Improving Licensing and Regulatory Frameworks for Factory Manufacturing of Facilities and Components for Small Modular Reactors

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1. Introduction

The global nuclear industry is undergoing a significant paradigm shift with the emergence of Small Modular Reactors (SMRs). Generally defined as reactors with an electrical output of less than 300 MWe, SMRs are distinguished not only by their reduced capacity and enhanced passive safety features, but more fundamentally by their reliance on factory-based serial production of standardized modules. Unlike conventional large-scale nuclear power plants constructed primarily through on-site, custom-built methods, SMRs are designed to be manufactured largely in controlled factory environments and then transported to and assembled at reactor sites.

This transition in construction and supply-chain architecture offers substantial potential benefits, including improved quality control, shortened construction schedules, reduced financial risk, and greater siting flexibility. Moreover, SMRs are increasingly regarded as a strategic technology for climate change mitigation, energy security enhancement, and the development of flexible and distributed power systems.

However, the shift from site-based construction to off-site factory fabrication presents significant regulatory challenges. Existing nuclear licensing systems—including the Korean framework under the Nuclear Safety Act (Act No. 17089, last amended June 9, 2020)—were developed on the premise that safety-related structures, systems, and components are manufactured, installed, and inspected primarily at the reactor site. SMR deployment fundamentally alters this assumption by relocating substantial manufacturing and quality assurance activities to independent industrial facilities.

In particular, the transport of large, near-complete nuclear modules from factories to construction sites introduces new and complex legal interfaces. These modules, potentially weighing thousands of tons, must traverse public infrastructure by land or sea, raising questions regarding manufacturing approval, inspection authority, transport authorization, safety oversight, inter-agency coordination, and allocation of regulatory responsibility. Current legal provisions do not comprehensively address factory-based serial production, off-site regulatory inspections, or the integrated management of manufacturing-to-installation processes.

This structural misalignment between technological innovation and regulatory design may create legal uncertainty and procedural inefficiencies that hinder SMR deployment. Accordingly, a systematic examination of whether existing legal instruments adequately accommodate the distinctive characteristics of SMR manufacturing and transport, while preserving the paramount objective of nuclear safety, is urgently required.

This paper analyzes the structural limitations of the current Korean licensing framework under the Nuclear Safety Act with respect to: (i) manufacturing approval of nuclear facilities and equipment; (ii) inspection during factory production; (iii) authorization for transport of nuclear modules; and (iv) regulatory oversight before and during transport. By identifying normative gaps and regulatory inconsistencies, the study proposes institutional reform measures aimed at enabling the safe, predictable, and efficient commercialization of SMRs within a robust and forward-looking regulatory framework.

2. Technical Characteristics of SMRs and Emerging Regulatory Interfaces

(1) Modular Design and Standardization

A defining feature of Small Modular Reactor (SMRs) is their reliance on standardized designs and modular architecture. Unlike conventional large nuclear power plants, which are often custom-designed and constructed through site-specific engineering processes, SMRs are developed with a high degree of design uniformity intended to support serial production. Standardization enables identical or near-identical reactor units to be replicated across multiple sites, thereby promoting regulatory predictability and facilitating economies of series.

The modular concept further allows major structures, systems, and components (SSCs), including reactor pressure vessels, containment modules, and engineered safety systems, to be fabricated and, in some cases, fully or partially assembled in controlled factory environments prior to shipment. Factory-based production offers enhanced quality control through stable environmental conditions, specialized tooling, and repeatable manufacturing procedures. It also enables more rigorous and consistent application of quality assurance programs compared to variable on-site construction settings.

From a regulatory perspective, however, this standardization and modularization challenge licensing frameworks that have traditionally been premised on site-specific design review and sequential construction oversight. The shift toward replicable designs and pre-assembled modules necessitates reconsideration of how design approval, manufacturing authorization, and conformity assessment are structured within existing legal systems.

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 [9]. 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.

3. Shift from On-Site Construction to Off-Site Man ufacturing

The increasing reliance on off-site manufacturing represents a fundamental transformation in the nuclear project delivery model. Under the traditional paradigm, most safety-related SSCs are fabricated, installed, and inspected at or near the reactor site, with regulatory authorities exercising direct oversight during the construction phase. By contrast, SMR deployment relocates a substantial portion of safety-relevant activities to remote manufacturing facilities.

