NRC Staff Prepared White Paper
"Micro-Reactor Licensing and Deployment Considerations:
Fuel Loading and Operational Testing at a Factory"
August 2023 Draft – Released to Support ACRS Interaction

THIS NRC STAFF WHITE PAPER HAS BEEN PREPARED AND IS BEING RELEASED TO SUPPORT INTERACTIONS WITH THE ADVISORY COMMITTEE ON REACTOR SAFEGUARDS (ACRS). THIS PAPER HAS NOT BEEN SUBJECT TO NRC MANAGEMENT AND LEGAL REVIEWS AND APPROVALS, AND ITS CONTENTS SHOULD NOT BE INTERPRETED AS OFFICIAL AGENCY POSITIONS.

SUBJECT: Micro-Reactor Licensing and Deployment Considerations: Fuel Loading and Operational Testing at a Factory

PURPOSE:

The purpose of this paper is to support upcoming interactions with the Advisory Committee on Reactor Safeguard (ACRS) on options for regulating the fuel loading and operational testing of commercial factory-fabricated micro-reactors.

BACKGROUND:

For licensing purposes, micro-reactors are commercial power reactors licensed under Section 103, "Commercial Licenses," of the Atomic Energy Act of 1954, as amended (AEA). Micro-reactors are expected to use non-light-water reactor technologies[1], have thermal power levels on the order of several megawatts to a few tens of megawatts, have small site footprints, and have low radiological consequences from potential radiological releases by virtue of radionuclide inventories that would be about one percent or less than those for typical large light-water reactors. Micro-reactors may also have an increased reliance on passive systems and inherent characteristics to control power and heat removal.

In SECY-20-0093, "Policy and Licensing Considerations Related to Micro-Reactors" (ML20129J985), the U.S. Nuclear Regulatory Commission (NRC, the Commission) staff identified several topics that should be addressed to support the licensing and regulation of micro-reactors including security; emergency preparedness; staffing, training, and personnel qualification; autonomous operations and remote operations; regulatory oversight; aircraft impact assessment; annual fee structure; manufacturing licenses and transportation; population-related siting considerations; and environmental considerations. Since the issuance of SECY-20-0093, the staff has developed approaches to resolving several of these topics through work on rulemaking efforts including Title 10, "Energy," of the *Code of Federal Regulations* (10 CFR) Part 53, "Risk Informed, Technology-Inclusive Regulatory Frameworks for Commercial Nuclear Plants" (SECY-23-0021 (ML21162A095)); Alternative Physical Security Requirements for Advanced Reactors (SECY-22-0072 (ML21334A003)); Emergency

[1] See "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness," (ML16356A670) for discussion of non-light-water reactor technologies. Non-light-water reactors are a subset of advanced reactors, as defined by the Nuclear Energy Innovation and Modernization Act of 2019 (Public Law 115-439).

Preparedness for Small Modular Reactors and Other New Technologies (SECY-22-0001 (ML21200A055)); and the Advanced Nuclear Reactor Generic Environmental Impact Statement (SECY-21-0098 (ML21222A053)). These technology-inclusive rulemakings include provisions that are scalable commensurate with the design features and risks posed by various technologies and propose approaches that could be applied to micro-reactors. The staff also issued the FY2023 fee rule (88 FR 39120) to provide fair and equitable fees for small modular reactors including non-light-water reactors which established new minimum and variable fees in recognition of the size and anticipated level of oversight for smaller reactors including micro-reactors. Other initiatives are underway such as the development of the Advanced Reactors Construction Oversight Program as discussed in SECY-23-0048, "Vision for the Nuclear Regulatory Commission's Advanced Reactor Construction Oversight Program" (ML23061A086), which will consider a range of plant designs, including micro-reactor designs, to inform and scale the scope of construction oversight for advanced reactors.

DISCUSSION:

As the advanced reactor landscape continues to evolve, stakeholder interest in the deployment of factory-fabricated micro-reactors is increasing. The NRC staff is currently in pre-application engagements with several factory-fabricated micro-reactor developers that are considering novel deployment models that include loading fuel at a factory, operating the reactor for testing at a factory prior to deployment, and transporting fueled reactors. The NRC staff is prioritizing development of strategies to provide for the predictable and efficient licensing and regulation of these designs and operational models, and the identification and resolution of associated policy issues.

The NRC staff is cognizant that some topics and policy issues are more broadly relevant to the deployment of all types of micro-reactors and other reactor technologies, such as light-water small modular reactors and larger non-light-water reactors. Although not explicitly addressed in this paper, the NRC staff will account for any such situations, as appropriate.

The NRC staff engaged with stakeholders through the periodic advanced reactor stakeholders meetings in March and July 2023. The NRC staff presented the topics proposed to be included in the paper during the meeting in March and provided preliminary information about the options under consideration by the NRC staff during the meeting in July. Stakeholders provided oral feedback during these meetings which the NRC staff considered during development of the paper. The NRC staff also engaged with other Federal agencies, such as the Department of Energy.

Factory-Fabricated Micro-Reactors

Factory-fabricated micro-reactors are a subset of micro-reactors that are expected to rely heavily on standardization of design features and mass production to simplify licensing and deployment. Some factory-fabricated micro-reactor designs may be "self-contained" in that they would incorporate the reactor, shielding, and balance of plant in one or several transportable containers and require minimal site preparation or construction activities at the deployment site[2].

[2] See 10 CFR 50.10, "License required; limited work authorization," for the activities considered to be construction and requiring a permit or license issued by the Commission.

Other designs may comprise a "core module" consisting of the core, reactor vessel, control elements, and other systems and components that is fabricated in a factory and then incorporated into or connected to permanent structures and systems constructed at the deployment site, such as a reactor building and power conversion equipment. This paper uses the term "factory-fabricated module" to generically refer to the part of the eventual micro-reactor nuclear power plant that would be fabricated in a factory and that may be of either a self-contained design (i.e., a complete facility) or a "core module" design.

Factory-Fabricated Micro-Reactor Deployment Model

Conceptually, the deployment model for factory-fabricated micro-reactors will include various activities requiring NRC licensing, certification, or approval. These may include design of reactors, fabrication at a factory, loading fuel at a factory, operating the reactors for testing at a factory, transporting fueled reactors to deployment sites (whether loaded with unirradiated or irradiated fuel), operating the reactors for the production of electrical or heat energy at the deployment sites, replacing reactors at the deployment sites, transporting reactors away from the deployment sites at the end of their useful lives, decommissioning or refurbishing and refueling reactors at locations away from the deployment sites, and re-deploying refurbished reactors to deployment sites. Figure 1 depicts the generic deployment model considered by the NRC staff in this paper and the enclosure, which incorporates developers' publicly available information and stakeholder feedback. In contrast to this deployment model, some factory-fabricated micro-reactor developers may propose deployment models in which loading fuel or performing operational testing or both would occur at the deployment site, rather than a factory.

