, however 10 CFR 50.160, per a recent rulemaking, provides a performance-based alternative to 10 CFR Appendix E.

Desired Outcome

An alternative methodology for meteorological data collection that would allow reliable pre-existing data readily available for sites across the U.S. (e.g., NOAA/NWS) instead of site-specific met tower data to meet the site selection regulations. This methodology would rely on the same data, supplemented only if necessary with locally sampled data from commercial-grade met station equipment to meet the operating dose and EP requirements. The methodology should also enable the use of approaches to establish a design that is relatively independent of the site-specific conditions, such as through bounding design limits or design features, to reduce or eliminate the need for site-specific information and analyses.

Potential Priority

High

11. Geologic and Geotechnical

Topic Description

Site geotechnical investigations are costly and time consuming requiring significant work for region analysis (200 miles), Site Vicinity Analysis (25 miles), Site Area Analysis (5 miles) and Site Location analysis (1 km). The Site area analysis in particular requires borings and investigations incur timelines of years and costs of tens of millions of dollars that do not enable the regulatory framework to meet the business case requirements for less than 180 days from site identification to operation or regulatory costs less than 1% of total capital costs.

Desired Outcome

An alternative methodology for geotechnical investigation that would allow reliable pre-existing data readily available for sites across the U.S. (e.g., USGS) instead of site-specific seismic hazards identification and evaluation to meet the site selection regulations. This methodology would rely on commercial best practices to collect locally sampled data through core borings. The methodology should also enable the use of approaches to establish a design that is relatively independent of the site-specific conditions, such as through bounding design limits or design features like seismic isolators, to reduce or eliminate the need for site-specific information and analyses.

Potential Priority

High

12. Flooding

Topic Description

The current regulation guidance for definition of the design basis (DB) flood can be found in RG 1.59 R2. There is however a draft Revision 3 in DG-1290 published in 2022. This RG provides methodologies for calculating potential flooding impacts from local intense precipitation, storm surge, seiche, tsunami, ice effects and combined events. The DG provides considerations for ARs and SMRs which may not have fully considered the technology capabilities or concept of deployment of rapid high-volume deployable reactors. The guidance provides a progressive screening approach which consists of a series of gradually refined methods that increasingly use more detailed site-specific data or analysis methods or both. This gives applicants flexibility in addressing flooding hazards by choosing sites that screen quickly (hilltop away from dams), grading the site appropriately to encourage run-off, or by factoring in design considerations that can withstand significant floods and choosing the design basis flood conservatively. Because the RG has flexibility and does not specify site specific data collection outside of site surveys required to determine site typography and create inundation maps, the flooding considerations in the site licensing of rapid high-volume deployable reactors is likely to enable the applicant to conduct site characterization and application preparation in 1 month or less and an NRC site license review of 5 months or less from the application submittal to issuance.

Desired Outcome

NRC clarity (e.g., in RG 1.59 Revision 3) that site-specific data collection, outside of site surveys, is not required to determine site typography and create inundation maps, such that the flooding considerations in the site licensing of rapid high-volume deployable reactors enables the applicant to conduct site characterization and application preparation in 1 month or less and an NRC site license review of 5 months or less from the application submittal to issuance. NRC clarity should include a process for sites that may require additional flooding assessments or site-specific design changes based on local flooding beyond the plant design basis that could enable a timeline of 180 days or less from site identification to operation.

Potential Priority

Medium-Low

13. Other External Hazards

Topic Description

Aircraft Impact, Meteorology, Seismology, Geology, and Hydrology are addressed in their own individual regulatory topic areas. Other External Hazards encompass transportation and industrial hazards, volcanic hazards and any other hazards potentially threatening the site, many of which today require site-specific analysis. 10 CFR 100 has explicit requirements for assessment of nearby industrial, military and transportation hazards. RG 1.91 provides guidance on assessing explosive hazards. EPRI 3002005287, "Identification of External Hazards for Analysis in Probabilistic Risk Assessment," contains guidance on the broader hazards screening process. Volcanic Hazards have specific guidance in RG 4.26. It is not clear whether, though it may be possible that, the NRC's existing regulatory framework for other external hazards enables a site licensing process of less than 5 months from site identification to issuance of the license, with all approvals and authorizations to operate the reactor.