This geographical and institutional separation raises significant legal and administrative questions. Quality assurance, inspection, and verification activities shall be conducted at manufacturing facilities that may be located far from the licensed site and, in certain cases, in different jurisdictions. Consequently, regulatory authorities must clarify the legal basis for exercising inspection powers outside the reactor site, including cross-border oversight where international supply chains are involved.

Moreover, the division between manufacturing authorization and construction licensing becomes increasingly complex. The regulatory system must ensure continuity of oversight from factory production to on-site installation, while avoiding duplication or gaps in supervision. Without clearly defined legal mechanisms for off-site inspection and approval, uncertainties may arise regarding compliance responsibility, documentation requirements, and the evidentiary status of factory-based quality assurance records within the overall licensing process.

4. Transportation and Installation Interfaces

The modular nature of SMRs necessarily entails the transportation of large, safety-related components from manufacturing facilities to the reactor site. Accordingly, regulatory approval is required not only for fabrication but also for transportation, handling, and final installation. These stages introduce new regulatory interfaces that were less prominent under traditional construction models.

Transportation of major reactor modules—potentially weighing several thousand tons—implicates issues of structural integrity, public safety, infrastructure compatibility, and, where applicable, radiological protection. Existing nuclear licensing systems often address the transport of nuclear fuel and radioactive materials; however, they may not explicitly contemplate the movement of large, integrated reactor modules that form part of a licensed nuclear facility. This creates potential ambiguity regarding the applicable authorization procedures, competent authorities, and scope of inspection before and during transport.

Furthermore, installation at the reactor site represents a critical transition point. Regulatory frameworks must ensure that factory-manufactured modules maintain their certified quality and safety characteristics throughout transport and handling, and that their integration into site-specific structures complies with approved design and safety analysis reports. The absence of clear legal provisions governing these interfaces may generate regulatory gaps, complicate project timelines, and undermine the predictability essential for large-scale SMR deployment.

In summary, the modular design, off-site manufacturing, and transportation requirements of SMRs collectively redefine the boundaries of nuclear regulatory oversight. Addressing these evolving interfaces coherently and systematically is essential to ensure both effective safety governance and the practical feasibility of SMR commercialization.

5. Limitations of Current Licensing and Regulatory Systems

The transition toward factory-based production and modular deployment of Small Modular Reactor (SMRs) exposes structural limitations embedded in conventional nuclear regulatory systems. While current frameworks have proven effective for large, site-specific nuclear power plants, they are not fully aligned with the industrial logic of standardized, serially manufactured reactor technologies. The principal challenges may be categorized as follows.

(1) Site-Centered Licensing Structure

Most nuclear regulatory regimes are fundamentally site-centered. Licenses are granted for the construction and operation of a nuclear installation at a defined geographic location, based on site-specific environmental, geological, and demographic assessments. Within this structure, manufacturing activities are typically addressed indirectly through procurement controls, quality assurance (QA) requirements, and vendor qualification processes rather than through independent manufacturing licenses.

This approach presumes that safety-relevant fabrication occurs either on-site or under the direct oversight of a licensee responsible for a specific facility. However, the SMR model conceptualizes the reactor, to a significant extent, as a standardized and transportable industrial product. The intrinsic linkage between permits and a specific site may therefore conflict with the logic of serial production, where identical modules are intended for deployment across multiple locations. As a result, regulatory uncertainty arises regarding whether and how manufacturing activities should be subject to standalone authorization distinct from site construction licenses.

(2) Ambiguity in Regulatory Jurisdiction

A related challenge concerns the scope of regulatory jurisdiction over off-site manufacturing facilities. In many jurisdictions, nuclear regulators exercise clear authority within licensed nuclear sites but possess less explicit statutory mandates for facilities that are geographically separate from those sites. Where manufacturing plants are located outside the licensed site, the legal basis for inspection, enforcement, and compliance verification may be unclear.

Such ambiguity can generate several adverse consequences, including overlapping oversight by multiple authorities, procedural delays stemming from jurisdictional disputes, or conversely, insufficient regulatory coverage. For SMRs, whose supply chains may involve multiple specialized vendors operating in different regions, the absence of clearly defined jurisdictional rules undermines regulatory predictability and complicates project planning.