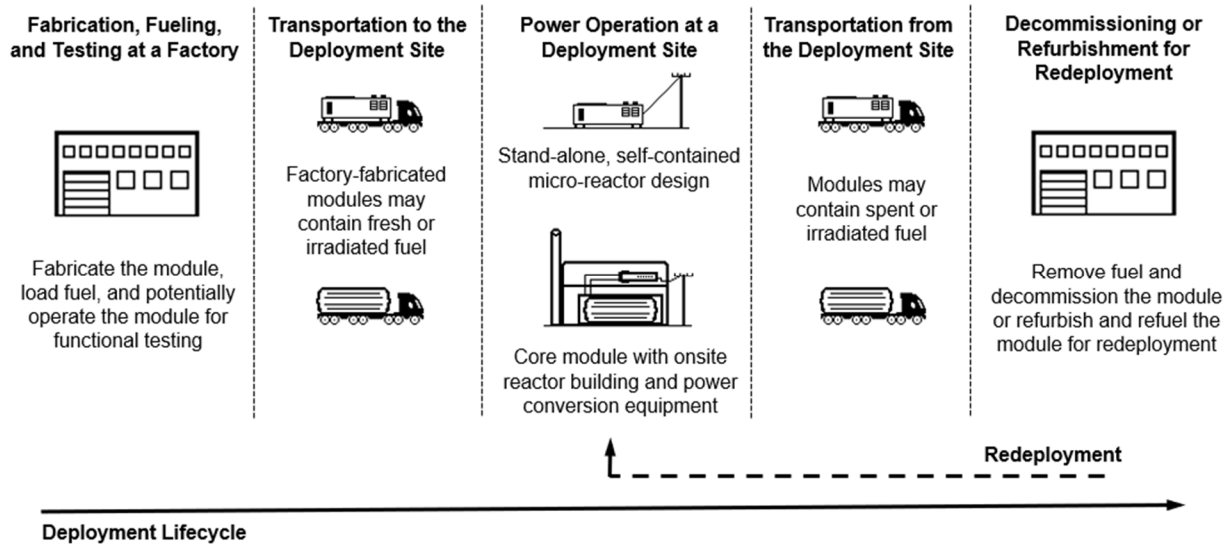

Figure 1: Generic factory-fabricated micro-reactor deployment model.

Deployment models could involve several other unique concepts not depicted in Figure 1. These include construction activities at the deployment site that could be completed in days to weeks to a few months depending on the design, the arrival of pre-fueled reactors at the

deployment site, remote reactor operations with few or no on-site reactor operators, autonomous reactor operation[3], and siting reactors in densely populated locations. The enclosure to this paper describes these aspects and the NRC staff's near-term strategies and next steps to address them.

Deployment models rely on the concept of a factory where modules would be fabricated, loaded with fuel, and potentially operated for testing. Based on early stakeholder feedback, the NRC staff assumes that a manufacturing license would be issued pursuant to Subpart F, "Manufacturing Licenses," of 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," for the factory-fabricated modules due to the desired high degree of standardization and plans for mass production. The manufacturing license would approve the design of the factory-fabricated modules and manufacturing processes to be used at the factory. Specifically, 10 CFR 52.157, "Contents of applications; technical information in final safety analysis report," requires a manufacturing license application to describe "the applicant's proposed means of assuring that the manufacturing conforms to the design and to reach a final conclusion on all safety questions associated with the design[.]" The manufacturing license would also authorize possession of the modules at the factory and include provisions for transferring the modules to licensees authorized to receive them. Matters resolved in the manufacturing license proceeding would have finality in accordance with 10 CFR 52.171, "Finality of manufacturing licenses; information requests." If the manufacturer also seeks licenses to operate the reactors at the factory (e.g., for testing), then the design issues that must be resolved for operation at the factory would largely overlap with the design issues to be resolved in a manufacturing license. The manufacturing license would satisfy the statutory requirements in AEA Section 101, "License Required," that a license issued pursuant to AEA Section 103 is required to manufacture, transfer, or possess any utilization facility.

Under the current regulatory framework, a facility operating license issued pursuant to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," or a combined license issued pursuant to 10 CFR Part 52 for a power reactor would be required to load fuel and perform operational testing. In these cases, construction of the factory or at least the portions of the factory that are relied on to ensure the safety of fuel loading or operational testing of the modules as described in the Part 50 or 52 license application, would be considered construction activities requiring a license under the regulations in 10 CFR 50.10(a). This paper presents an option where fuel could be loaded into a module under a license issued pursuant to 10 CFR Part 70, "Domestic Licensing of Special Nuclear Material," without a 10 CFR Part 50 or 52 license. Under this option, the portions of the factory supporting fuel loading would be subject to requirements in 10 CFR Part 70.

Deployment models envision mass production of factory-fabricated modules on the order of tens of modules per year or more. Under the current regulatory framework, each module would need

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[3] As discussed in detail in the enclosure, the term "autonomous operation" lacks a consistent definition across the various domains and contexts in which it is used. For the purposes of this paper, autonomous systems are considered those "…able to perform their task and achieve their functions independently (of the human operator), perform well under significant uncertainties for extended periods of time with limited or nonexistent communication, with the ability to compensate for failures, all without external intervention." (M. R. Endsley, "From here to autonomy: lessons learned from human–automation research," *Human factors*, vol. 59, no. 1, pp. 5–27, 2017.)

to be covered by a facility operating license or combined license. The NRC staff previously assessed alternatives for the structure of the licenses that could be issued for multi-module facilities under 10 CFR Parts 50 and 52 in SECY-11-0079, "License Structure for Multi-module Facilities Related to Small Modular Nuclear Power Reactors," dated June 12, 2011 (ML110620459). One alternative is to issue a single license for a facility consisting of one or more modular reactor units. This alternative may not be practical for all modules to be manufactured, fueled, and operated for testing over the life of a factory because all the modules to be covered under a single license would have to be constructed before issuance of the operating license or the authorization to operate under a combined license[4]. However, a single license may be useful for licensing fuel loading or operational testing of several modules that would be manufactured at about the same time. Another alternative assessed in SECY-11-0079 is to issue a separate license for each reactor module[5]. The NRC staff also assessed a possible hybrid of the single facility license and individual module license that would take the form of a master facility license and individual reactor module licenses. The NRC staff noted in SECY-11-0079 that, "the NRC would need to develop processes and possibly new regulations to define how the master facility license would fit within the existing technical and legal requirements." Under these strategies an applicant could also combine licensing requests for numerous modules in a single application, possibly to include modules intended to be refurbished, refueled, and potentially retested at the factory. These strategies are further discussed in the enclosure to this paper as they relate to licensing replacement reactors at deployment sites.