Desired Outcome

Clarification that NRC's existing regulatory framework for other external hazards currently enables (or a regulatory framework is established that would enable) these other external hazards (e.g., industrial, military, transportation, volcanic hazards and any other hazards potentially threatening the site – not including topics addressed separately such as seismic, meteorology and flooding) to be addressed generically outside of a site specific license (i.e., through a one-time up-front in a generic technology-inclusive approval, or an approval of a standardized design). This regulatory framework would enable the site license application to solely focus on verification of the site's conformance to the site parameter envelope (established in those one-time up-front approvals) for these other external hazards and not require any additional analysis or result in new or additional considerations in the site license application. Such a regulatory framework for other external hazards would allow site characterization, including the collection of any necessary locally sampled data, with a timeline that enable a timeline of 1 month or less from the site identification to application submittal followed by an NRC acceptance review, verification of conformance to the site parameter envelope, final Commission approval and issuance of the site license, and including the public engagement process, to be completed within 4 months.

Potential Priority

Low

3.3.3 Concept of Operations Topics

The topics in this section relate to the topics that provide a basis for enabling the concept of operations for rapid high-volume deployable reactor. The focus of these topics is to provide reasonable assurance of adequate protection during the operation of the reactor. There are 11 interrelated topics arranged to illustrate how they enable the business case for time and costs.

14. On-Site Staffing

Topic Description

NRC-required staffing functions include licensed operators, fire brigade, normal surveillance and reactivity manipulations which will depend on the ability to achieve autonomous operations, remote monitoring and remote operations. It also includes staffing for security, emergency preparedness, and radiation protection. Site staffing requirements are defined in 10 CFR 50.54(m), 10 CFR 50.48, 10 CFR 50.120, and NUREG-0737 and drive the bulk of operations staffing. Advanced reactor designs have not been factored into existing regulation, such that exemptions need to be submitted based on the licensee's concept of operations. The concept of operations for rapid high-volume deployable reactors will deviate from many of the NRC requirements and guidance, and may raise new policy issues.

Desired Outcome

NRC establishes an alternative regulatory framework for staffing that is commensurate with the technology capabilities and concept of operations for rapid high-volume deployable reactors. The alternative regulatory framework is based on, and similar to, RTRs, with taking into account the use of automatic operations, remote monitoring and remote operations, as well as the potential to leverage staff from co-located facilities.

Potential Priority

Medium

15. Automatic and Autonomous Operations

Topic Description

Autonomous operations will be necessary to meet the business case for the 1st reactor (with local operations) and beyond the 20th reactor (with remote operations). This is envisioned to be only one on-site licensed operator (with collateral duties) for the 1st reactor, and about 4 operators for large fleets of over 100 reactors in a future remote operations center. This issue will focus on automation necessary to enable only 1 on-site operator, though the level of automation to enable remote operations (should also be considered during initial design decisions). While the NRC approved the NuScale design with 6 operators for 12 reactors, it is important to note that the NRC has not previously approved a condition of only a single operator on-site (except perhaps for research and test reactors).

The NRC has already begun the consideration of autonomous operations in the recent SECY 24-0008. The NRC has said that the requirements in 50.54(i), (j), (k), and (m) would be applicable, that require only licensed operators to manipulate controls and other mechanisms that affect reactivity. The ACRS has stated its opposition to the notion of unsupervised operations, regardless of the level of automation, and the NRC has indicated that a licensed operator may be required to be present at the controls even if they are not necessary, as a matter of defense in depth.