(3) Absence of Graded and Risk-Informed Approaches

Conventional licensing systems often apply uniform regulatory requirements to safety-related components, regardless of their relative safety significance. Although this conservative approach reflects the high safety standards of the nuclear sector, it may prove disproportionately burdensome in the context of SMR factory manufacturing.

SMR designs frequently rely on passive safety features, simplified system configurations, and standardized components produced through repeatable industrial processes. Many factory-fabricated modules may present lower risk profiles compared to complex, site-assembled structures in traditional large reactors. Without a graded and risk-informed regulatory framework, that can calibrate inspection intensity, documentation requirements, and approval procedures according to safety significance, manufacturers may face unnecessary administrative burdens that erode the economic advantages of serial production.

(4) Inspection and Oversight Model

Traditional inspection models rely heavily on resident inspectors stationed at large construction sites, where fabrication and assembly activities occur over extended periods. This oversight structure is not readily transferable to distributed manufacturing networks involving multiple factories, potentially located in different regions or countries.

Serial production in factory settings demands a different regulatory approach, emphasizing system-level quality management audits, supplier accreditation, and periodic conformity assessments rather than continuous on-site inspection of a single project. Without adapting the oversight model, regulators may struggle to supervise complex, globally distributed supply chains effectively.

(5) Interface between Manufacturing and Construction Licenses

Currently, existing regulatory systems often lack a clearly articulated division of responsibility and procedural handover between factory manufacturing authorization and site-specific construction or operating licenses. The transition from production to transport, installation, commissioning, and operation constitutes a critical regulatory interface.

In the absence of explicit legal provisions governing this interface, uncertainties may arise regarding documentation transfer, liability allocation, inspection continuity, and the verification of compliance with approved design specifications. A coherent regulatory architecture must therefore define the relationship between manufacturing licenses (covering production and quality assurance) and construction or operating licenses (covering assembly, commissioning, and operation) to prevent gaps or overlaps in oversight.

Collectively, these structural limitations reveal a regulatory framework optimized for large, site-built nuclear installations rather than standardized, factory-manufactured reactor technologies. Addressing these constraints through systematic legal and institutional reform is essential to enable the safe, efficient, and internationally competitive deployment of SMRs.

(6) Limited International Harmonization for Supply Chain Licensing

Finally, SMR deployment is expected to rely on global, multi-vendor supply chains. However, divergences in national regulatory requirements for manufacturing inspections, certifications, and approvals present significant barriers to cross-border collaboration. Each supplier may be required to obtain separate, countryspecific certifications, leading to duplication of effort, increased costs, and delays.

The limited degree of international harmonization in manufacturing standards and inspection recognition undermines economies of scale—one of the principal economic rationales for SMR development. Without greater mutual recognition or convergence of regulatory approaches, the global commercialization of SMRs may face structural inefficiencies.

6. Comparative Analysis of Regulatory Framework s for Factory Fabrication: Manufacturing Approv al and Inspection

(1) United States

In the United States, nuclear regulation is founded upon the Atomic Energy Act of 1954 and implemented through regulations promulgated by the U.S. Nuclear Regulatory Commission in Title 10 of the Code of Federal Regulations. With respect to factory fabrication, key provisions include 10 CFR Parts 50 and 52 (facility licensing), Part 21 (defect reporting), and Part 71 (transportation of radioactive material).

The U.S. adopts a licensee-centered model. Manufacturers are not directly licensed in the same manner as plant operators; instead, the construction permit or combined license (COL) holder bears ultimate responsibility for supplier compliance. Manufacturing approval is therefore embedded within the facility licensing framework.

A principal mechanism for demonstrating fabrication capability is compliance with Section III of the ASME Boiler and Pressure Vessel Code, administered by the American Society of Mechanical Engineers. Safety-related component manufacturers must obtain ASME “N-stamp” accreditation, evidencing an NQA program consistent with 10 CFR Part 50, Appendix B. Although accreditation is granted by ASME, it is recognized by the NRC as an acceptable quality assurance basis.

Manufacturing inspection operates through layered oversight: ASME code inspections, licensee supplier audits, and NRC vendor inspections. Ongoing regulatory reforms, including the Part 53 rulemaking and digital oversight initiatives, signal a gradual transition toward risk-informed and data-driven inspection models suitable for modular and factory-based production.