Legislative and Regulatory Considerations

The NRC staff assessed the current regulatory framework in 10 CFR Ch. I and the AEA. The options described in this paper are potential regulatory approaches to fuel loading and operational testing of factory-fabricated modules that do not involve rulemaking. The draft proposed rule package for 10 CFR Part 53 discusses and suggests requests for comments on fuel loading and operational testing and may result in rulemaking that provides longer-term ways to address these issues for micro-reactors and other reactor technologies. In this paper, the NRC staff is considering near-term non-rulemaking options that could be available ahead of finalization of rulemaking.

A fundamental subject of this paper is whether the Commission's historical position that considers fuel load as part of operation of the reactor is applicable to factory-fabricated modules[6]. As an outgrowth from this position, each factory-fabricated micro-reactor module that is fueled in the factory would be required to have a facility operating license or a combined license, regardless of whether or not it is operated for testing at the factory. This position also means that a factory-fabricated module would be considered to be "in operation" when loaded with fuel. The NRC's current regulatory framework does not provide for authorizing

4 AEA Section 185a. requires a finding that the facility was constructed as required prior to issuing an operating license, and AEA Section 185b. requires a preoperational finding that the acceptance criteria in the combined license are met, where meeting the acceptance criteria shows that the facility was constructed as required.

5 These licenses might reference shared common elements (e.g., technical specifications), but such an approach could become complicated if there are design changes during manufacturing.

6 See "Licenses, Certifications, and Approvals for Nuclear Power Plants; Final Rule," 72 FR 49351 and 49390 (August 28, 2007) which stated, "The NRC has historically viewed 'operation' as including loading of fuel into the reactor."

transportation of utilization facilities that are "in operation," meaning that a factory-fabricated module could not be transported to a deployment site when loaded with fuel at a factory. This paper includes an option under which a factory-fabricated module with features to preclude criticality would not be "in operation" when loaded with fuel.

This paper does not address physical security requirements for the factory, the deployment site, a decommissioning or refurbishment and refueling facility, or transportation. As mentioned above, in SECY-20-0093 the NRC staff identified security requirements as a topic that should be addressed for micro-reactors. The NRC staff recognizes that deployment models for factory-fabricated micro-reactors raise additional potential security considerations not discussed in SECY-20-0093, such as transportation security for fueled factory-fabricated modules. The NRC staff has separate ongoing activities related to physical security that would apply to micro-reactors, such as SECY-18-0076, "Options for Physical Security for Light-Water Small Modular Reactors and Non-Light-Water Reactors," dated August 1, 2018 (ML18170A051), SECY-22-0072, and SECY-23-0021. Based on Commission direction on the options in this paper, other ongoing activities, and further stakeholder engagement, the NRC staff will consider whether additional Commission engagement is needed related to physical security requirements for factory-fabricated micro-reactor licensing and deployment.

Options for Features to Preclude Criticality, Fuel Loading at a Factory, and Operational Testing at a Factory

The NRC staff identified fuel loading and operational testing at a factory as near-term policy issues because they are key front-end aspects of micro-reactor deployment models. As mentioned above, features to preclude criticality that would allow the NRC staff to consider a factory-fabricated module as "not in operation" when loaded with fuel are integral to the viability of several of the options presented in this paper. Stakeholders are engaged in pre-application discussions with the NRC staff on these issues and have requested clarity on what options are available as they develop licensing documents over the next several years to support deployment before 2030. The NRC staff notes that the options for fuel loading and operational testing are not mutually exclusive, and the Commission could direct the NRC staff to pursue more than one.

Topic 1: Features to Preclude Criticality

Features to preclude criticality would effectively prevent operation of a factory-fabricated module by rendering it incapable of sustaining a nuclear chain reaction under any conditions, including single failures and common-cause failures. Such features could include, for example, bolts, locks, or welds to fix control elements in place; decoupling of control element drives; and additional fixed neutron absorbers. The installation and removal of these features would entail significant modifications to the module. The features to preclude criticality would be described in the design of the factory-fabricated module, which would be included in an application for a manufacturing license, standard design certification, or other permit or license.

Option 1a—Status quo

Under this option, the NRC would apply the Commission's historical position that operation of a reactor includes the loading of fuel (regardless of whether features to preclude criticality are

installed) and consider a factory-fabricated module to be "in operation" when loaded with fuel. This would require the fabricator to hold a facility operating license issued pursuant to 10 CFR Part 50 or a combined license issued pursuant to 10 CFR Part 52 that authorizes operation in order to load fuel. Also, because the NRC's current regulatory framework does not provide for authorizing transportation of utilization facilities that are "in operation," under this option a factory-fabricated module could not be transported when loaded with fuel.

Implementation

This option would not necessarily require staff action to implement. However, to implement the options below under which fuel would be loaded at a factory, the NRC staff would need to develop alternative approaches to authorizing transportation of fueled modules, which might include rulemaking. The NRC staff did not consider rulemaking in the development of this paper because this paper focuses on options that could be implemented in the near term (1-2 years) with fewer resources than those that would be required for rulemaking.

Advantages

- This option would not require NRC staff resources to develop guidance for features to preclude criticality.
- This option would maintain a consistent approach to licensing of all new reactors where fuel load is considered part of operation.

Disadvantages

- This option would present significant challenges to deployment models that include fuel loading in a factory because it would require compliance with the regulations for an operating reactor during transportation of a fueled module from a factory to a deployment site. The regulations for operating reactors are based on operation at a fixed site and would not be practical to implement for modules that are considered to be "in operation" during transport.
- This option would require the fabricator to obtain a facility operating license or a combined license to load fuel into the reactor at the factory, even if the reactor is not further operated at the factory. There is a high regulatory burden associated with such a licenses, which may not accord with the level of risk posed by fuel loading.