Desired Outcome

NRC establishes a regulatory framework for the use of autonomous operations enabling business models that have as few as one (1) person on-site at one time, or no staff on-site when the plant is operated remotely. NRC addresses the definition of “autonomous operations” with “levels of autonomy” providing more precise definitions of the intended concept of operations. This regulatory framework would ensure that Human Factors Engineering (HFE) guidance is developed for autonomous operations, including levels of autonomy up to the use of artificial intelligence.

Potential Priority

Medium

16. Remote Monitoring

Topic Description

The NRC has previously addressed remote and autonomous operations, but not explicitly remote monitoring, which will include cyber security considerations. Remote monitoring is envisioned to be utilized for the 1st reactor and beyond, eventually being complemented with remote operations from about the 20th reactor and beyond. Remote monitoring may be necessary to enable only 1 operator on-site at each reactor, in that it may need to be credited for the regulatory requirements of detection, assessment and notification (e.g., for security and emergency preparedness). Remote monitoring will also serve as developing the data that will provide a basis for confidence in remote operations (in the areas of connectivity, cyber security, etc.).

Desired Outcome

NRC establishes a regulatory framework for the use of remote monitoring of the plant operations and instrumentation.

Potential Priority

Medium

17. Remote Operations

Topic Description

The NRC has already begun the consideration of remotely operated reactors in their “Ground Rules” document and in the recent SECY 24-0008. The NRC has indicated that they would apply the requirement of 50.34(f)(2)(iii) that would require on-site capabilities for 1) prompt hot shutdown with I&C to maintain a safe condition, and 2) (potential) subsequent cold shutdown through suitable procedures. For the remote facility, the NRC has said that the requirements in 50.54(m) for minimum licensed operator staffing would be applicable, and deviations would require an exemption request. However, these efforts have not considered the unique concept of remote operations for rapid high-volume deployable reactors, which are expected to rely on remote operations from a central location once the licensee’s deployment of reactors reaches a certain number, e.g., more than 20. Not only would this mean that there are no permanent on-site operators 24/7, but that also the remote operators would oversee a large number of reactors per operator. As an example, there may be 4 operators at all times at the controls in a remote facility (1 ops manager, 2 licensed operators over 50 reactors each, and 1 flex position) for a large fleet of over 100 reactors. This would be a dramatic change even from the NRC’s approval of the NuScale design which required 6 operators on-site for 12 reactors.

Desired Outcome

NRC establishes a regulatory framework for the use of remote operations of many reactors by only a few operators, consistent with the HFE and task analysis. NRC staff agrees in principle that the concept of operation can be achieved safely including defining “main control room” or “at the controls” to include control rooms established in remote locations. This regulatory framework would ensure that Human Factors Engineering (HFE) guidance is developed for remote operations.

Potential Priority

Medium

18. Cybersecurity

Topic Description

Autonomous operations, remote monitoring, and remote operations (see those issues) all depend on operations that could be susceptible to cyber-attacks, which could intercept the controls and result in undesired outcomes. The most cost-effective approach would be to design the micro-reactor to eliminate the ability for a cyber threat vector that could challenge the ability to protect the public health and environment (e.g., reactor protection overrides not susceptible to cyber-attacks would always put the reactor in a safe configuration). If the design could not eliminate all cyber threat vectors, then it may require extensive facility design and programmatic elements to assure protection.

Desired Outcome

A cybersecurity program scoped to ensure that only systems that perform or rely on functions that can contribute to the consequences stated in the regulation are assessed and protected. A ‘security by design’ approach may also resolve or mitigate additional security issues. Documentation of the design basis elements and physical protection system features are needed to justify why a cyber-attack does not result in unacceptable consequences as described in the regulation.

Potential Priority

Medium

19. Physical Security

Topic Description

The NRC regulatory framework for Physical Security, including the proposed alternative approaches in the NRC limited scope rulemaking for SMRs and other nuclear technologies (ONT) and the Part 53 rulemaking, does not fully contemplate the technology capabilities and concept of deployment and operations for rapid high-volume deployable reactors. Many of these designs are expected to be very small, simple and incorporate safety features that would result in potential consequences to the public that are more similar to RTRs than the advanced reactors that have been considered for the proposed alternative regulatory frameworks. Furthermore, it is not clear that the NRC would need to require protection against a Design Basis Threat (DBT) for this class of reactors in order to provide reasonable assurance of adequate protection of the public health and safety.

Desired Outcome

NRC establishes an alternative regulatory framework for physical security that is appropriate for the class of rapid high-volume deployable reactors that fully considers the technology capabilities, and the concept of deployment and operations. This alternative regulatory framework (whether incorporated into the alternative framework for SMRs and ONT and/or Part 53, or in a new rulemaking) should consider, and be based upon, the regulatory framework for non-powered reactors, and adjusted as appropriate to be commensurate with the simplicity, safety features, and consequences and risks of the technology. Similar to the considerations of this class of reactors for AIA requirements, the alternative regulatory framework for physical security should consider that a class of reactors that are very small, and which have such low radionuclide inventories that a potential credible attack is unlikely to pose a substantial hazard to the public health and safety (as the NRC may define in a performance-based acceptance criteria related to source term, radiological inventory or thermal power level) would adequately protect the public health and safety without the need to protect against the DBT. The NRC's determination could be made in part on the basis that these designs would likely not need the reactor core to remain actively cooled or the containment remain intact and the spent fuel cooling or spent fuel pool integrity is not needed to be maintained in order to meet NRC dose requirement in 10 CFR 50.34. The rulemaking should include, as appropriate, requirements (e.g., barriers, detection and assessment equipment, etc.) that would be needed to provide reasonable assurance that the performance of a design would meet the performance-based acceptance criteria. The alternative regulatory framework would also need to establish requirements for security staffing that enable the two concepts of operations (discussed in detail in this report that would not have dedicated security staff): 1) only one person on-site at any time, and 2) no on-site staff with remote operations and field technicians that visit the site periodically. The staffing requirements would include consideration of routine security functions such as access control, detection, assessment and notification of local responders. This should also consider the potential for leveraging staff at co-located facilities, such as might exist at remote industrial applications. The alternative regulatory framework would also credit advanced technologies, e.g., facial recognition, AI, to meet physical security requirements.

Potential Priority

Medium

20. Emergency Preparedness

Topic Description

The NRC regulatory framework for Emergency Preparedness (EP), including the recently issued "Emergency Preparedness for Small Modular Reactors and Other New Technologies: Final Rule," 50.160, does not fully contemplate the technology capabilities and concept of deployment and operations for rapid high-volume deployable reactors. It is expected that a micro-reactor facility will have an emergency planning zone (EPZ) at the property fence line (i.e., site boundary), which will typically be within 100 meters of the reactor. 50.160 provides a performance-based, technology-inclusive, risk-informed, and consequence-oriented EP framework for use by advanced reactor facilities. However, it is not clear whether the rule provides the flexibility necessary to achieve a cost-effective emergency plan for rapid high-volume deployable reactors.

Desired Outcome

NRC clarification that 50.160 provides the flexibility necessary to achieve a cost-effective emergency plan for rapid high-volume deployable reactors. This includes the necessary EP infrastructure and the site and remote operations center, if applicable, and the ERO staffing plan that supports the two operational concepts: 1) only one person on-site at any time, and 2) no on-site staff with remote operations and field technicians that visit the site periodically. This should also consider remote industrial applications and the potential for leveraging staff at the co-located industrial facility. Obtaining such clarity is important to define the anticipated EP needs for a facility soon. If 50.160 does not provide the needed flexibility then rulemaking, exemption pathways, and/or additional guidance could be necessary.