Option 1b— A factory-fabricated module with features to preclude criticality is not in operation when loaded with fuel

Under this option, a factory-fabricated module that included features to preclude criticality would not be "in operation" when loaded with fuel. However, the factory-fabricated module would still be considered a utilization facility and require, at a minimum, a 10 CFR Part 52 Subpart F manufacturing license to satisfy the statutory requirement in AEA Section 101 that a license issued pursuant to AEA Section 103 is required to manufacture or possess any commercial utilization facility.

The Commission has historically viewed operation as including loading of fuel into the reactor. It

took this view for reasons of safety based on recognition that loading fuel into and initial testing of a reactor involves a nuclear risk which would not otherwise be present[7]. In 1970, the Atomic Energy Commission (AEC) proposed a new regulation in 10 CFR 50.35, "Issuance of construction permits," to authorize the initial loading of nuclear fuel in the reactor core, *without attainment of a critical reaction*, under a construction permit[8]. The AEC cited the "minimal" hazards associated with the loading of unexposed (unirradiated) fuel to justify the proposal. The final rule issued in 1971 did not include the authority to load fuel under the construction permit because the comments received and further study by the Commission indicated that it would have little effect in reducing the time required for the completion of the licensing process and might result in complications with respect to AEC licensing procedures[9].

Features to preclude criticality would ensure that a factory-fabricated module would not attain criticality and that the potential hazard associated with loading fuel would be even less than the "minimal" hazards for fuel loading of reactors without such features that were previously considered by the AEC as a potential justification for authorizing fuel loading without an operating license. Further, with features to preclude criticality, the presence of fuel in the module would not create a nuclear hazard different than the presence of the same fuel in a storage location or container licensed under 10 CFR Part 70—therefore, licensing fuel load at the factory under 10 CFR Part 70 would adequately protect safety, as discussed below in the options for loading fuel at a factory. The NRC staff also notes that in contrast to the AEC's reasons for ultimately not authorizing fuel load under a construction permit, loading fuel in a factory without an operating license or combined license could improve regulatory efficiency of licensing and deployment of factory-fabricated micro-reactors without a reduction in safety. In addition, the ability to transport factory-fabricated modules after fuel loading and operational testing at a factory could have overall safety benefits for factory-fabricated micro-reactor deployment. These might include handling fuel in the controlled environment of the factory as opposed to the various deployment sites and the ability to identify and correct defects or operational issues at the factory to avoid having to transport modules back and forth between the deployment site and the factory.

The NRC staff also considered potential complications with the current licensing procedures and regulations. Certain regulations in 10 CFR Parts 50 and 52 use initial fuel load as a regulatory milestone. There are potential complications caused by a factory-fabricated module arriving at the deployment site already loaded with fuel. However, these potential complications would exist whether fuel loading at the factory is licensed under 10 CFR Part 70 or licensed under 10 CFR Parts 50 or 52. Also, as discussed in the enclosure to this paper, the NRC staff has strategies for addressing these complications.

When features to preclude criticality are present, the NRC staff is considering whether it would be appropriate that operation would begin with the removal of those features. Removing criticality preclusion features may be the best analogue to initial loading of fuel for reactors

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7 AEC-R 2/15, "Proposed Revision of 10 CFR, Part 50, Licensing of Production and Utilization Facilities" (ML21237A274), July 15, 1960. In this paper the AEC staff explained why it did not agree with a comment on the proposed rule suggesting that fuel loading and initial operational testing be authorized under a construction permit—the commenter's suggestion was not adopted by the Commission.

8 See the proposed rule at 35 FR 16687, October 28, 1970.

9 See the final rule at 36 FR 8861, May 14, 1971.

without such features because both are distinct actions that put a fully constructed utilization facility in a position to sustain a nuclear chain reaction, and in both cases, the utilization facility cannot sustain a nuclear chain reaction (for lack of sufficient reactivity) until the action takes place.

Several of the options below for fuel loading at a factory and operational testing at a factory are predicated on the inclusion of features to preclude criticality. Under one option, the holder of a manufacturing license could load fuel in a module that included features to preclude criticality under a 10 CFR Part 70 license without obtaining a 10 CFR Part 50 operating license or a 10 CFR Part 52 combined license. Under options for operational testing at a factory, the installation of features to preclude criticality would take the module out of operation and allow for transportation of the fueled module.

Features to preclude criticality would allow for transportation of a fueled module under the current regulations because the module would not be "in operation" during transport. The module could be covered by provisions in the manufacturing license that allow for transfer to a licensee authorized to acquire the module, while the radioactive material in the module would be controlled by materials licenses and the existing transportation regulations in 10 CFR Part 71, "Packaging and Transportation of Radioactive Material." The enclosure to this paper describes the NRC staff's near-term strategy for reviewing packages for the transport of factory-fabricated modules that are loaded with fuel under 10 CFR Part 71. In accordance with the NRC and the Department of Transportation regulations, the package contents would be under the responsibility of the shipper (factory licensee) until receipt by the deployment site licensee.

The draft proposed 10 CFR Part 53 rulemaking package discusses and requests comments on an alternative theory for dispensing with an operating license or combined license for factory fuel loading under which the module would not be considered a utilization facility. The NRC staff is not pursuing this alternative in this paper under the current regulatory framework.

Implementation

The NRC staff would implement this option using the existing regulations for utilization facilities by developing guidance for including features to preclude criticality in factory-fabricated modules. Some exemptions may be required to implement this approach. For example, there are regulations that use "initial fuel load" or other activities or events as the milestones by which certain operational programs must be implemented or reports submitted. Exemptions or other appropriate regulatory vehicles may be needed to substitute other activities or events, such as the removal of features to preclude criticality, for the current milestones in the regulations.

Advantages

- This option would allow for novel approaches for licensing fuel loading in a factory-fabricated module without requiring a facility operating license or combined license and for regulating the safe transport of fueled modules without a rulemaking to establish requirements for transportation of utilization facilities that are in operation.
- This option would provide a predictable regulatory framework for fuel loading and transport of fueled factory-fabricated modules that could be available for use by developers in the near-term.

Disadvantages

- The NRC staff would need to develop technology-inclusive guidance on the use of features to preclude criticality for fuel loading in the factory and transportation of fueled modules.

Topic 2: Fuel Loading at a Factory

Some factory-fabricated micro-reactor developers have indicated that fuel loading at the factory and transportation of fueled modules to the deployment sites may be essential for their deployment models. Depending on the reactor design, fuel loading and any subsequent fabrication steps, such as closing the reactor vessel, may require expertise and specialized equipment that would be inefficient or impractical to make available at each deployment site.

Option 2a—Authorize only fuel loading at the factory under a power reactor license

This option would be consistent with the Commission's historical position that operation of a reactor includes the loading of fuel. Under the current regulatory framework and this historical position, each factory-fabricated module that would be loaded with fuel at the factory would be required to have a facility operating license or combined license issued pursuant to Section 103 of the AEA before loading fuel. A manufacturing license would allow the manufacture of unfueled reactors, but it would not authorize fuel load or any other aspect of operation or the possession of special nuclear material.

Option 2a would designate each factory-fabricated module and potentially certain portions of the factory as a utilization facility and require the fabricator to obtain a facility operating license or a combined license for a nuclear power reactor and to have appropriate licensed personnel to load fuel. To issue a combined license under 10 CFR Part 52, the NRC staff would need to prepare a safety evaluation report and an environmental impact statement (EIS), the ACRS would have to review the application, and the mandatory hearing and any contested hearing would need to be held. For each of these steps, the NRC could consider all contemplated combined licenses together in one application. Comparable activities are required for the issuance of a facility construction permit under 10 CFR Part 50, which could cover multiple reactors.

For a 10 CFR Part 52 combined license, the AEA requires that the NRC find that the acceptance criteria in the inspections, tests, analysis, and acceptance criteria (ITAAC) for that reactor are met before the reactor may begin operation. The NRC must also provide an opportunity for hearing on conformance with the acceptance criteria at least 180 days before scheduled initial fuel load. Because modules may be fabricated in much less than 180 days, this hearing opportunity may be noticed prior to beginning the fabrication of the subject module. To issue a 10 CFR Part 50 operating license under the current regulatory framework, the NRC staff would need to prepare a safety evaluation report and a supplemental EIS, the ACRS would have to review the application, and any contested hearing would need to be held. As described in the enclosure to this paper, the timeframe to complete a contested hearing and environmental review for issuance of a 10 CFR Part 50 operating license could be 24 months or less, but these actions could be initiated upon submission of each operating license application well in advance

of beginning construction of each module. To some degree, these activities could be consolidated for several or all modules contemplated by the fabricator using the multi-module licensing strategies in SECY-11-0079 previously described in this paper.

Whether licensed under 10 CFR Part 50 or 52, the licensee would need to implement operational programs for matters such as security, emergency preparedness, fitness for duty, and operator training and qualification. As described in SECY-20-0093, the Commission could use regulatory vehicles including exemptions, hearing orders, or rules of particular applicability to scale the amount of information to be submitted in a license application and adjust the NRC staff review accordingly to issue a license that authorizes fuel load but not additional operation. For example, for a factory-fabricated module that is not authorized to undertake operational activities beyond fuel loading, it may not be necessary for the licensee to implement certain operational programs and technical specifications. However, the AEA mandates certain requirements such as hearings, ITAAC, and review by the ACRS even for a factory-fabricated module that is only authorized to load fuel.

Implementation

The NRC staff could appropriately scale reviews and develop processes for efficient reviews of applications for licenses that would only authorize fuel load and not additional operation of factory-fabricated modules. The specific reviews supporting factory-fabricated modules could take advantage of other actions on the subject design such as a related manufacturing license and, where applicable, other certifications and approvals. Implementation of this approach may include additional Commission engagement, particularly if hearing orders or rules of particular applicability are used.

Advantages

- This option relies on established processes for the licensing of nuclear reactors and could largely use existing guidance on appropriately scaling reviews to address the specific risks associated with loading fuel at the factory.
- The existing requirements in 10 CFR Part 70 and associated guidance could be used to facilitate the licensing of fuel loading under this approach.

Disadvantages

- There could be a high regulatory burden associated with requiring the reactor manufacturer to obtain a facility operating license or a combined license for the sole purpose of fuel load in light of the minimal risk posed by that activity alone.
- Manufacturers will likely seek to accelerate the timeframes for authorization to load fuel under a 10 CFR Part 52 combined license by submitting the notifications and schedules related to ITAAC completion required by 10 CFR 52.99, “Inspection during construction; ITAAC schedules and notifications; NRC notices,” as early as possible for each factory-fabricated module. This could result in noticing intended operation and the related hearing opportunity prior to the start of fabrication of a module. Similarly, a manufacturer might submit a 10 CFR Part 50 operating license application and the NRC issue the related notice of opportunity for hearing before beginning construction of a module.

Option 2b—Authorize only fuel loading at the factory under a Part 70 license

This option would provide an approach for loading fuel at the factory without requiring a facility operating license under 10 CFR Part 50 or a combined license under 10 CFR Part 52 for a factory-fabricated module. Instead, a manufacturing license would authorize possession of the module and loading fuel would be authorized and conducted solely under a license issued pursuant to 10 CFR Part 70 for possession of special nuclear material. This option relies on the use of features to preclude criticality so a factory-fabricated module would not be "in operation" when loaded with fuel and would not require a facility operating license or combined license to load fuel.

Under this option, a manufacturer could combine an application for a 10 CFR Part 70 license with an application for a 10 CFR Part 52 manufacturing license consistent with 10 CFR 52.8, "Combining licenses; elimination of repetition." Guidance on the contents of a 10 CFR Part 70 license application is available in a draft standard review plan, "Standard Review Plan for Applications for 10 CFR Part 70 Licenses for Possession and Use of Special Nuclear Materials of Critical Mass but Not Subject to the Requirements in 10 CFR Part 70, Subpart H – Draft Report for Comment (NUREG-2212)" (ML22335A087), that the NRC staff currently plans to issue as final in the summer of 2024[10]. The application would include the information required by 10 CFR 70. 22, "Contents of applications," including the technical qualifications of the manufacturer to engage in fuel loading activities in accordance with applicable regulations and a description of the equipment and facilities and the proposed procedures which will be used to protect health and minimize danger to life or property.

The 10 CFR Part 70 license (or 10 CFR Part 70 conditions included in the manufacturing license) would specify the quantity and form of special nuclear material allowed to be possessed and include the appropriate conditions in 10 CFR 70.32, "Conditions of licenses." The manufacturing license would include the final design information for the factory-fabricated module and the features to preclude criticality. Whereas a manufacturing license focuses on the reactor design and manufacturing process and has not traditionally been thought to include conditions related to radiological safety at the manufacturing facility itself, the Part 70 license would place requirements on areas, structures, and equipment within the manufacturing facility where the fuel is handled and stored. Therefore, the applicant for or holder of the manufacturing license may benefit from approval of the Part 70 license prior to building the manufacturing facility.