Potential Priority

Low

21. Fitness for Duty and Access Authorization

Topic Description

The Access Authorization and Fitness for Duty programs are designed to ensure personnel meet high standards of trustworthiness and reliability by ensuring personnel are fit to perform nuclear duties safely and competently, free from impaired conditions. Ensuring the integrity of Access Authorization and Fitness for Duty programs directly contributes to viable insider threat mitigation initiatives and supports an effective safety program. The criterion applicable to the design will determine the program requirement need. The current regulatory framework for Access Authorization and Fitness for Duty programs establishes criteria prescribed in 10 CFR 53.860 and 10 CFR 53.4330. The Part 53 rulemaking proposed alternative requirements with easier access authorization and fitness for duty mandates than would be required today for large LWRs and other advanced reactors. However, it is not clear whether the proposed Part 53 alternative requirements have fully contemplated the concept of operations for the rapid high-volume deployable reactors.

Desired Outcome

NRC establishes an alternative regulatory framework for access authorization and fitness for duty (AA/FFD) that is commensurate with the technology capabilities and concept of operations for rapid high-volume deployable reactors. The alternative regulatory framework would create an AA/FFD program that enables the two options of concept of operations (described more fully in Section 2.4): 1) a single person on-site, and 2) no on-site staffing, operations from a remote center and field technicians that visits site periodically. The alternative regulatory framework would consider, and be based upon, the existing programs for access authorization programs for non-powered reactors, and adjusted as appropriate to be commensurate with the simplicity, safety features, and consequences and risks of the technology. The alternative regulatory framework would also credit advanced technologies, e.g., facial recognition, AI, to meet the required function of the AA/FFD program. The program would continue to meet the standard of providing reasonable assurance that individuals that are subject to the program are trustworthy and reliable.

Potential Priority

Medium

22. Radiation Protection

Topic Description

The approved radiation protection (RP) program (*including radiation monitoring strategy*) will be highly dependent upon the approved operations approach (e.g., remote Ops). If a remote operations approach is accepted by the NRC, it will be easier to justify why onsite RP is not needed. However, if someone is required to be onsite the individual would potentially either need to be qualified in RP or an RP person may be needed. Justifying that a baseline background study is not needed will also be a challenge.

Desired Outcome

The NRC accepts that a corporate RP Program that has oversight of multiple remote micro-reactor sites, where RP qualified individuals are not on site at all times, can still meet the requirements of 10 CFR 20.1101, "Radiation protection programs". In addition, acceptance by the NRC that extensive evaluation of pre-operational baselines (e.g., background radiation studies) may be unnecessary or can heavily rely on previously established data that was used to characterize the sites.

Potential Priority

Medium-Low

23. NRC Oversight and Inspection

Topic Description

For operations oversight and inspection today the NRC has two (2) resident inspectors at each reactor site, which for a fleet of 100 micro-reactors (potentially all at different sites) would be 200 NRC inspectors, plus any regional inspectors. However, to enable the business model and meet the business requirement that regulatory costs are less than 1% of total O&M costs, the NRC will need to achieve about three (3) total inspectors for a fleet of 100 micro-reactors. This means that the inspectors would not visit a site more than one or a few times per year. While this may be similar to the level of oversight and inspection for RTRs, the NRC has not provided clarity on whether the operations oversight and inspections will achieve the effectiveness and efficiency commensurate with the technology.

For construction oversight and inspection the NRC is developing the Advanced Reactor Construction Oversight Program (ARCOP), but is not clear whether the ARCOP will achieve effective and efficient oversight and inspections commensurate with the technology, or whether oversight and inspections for rapid high-volume deployable reactors would be more similar to other larger advanced reactors.

Desired Outcome

The NRC establishes, for both construction and operations, an oversight and inspection program for rapid high-volume deployable reactors commensurate with the technology, which is based on, and very similar to, the oversight for research and test reactors, as well as takes into account the novel features of factory pre-fabrication, closure of all ITAAC prior to emplacement at site, simplicity and reduced safety systems/controls, and remote operations.

Potential Priority

Medium-High

24. NRC Annual Fees

Topic Description

The NRC's current annual fee for micro-reactors is estimated to be about 2.43% of annual plant generating costs (O&M costs) for a 50 MW-thermal micro-reactor. This annual fee would constitute a much larger percentage than that paid of current large light water reactors in operation today (only 1.7% of annual plant generating costs). For smaller micro-reactors (less than 50 MWt), the percentage is even larger. Most notably, this causes an undue disproportionate economic burden, and unequitable outcome, for future micro-reactor licensees. Further, this regulatory gap creates uncertainty for prospective applicants who are currently making investments decisions. This does not meet the business case of annual total regulatory costs less than 1% of capital, and O&M costs, and more importantly, is not commensurate with the low-risk profile of micro-reactors.

Desired Outcome

Annual fees for microreactors should avoid disproportionate impacts to licensees and their customers. The annual fees should reflect micro-reactors' inherent simplicity, small radionuclide inventories, reliance on inherent and passive safety features, and as such, result in lower regulatory and oversight costs. This would include lower (and simplified) regulatory costs for inspections, NRC project managers, etc. Further, based on their low risk profile, resident inspectors should not be necessary for micro-reactors, which is consistent with RTR oversight.

Potential Priority

High

3.3.4 Total Lifecycle Topics

The topics in this section relate to the lifecycle topics (i.e., not related to the period of reactor operations) that provide a basis for enabling the licensing process of a rapid high-volume deployable reactor. The focus of these topics is to enable all safety and environmental considerations to achieve finality through generic and design specific licensing actions, and enabling a rapid collection of site characterization data that will be used to verify conformance to prior NRC approved conditions. There are 7 interrelated topics arranged in two categories – Pre-Operational and Post-Operations – to illustrate how they enable the business case for time and costs.

Pre-Operational

25. Use of Contractors by Manufacturing Licensees

<u>Topic Description</u>

While the use of subcontractors is seen as a normal business practice, it is not specifically endorsed in Subpart F, leaving open concerns that NRC might object to the practice for the manufacture of reactors, particularly where factory fueling and operational testing are involved. Specifically, the concern of this area is liability and coverage of the scope of the licenses. NRC acknowledged this gap in SECY-24-0008 and are considering guidance on this issue.

Fabrication, assembly and fueling of a micro-reactor at the factory may involve sub-contractors' facilities (i.e., owned by entities that are not holders of the Manufacturing License). If sub-contractors cannot be used to perform licensed activities, then it could significantly increase the cost or schedule.

<u>Desired Outcome</u>

NRC establishes that subcontractors and their facilities can be used in fabrication, assembly and fueling of a micro-reactor at the factory or a determination that either guidance or a change to Subpart F is required.

<u>Potential Priority</u>

Medium

26. Loading Fuel at Factory

<u>Topic Description</u>

NRC regulations in Part 52, Subpart F nor in the draft proposed Part 53, address loading fuel in the factory. Other Parts, such as Part 70, may be used to load fuel at the factory. Regulatory changes may be needed to address this issue. Loading fuel in the factory will require the installation of features to preclude criticality. The proposed Part 53 rulemaking includes language on factory fuel loading and the NRC staff.

<u>Desired Outcome</u>

NRC establishes guidance for developing an application for a 10 CFR Part 70 license in conjunction with a Part 50 license or a manufacturing license to authorize fuel loading at the factory. The NRC pursues rulemakings, as necessary to use other licensing processes to load fuel in a factory (e.g., Part 52 Subpart F, Part 53).

<u>Potential Priority</u>

Medium

27. Testing at the Factory

<u>Topic Description</u>

NRC regulations in Part 52, Subpart F and the draft proposed Part 53 do not address loading fuel in the factory or operational testing at the factory. SECY-24-0008 suggests that a power license or a

Commission policy decision on the application of non-power reactor regulations is necessary. Regulatory changes will be needed to enable this activity.