The regulations in 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions," require the NRC to perform environmental reviews in connection with issuance of the 10 CFR Part 70 license and the 10 CFR Part 52 manufacturing license. The environmental review for the 10 CFR Part 70 license could require

[10] Loading fuel into a micro-reactor under this option is not encompassed by the enumerated activities in 10 CFR 70.60, "Applicability," that are subject to 10 CFR 70 Subpart H, "Additional Requirements for Certain Licensees Authorized To Possess a Critical Mass of Special Nuclear Material," and is not an activity meeting the 10 CFR 70.60 criterion "could significantly affect public health and safety" because it lacks the significant hazards associated with the enrichment, conversion, and fabrication activities that are subject to the requirements of Subpart H, *provided that* measures to preclude criticality as described in Option 1b approach are correctly implemented.

an EIS, an environmental assessment, or it could qualify for a categorical exclusion, depending on the activities to be authorized, and the NRC staff would determine the appropriate environmental review on a case-by-case basis. The NRC staff would perform an environmental assessment in accordance with 10 CFR 51.30(e) in connection with the manufacturing license. This environmental assessment would be limited to the consideration of the costs and benefits of severe accident mitigation design alternatives and the bases for not incorporating severe accident mitigation design alternatives in the design. Additional environmental reviews would be performed for each deployment site consistent with the regulations for issuance of permits and licenses under 10 CFR Parts 50 or 52.

Under this option, there may be a potential regulatory gap in financial protection requirements. The regulations in 10 CFR 140.11, "Amounts of financial protection for certain reactors," and 10 CFR 140.12, "Amount of financial protection required for other reactors," address financial protection for reactors in operation. As such, these requirements would not be applicable to factory-fabricated modules that included features to preclude criticality that would only be loaded with fuel and not operated at a manufacturing facility. In addition, holders of construction permits prior to issuance of an operating license and holders of combined licenses prior to the Commission's 10 CFR 52.103(g) finding who also hold a license under 10 CFR Part 70 authorizing ownership, possession and storage only of special nuclear material must have and maintain financial protection in the amount of $1,000,000. Additional financial protection requirements are provided in 10 CFR 140.13a, "Amount of financial protection required of certain holders of construction permits and combined licenses under 10 CFR part 52," and 10 CFR 140.13b, "Amount of financial protection required for plutonium processing and fuel fabrication plants," for 10 CFR Part 70 licensees; however these requirements are limited to licensees authorized to possess and use plutonium at a plutonium processing and fuel fabrication plant or licensees for enrichment facilities. There are no financial protection regulations explicitly addressing fuel loading under a manufacturing license and 10 CFR Part 70 license. The NRC staff would consider the use of license conditions or another appropriate regulatory vehicle to ensure financial protection during the period before issuance of the operating license or before the Commission makes the finding under 10 CFR 52.103(g).

Implementation

If the Commission directs the NRC staff to pursue this option, the NRC staff would develop guidance for an application for a 10 CFR Part 70 license in conjunction with a manufacturing license to authorize fuel loading at the factory. The NRC staff would also consider developing guidance or pursuing other means for ensuring adequate financial protection and establishing indemnity agreements, as appropriate.

Advantages

- The requirements for 10 CFR Part 70 licenses may better match the technical and safety aspects of activities involving the possession only of special nuclear material than the requirements of 10 CFR Parts 50 and 52 that apply to an operating utilization facility.
- The NRC staff could implement this option in the timeframes being considered by micro-reactor developers for deployment of factory-fabricated modules.
- Compared to Option 2a, this approach could reduce the number of administrative requirements and legal proceedings for individual modules, which would likely improve the

efficiency and timeliness of licensing and deployment.

Disadvantages

- The NRC staff has not used 10 CFR Part 70 licensing in conjunction with a manufacturing license for this purpose and the staff would need to develop related guidance, including on features to preclude criticality that would be specified in the manufacturing license and provide criticality prevention required by the 10 CFR Part 70 license.
- Under this option, the NRC staff may have to develop guidance or pursue other regulatory vehicles to ensure licensees establish and maintain adequate financial protection and indemnity agreements.

Topic 3: Operational Testing at a Factory

Some factory-fabricated micro-reactor deployment models include operational testing of factory-fabricated modules at the factory prior to delivery to the deployment site. In one scenario, the factory-fabricated module would be operated at low power levels for the purpose of physics testing. In another scenario, which would more likely apply to self-contained designs, the factory-fabricated module would be operated at full power in order to verify that all systems function as designed.

Operational testing at a factory would require the fabricator to obtain a facility operating license or combined license issued pursuant to 10 CFR Part 50 or Part 52, respectively, and comply with all relevant regulatory requirements for each factory-fabricated module and any other structures or systems that would be necessary to construct at the factory to conduct operational testing (e.g., cooling systems, shielding, and ventilation). After completion of operational testing, the licensee would install features to preclude criticality to take the reactor out of operation in addition to ensuring all other necessary measures are taken to protect personnel and maintain the module in a safe condition prior to shipment. The factory-fabricated module would be covered under the manufacturing license holder's Part 30 and Part 70 licenses authorizing the possession of the byproduct and special nuclear material contained in the module. The manufacturing license would also continue to authorize possession of the factory-fabricated module until its receipt by a licensee authorized to acquire it at the deployment site under a separate Part 50 or 52 license.

The options below would cover both fuel loading and operational testing at the factory.

Option 3a—Authorize operation for testing under a power reactor license

Under this option, the fabricator would need a power reactor facility operating license or combined license to operate each factory-fabricated module as a commercial micro-reactor for operational testing at the factory. The regulatory processes for obtaining the necessary permits and licenses would be the same as those described in Option 2a, above, including the use of the multi-module licensing approaches in SECY-11-0079. The fabricator could submit a single application that included the application for the manufacturing license and applications for combined licenses for operational testing of each factory-fabricated module intended to be tested over the life of the factory. Also, the ITAAC closure and hearing processes for each module could potentially be coordinated for both the factory and deployment site if the

deployment site is known at the time of licensing for operational testing at the factory. The NRC staff's review of applications for permits and licenses for operational testing would rely on the prior approval of the reactor design in the manufacturing license (and any other prior approvals).