Desired Outcome

NRC Policy decision to enable the testing of a fueled and operational reactor at the factory.

Potential Priority

Medium-High

28. Use of Features to Preclude Criticality

Topic Description

Features to preclude criticality (FPC) were identified as a requirement to enable safe transport of factory fuel-loaded micro-reactors in SECY 24-0008. However, specific design criteria were not addressed. Therefore, it is unclear what the performance-based acceptance criteria will be for a design that would enable a fueled rapid high-volume deployable reactor to be transported to site. Features to preclude criticality will almost certainly be included in the factory fuel loading provisions and will have to be addressed in language regarding operational testing in the factory.

Desired Outcome

NRC establishes a technology-inclusive, performance-based and risk-informed regulatory framework for features to preclude criticality that enable the transport of fueled reactors from the factory to the operating site, and used fueled reactors from the operating site to the location where fuel will be removed from the reactor. The framework should also address the transport of reactors with fuel in the reactor core from one operating location to another operating location (a.k.a. mobile reactors). The regulatory framework should clarify the requirements to attain NRC approval of standardized designs (e.g., ML) that enable the reactors to be delivered to site and emplaced in their operating location prior to the NRC issuing the site license. The regulatory framework for FPC should address requirements for the design, installation, and removal of the required features to prevent criticality, including any reliability considerations that must be addressed by the licensee and designer. This should consider installation and removal of the features to prevent criticality both before and after operation of the reactor, including identification of any potential accident scenarios associated with installation or removal of the features to prevent criticality and mitigation strategies, specifically addressing worker and public safety.

Potential Priority

Medium

29. Transporting a Fueled Reactor

Topic Description

Existing regulations in 52.157(f)(26)(iv), 52.167(c)(2) and draft 52.620(e) address transport of a manufactured reactor. However, they do not address transporting a fueled reactor. Changes to, or exemptions from, these regulations to address transporting a fueled reactor would have to be developed. Resolutions to unique technical issues may also be necessary. It is not clear how the requirements in Part 52, Subpart F, and Part 71 will need to be reconciled, if at all. The NRC in SECY 24-0008 noted that transport of a fueled reactor would require features to preclude criticality (FPCs) and would classify the module as a Type AF package for front-end transport and either Type AF or BF package for back-end transport. Packages would also be subject to requirements from the Department of Transportation (DOT) and potentially other agencies, including tests and conditions for normal conditions of transport, hypothetical accident conditions, and maintenance of criticality safety. Current regulations allow this with exemptions for each reactor, but not on a large scale and with a public perception cost.

Desired Outcome

A regulatory framework is established that enables the transport of a fueled reactor from the factory to the site of operation, and a used fuel reactor from the site of operation to a facility for removing the fuel.

Potential Priority

Medium-High

Post-Operations

30. Replacing Modules at Site

Topic Description

The NRC regulatory framework does not address the concept of deployment and operations, where a fueled reactor that is at the end of the fuel life is replaced by a replacement newly fueled reactor transported to site. In SECY 24-0008, the NRC identified a path forward under Parts 50 and 52, as described in SECY-11-0079. However, this only addresses licensing issues for multiple reactors or modules on a site at the same time. Beyond those licensing issues there are operational challenges associated with re-installing the features to prevent criticality, radiation protection for workers and the public during the re-installation, preparing the reactor for transportation as an approved package, and identifying any accident scenarios and mitigation strategies associated with re-installing the FPC or removing the reactor from the operation location. It is also not clear whether this could create environmental considerations that need to be included in a standardized design application.

Desired Outcome

NRC clarifies the regulatory and technical issues involved with replacing a reactor module and transporting it to a refueling or refurbishment facility, the licensing approaches that could be used to obtain NRC approval, if necessary, for these activities. NRC resolves any potential policy issues that may be identified, and completes a rulemaking if additional requirements are needed.

Potential Priority

Medium-Low

31. Storing Used Fuel at Site

Topic Description

The existing regulatory framework (10 CFR Part 72) for on-site used fuel storage is well suited to storage of used fuel for advanced reactor on site for renewable periods up to 40 years. However, the existing regulatory framework has not fully contemplated the technology capabilities, and concept of deployment and operations of rapid high-volume deployable reactors. Rapid high-volume deployable reactors will have radiological inventories that are expected to be more than 20 times less than the dry storage casks used for large LWR fuel today. These reactors are also expected to be smaller than today's dry storage casks, able to fit on a legal weight truck. Furthermore, the storage of used fuel on-site is expected to include at most one used fueled reactor for only the time necessary to enable safe transport of the used fueled reactor to the location where the used fuel will be removed. This is in contrast to the concept of operations for dry cask storage at reactor sites today, which store 10s of dry storage casks in close proximity on a shared pad for years at a time. Thus, the potential consequences and risks of a used fueled rapid high-volume deployable reactor stored on-site will be substantially less than the consequences and risks of dry cask storage of LLWR fuel at existing reactors today.

Two specific issues have been identified that require full consideration by the regulatory framework for used fuel on-site for this class of reactors:

1. The definition of spent fuel in 10 CFR Part 72.3 will need to be clarified. It currently reads: "Spent Nuclear Fuel or Spent Fuel means fuel that has been withdrawn from a nuclear reactor following irradiation, has undergone at least one year's decay since being used as a source of energy in a power reactor, and has not been chemically separated into its constituent elements by reprocessing. Spent fuel includes the special nuclear material, byproduct material, source material, and other radioactive materials associated with fuel assemblies." (emphasis added). Essentially, the key to doing this will be to build on the commonalities between storage in used reactor vessels and storage in dry casks to demonstrate that the used reactor vessels are as safe or better than existing dry cask storage systems. NRC staff has shown receptivity to this position.

2. The NRC implementation of the Part 72 requirements for dry storage does not fully incorporate risk-informed decision making, and often enforces positions that greatly exceed that which is commensurate with the potential consequences and risks of the technology and would be needed to provide reasonable assurance of adequate protection of the public health and safety. Such implementation of Part 72 requirements by the NRC has resulted in evolving and increasingly more stringent interpretations of the requirements for issues that are of very low safety significance, often without a basis that a new unresolved safety issue has been identified through operating experience. The NRC resolution of these very low safety significant issues typically take years to resolve, resulting in considerable NRC and licensee resources being spent on resolving very low safety significant issues, and sometimes stopping dry storage activities until there is clarity that these operations should be permitted to continue while the issue is being resolved. These NRC practices for implementing Part 72 requirements could make it challenging to enable the business case requirements for rapid high-volume deployable reactors, especially as the storage of used fueled reactors on-site are expected to have substantially lower potential consequences and risks than those of dry case storage at today's existing reactors.

Desired Outcome

NRC clarification on the regulatory and technical issues involved with the storage of used fueled rapid high-volume deployable reactors (and other similar advanced reactors) on site, and the associated licensing approaches. The regulatory framework would need to enable licensees to store used fuel on-site inside of the reactors in which the fuel was used during operations, without the need for additional overpacks. The regulatory framework would need to address the technology capabilities, and the concept of deployment and operations for this class of reactors, including the substantially lower potential consequences and risks than those of dry case storage at today's existing reactors. NRC implementation of Part 72 would need to include a process for rapid efficient resolution of newly identified safety concerns. This rapid efficient emerging issues resolution process would ensure that the identification of any new unresolved safety issue establishes a regulatory basis that includes new information from operating experience. The rapid efficient emerging issues resolution process would also ensure that very low safety significant issues would be dispositioned quickly and would not impact the continued on site used fuel storage operations.

Potential Priority

Medium-Low