In order to perform operational testing, the factory site licensee would need to establish adequate operational programs for matters such as security, emergency preparedness, fitness for duty, radiation protection, and operator training and qualification. As stated in SECY-20-0093, micro-reactors differ significantly from large light-water reactors and operational requirements in the regulations that were developed with large light-water reactor facilities in mind may be more extensive than micro-reactors require to operate safely. SECY-20-0093 also states that, "[p]rovided a micro-reactor applicant can demonstrate the safety and security of its design and show the facility represents a low risk, the [NRC] staff recognizes that different licensing and regulatory approaches are appropriate for such facilities." Operational testing at a factory would generally further reduce the risk associated with operation of a micro-reactor by imposing limitations on the maximum power level or cumulative operating time or both through license conditions. Such limitations would result in a lower radionuclide inventory and correspondingly reduce the potential radiological hazards to the public in the unlikely event of an accident to a very small fraction of those considered for extended operation of large light-water reactors. Also, limitations on the power level and duration of operation could, for example simplify operational programs for radiation protection during and after operation due to smaller amounts of radioactive effluents and lower radiation fields. For these reasons and others, compliance with all requirements (e.g., those related to operational programs) in 10 CFR Part 50 or Part 52 might not be commensurate with the expected lower risk associated with operational testing at the factory. Depending on the specifics of the operational testing program, it may be possible to use existing guidance and appropriate regulatory vehicles to scale the NRC staff review necessary to issue a license that authorizes operational testing. However, certain requirements such as hearings, ITAAC, and ACRS review are mandated by the AEA. In addition, if operational programs were scaled for testing at a factory, those programs would likely not be adequate for full power extended operation at deployment sites and would have to be reviewed as part of the application for the facility operating license or combined license at the deployment site.

Implementation

The NRC staff would implement this option by applying the current regulations for power reactor licensing and the guidance for appropriately scaling reviews of applications for licenses that would authorize operational testing of micro-reactors at a factory. The NRC staff would consider whether license conditions, exemptions, hearing orders, rules of particular applicability, or other regulatory vehicles would also be appropriate to use for scaling reviews.

Advantages

- This option relies on established processes for the licensing of nuclear reactors and could use existing guidance on appropriately scaling reviews to address the specific risks associated with operational testing at the factory. Where the fabricator has a final design already approved by the NRC with maximum standardization (such as in a manufacturing license), the scope of review for licensing operational testing could be focused on operational programs.

- This option could facilitate combining applications for a manufacturing license, licenses for operational testing of modules at a factory, and possibly combined licenses at the deployment site. This could enhance efficiency of the NRC staff reviews of the applications and other related regulatory processes, such as hearings.

Disadvantages

- There is a high regulatory burden on the manufacturer and NRC staff associated with requiring a power reactor facility operating license or a combined license for the sole purpose of operational testing in light of the expected short duration and low risk posed by that activity.
- The staff would need to appropriately scale power reactor requirements for the review of a factory-fabricated module that would be licensed only for operational testing. Although relevant guidance exists, this could require substantial NRC staff resources compared to Option 3b, below, that would apply the non-power reactor regulations to operational testing at the factory. In addition, operational programs that were scaled for testing at a factory would likely not support licensing at the deployment site.

Option 3b—Apply the regulations for non-power reactors to authorize fuel loading and operational testing at a factory

This option would provide a second regulatory pathway for applicants under Part 50 that would apply the regulations for non-power reactors to licensing of fuel loading and operational testing at a factory. Under this option, the factory-fabricated modules would be manufactured in accordance with a manufacturing license issued pursuant to 10 CFR Part 52 that includes an approved nuclear power reactor design. The alternatives in SECY-11-0079 for licensing multi-module sites under 10 CFR Part 50 would be the same as for the Part 50 licensing approaches under Options 2a and 3a. However, instead of applying the regulations for power reactors, the NRC staff would apply the regulations for non-power reactors to the review of the construction permit application and operating license application(s). In contrast to the regulations for nuclear power reactors which were developed largely for large light-water reactors, the regulations for non-power reactors are generally performance-based and include far fewer and less prescriptive requirements. The NRC staff notes that this option and Option 3a are not mutually exclusive. If the Commission directs the NRC staff to pursue both options, it would be up to the manufacturer to decide if the approach described in this option would be advantageous for their deployment model.

The operational characteristics of and safety considerations for commercial micro-reactors operated at the factory only for testing would be similar to most currently licensed non-power reactors. The NRC staff expects that operational testing could be done in a few days of operation or less at power levels between a few kilowatts to several tens of megawatts. Operational testing at a factory should have low potential radiological consequences because the radionuclide inventories generated during operational testing would be comparable to those for existing non-power reactors and a fraction of a percent of those generated by extended operation of large light-water reactors. Similar to currently licensed non-power reactors, the commercial micro-reactors operated for testing in a factory under this option may also have fewer and simpler systems and operating procedures, require less cooling during and after

operation, rely less on active safety features, and generate very small amounts of radioactive effluents compared to large light-water reactors. The non-power reactor regulations have been applied to dozens of facilities with a wide range of operational and safety characteristics that encompass those expected for operational testing of micro-reactors. For these reasons, the non-power reactor regulations would be a better fit than the power reactor regulations for making the required findings and reasonable assurance determinations for issuing permits and licenses for operational testing of commercial micro-reactors at a factory.

However, the current definition of "non-power reactor" in 10 CFR 50.2 is for "research and test reactor[s]" for "research and development." In SECY-19-0062, "Final Rule: Non-power Production or Utilization Facility License Renewal" (ML18031A000), the NRC staff recommended a revised definition of non-power reactor that includes a commercial or industrial reactor licensed under 10 CFR 50.22, "Class 103 licenses; for commercial and industrial facilities," as a distinct category of non-power reactors. The NRC staff recommended this change in definition to account for commercial facilities that would be operated for commercial or industrial purposes, such as commercial medical isotope production or industrial radiography (or in the case of this paper, operational testing), and not the production of electrical or thermal energy for use. The NRC staff also recommended conforming changes to other regulations in 10 CFR Ch. I that currently refer to non-power reactors, research and test reactors, or facilities licensed under 10 CFR 50.22 that are not nuclear power reactors to cover commercial and industrial non-power reactors. These proposed conforming changes recognize that commercial or industrial non-power reactors would have risk profiles and operational characteristics similar to non-power reactors currently licensed as research and development facilities. If the NRC staff identifies any gaps in the non-power reactor regulations when applying them to licensing operational testing of commercial micro-reactors at a factory, the NRC staff would consider the recommended rule changes in SECY-19-0062 (if the draft final rule remains under Commission consideration at that time) and use an appropriate regulatory vehicle to address the gaps.

Under option 3b, the applicant would prepare its construction permit and operating license applications and the NRC staff would conduct its reviews primarily using the guidance in NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," dated February 1996 (ML042430055 and ML042430048). Commercial and industrial non-power reactors considered in SECY-19-0062 and the commercial micro-reactors operated for testing under this option would generally be adequately covered by the existing non-power reactor licensing guidance in NUREG-1537. The NRC staff would rely on the approval of the design in the manufacturing license in its safety evaluations related to operational testing. The NRC staff would focus its reviews on operational programs and any unique considerations for non-power reactors not covered in the approval of the design in the manufacturing license. The regulations and guidance for operational programs for non-power reactors provide for applicants and licensees to appropriately scale operational programs to account for a wide variety of designs and operational characteristics. Under this option, the applicant should also describe the number of commercial reactors proposed to be constructed at the factory, the number to be operated simultaneously, and the total number of fueled reactors proposed to be located at the site at one time. The NRC staff would need this information to appropriately consider the cumulative risk associated with the licensed activities at the factory in its safety evaluation supporting issuance of the construction permit and operating licenses. This information would also be necessary for the NRC staff to make other

determinations, such as the appropriate environmental review and the amount of financial protection required by 10 CFR 140.11 and 10 CFR 140.12.

Option 3b would require the Commission to agree as a matter of policy that a factory-fabricated module could be licensed for operational testing at the factory by applying the regulations for non-power reactors even though the module would have been manufactured and constructed as a power reactor at the factory and would ultimately be operated as a power reactor at a deployment site. The NRC staff's practice has been to apply power reactor regulations throughout the lifecycle of a power reactor and this option would be a departure from that practice. This option would also require the fabricator to seek an exemption from compliance with the regulations for power reactors in the license application for operational testing. In addition, licensing operational testing at a factory by applying the non-power reactor regulations would limit the ability to combine licensing proceedings at the factory with licensing proceedings at deployment sites because different regulatory requirements would apply to each proceeding.

The NRC's regulations for power reactors appear in different parts of 10 CFR, Ch. I, and the applicant would need to address the pertinent exemption criteria for the regulations in each part. For example, exemptions from regulations in 10 CFR Part 50 must satisfy 10 CFR 50.12, "Specific exemptions," which requires that exemptions be authorized by law, not present an undue risk to the public health and safety and be consistent with the common defense and security. The NRC staff notes that such an exemption is consistent with AEA Section 103, which provides for licensing commercial utilization facilities whether or not they are power reactors. Further, as discussed above, the fabricator would likely be able to show that appropriate application of the non-power reactor regulations to operational testing at the factory would provide reasonable assurance of adequate protection of public health and safety and the common defense and security. This is based on the NRC staff's expectation that the operational and safety characteristics of factory-fabricated modules when operated for testing at a factory will be similar to those of non-power reactors currently licensed for operation.

The regulations in 10 CFR 50.12 also specify that the Commission will not consider granting an exemption unless special circumstances are present. For operational testing of factory-fabricated modules, the applicant may be able to show that special circumstances are present such as those described in 10 CFR 50.12(a)(2)(ii) which state, "[a]pplication of the regulation in the particular circumstances would not serve the underlying purpose of the rule or is not necessary to achieve the underlying purpose of the rule." As discussed in this option, application of the 10 CFR Part 50 power reactor regulations may not be necessary to achieve the underlying purpose of those rules if the applicant can demonstrate that the non-power reactor regulations are adequate to accomplish those purposes. In any case, the fabricator would be responsible for demonstrating that special circumstances exist, as specified in 10 CFR 50.12(a)(2), in its justification for a request for an exemption from the power reactor regulations.

An EIS or a supplement to an EIS is required by 10 CFR 51.20(b) for construction permit and full power operating license applications for power reactors and testing facilities, but an EIS is not automatically required for a construction permit or operating license application for non-power reactors other than testing facilities. An exemption from the EIS requirements for power reactors in 10 CFR Part 51 might be appropriate for applications to operate factory-fabricated modules only for testing. Any such exemptions must satisfy 10 CFR 51.6, "Specific exemptions." Because EISs are required for testing facilities, the NRC staff would, in deciding whether to

grant such exemptions, consider whether the technical characteristics of the factory-fabricated module when operated for testing at a factory might otherwise fall within the definition of "testing facility" in 10 CFR 50.2, as well as the number of modules to be constructed and operated at the factory and the proposed scope of operational testing. If the NRC staff determines that an exemption from the requirements for an EIS is warranted, the staff would prepare an environmental assessment. If the staff makes a finding of no significant impact after preparing the environmental assessment, then an EIS would not be required.

Implementation

If the Commission directs the NRC staff to pursue this option, the NRC staff would implement it through the current regulatory framework for licensing non-power reactors and use license conditions, exemptions, hearing orders, rules of particular applicability, or other regulatory vehicles, as appropriate. The NRC staff would also consider developing additional guidance, as necessary, related to applying non-power reactor regulations to the preparation and review of construction permit and operating license applications for operational testing of factory-fabricated modules at a factory, including those that reference a power reactor design approved in a manufacturing license.

Advantages

- This option would eliminate the need to tailor the power reactor regulations on a case-by-case basis for authorizing operational testing at a factory because the regulations for non-power reactors are well established and are generally adequate for authorizing operational testing of factory-fabricated modules.
- Compared to Option 3a, the operational programs required for operational testing under this option could be more commensurate with the risks associated with the limited scope and duration of operational testing envisioned by factory-fabricated micro-reactor developers and reduce the associated regulatory burden while maintaining adequate protection of public health and safety and the common defense and security.
- The environmental review would also be simplified compared to Option 3a if licensing of the factory-fabricated module for operational testing at a factory could be appropriately covered by an environmental assessment rather than an EIS.

Disadvantages

- It may not be possible to combine the proceedings for issuing the facility operating licenses at the factory with the proceedings associated with power reactor licenses at the deployment sites (as would be the case under Option 3a) because the regulations for non-power reactors would be applied at the factory and the regulations for power reactors would be applied at the deployment site.

Enclosure:
Technical, Licensing, and Policy Considerations
for Factory-Fabricated Micro-Reactors