(2) Canada

Canada’s regulatory regime is grounded in the Nuclear Safety and Control Act and administered by the Canadian Nuclear Safety Commission. SMRs are regulated as Class I nuclear facilities, with technical requirements defined through regulatory documents and CSA standards (notably the N285 and N286 series).

Unlike the U.S. N-stamp system, Canada does not rely on a single code-based accreditation. Instad, the CNSC may authorize fabricators based on demonstration of a compliant quality assurance program, assessed within the broader facility safety case. The licensee remains responsible for supplier control.

A distinctive feature is the Vendor Design Review (VDR), a voluntary pre-licensing process allowing early regulatory feedback on reactor designs and associated manufacturing strategies. This mechanism supports innovation in modular fabrication by reducing uncertainty prior to formal licensing.

Inspection practices are risk-informed and performance-based. The CNSC conducts audits of domestic and international manufacturing facilities, focusing on whether quality systems achieve safety objectives rather than strict procedural conformity. This flexible approach accommodates advanced manufacturing technologies while maintaining regulatory oversight.

(3) United Kingdom

In the United Kingdom, nuclear regulation is exercised by the Office for Nuclear Regulation under statutory frameworks including the Energy Act 2013 and the Nuclear Installations Act 1965. Manufacturing oversight is closely linked to the Generic Design Assessment (GDA) process.

The GDA, originally focused on reactor design, is increasingly incorporating manufacturing strategies and supply chain governance. For example, the SMR program led by Rolls-Royce SMR proposes designated “SMR Design Points”—licensed factories responsible for standardized module production. This concept directly integrates manufacturing facility approval into the design assessment framework.

ONR guidance on supply chain control requires licensees to demonstrate effective oversight of manufacturing facilities, including quality management systems and personnel competence. Digital compliance tools, such as digital twins and lifecycle traceability systems, are being incorporated to strengthen inspection and configuration management. Compared with other jurisdictions, the UK model more explicitly aligns design approval with manufacturing authorization.

(4) China

China’s regulatory system is based on the Nuclear Safety Law (2018) and administered by the National Nuclear Safety Administration. Technical standards are provided through national (stands for Guójiā Biāozhǔn, GB) and nuclear industry standards (EJ, part of the industry standard system used in the nuclear sector)

China employs a centralized and vertically integrated model. The China National Nuclear Corporation(CNNC) frequently acts as designer, manufacturer, constructor, and operator. The ACP100, known as Linglong One, was conceived for serial factory production from the outset.

Manufacturing approval is integrated into the overall project authorization process. The National Nuclear Safety Administration (NNSA) reviews standardized designs together with designated manufacturing facilities, relying on state-mandated quality systems within state-owned enterprises. Inspection benefits from centralized supply chain control, and the first reference plant serves to validate production processes for subsequent replicated units.

(5) Comparative Observations

Across jurisdictions, four broad regulatory models emerge:

- Licensee-Centered and Code-Based Model (United States): Relies on third-party code accreditation (ASME N-stamp), layered inspections, and progressive risk-informed reform.
- Performance-Based and Vendor-Engagement Model (Canada): Combines flexible, risk-informed inspection with early vendor design review.
- Design–Manufacturing Integrated Model (United Kingdom): Aligns generic design assessment with manufacturing facility authorization and digital lifecycle compliance.
- State-Integrated Standardization Model (China): Employs centralized approval, vertical integration, and replication of standardized factory production.

These models reflect differences in institutional structure and regulatory philosophy. Nevertheless, all jurisdictions are adapting their frameworks to address the regulatory implications of modular, factory-based nuclear construction.

7. Case Studies in SMR Factory Fabrication: Regulatory Approaches to Manufacturing Approval

(1) United States: NuScale VOYGR

The U.S. approach to SMR factory fabrication is illustrated by the NuScale Power design and its VOYGR plant configuration. The NuScale module is an integral pressurized water reactor rated at approximately 77 MWe per unit, with up to twelve factory-fabricated modules installed in a common pool arrangement.

Manufacturing Strategy.

The reactor pressure vessel and major integral components are designed for off-site fabrication by nuclear-qualified heavy industry suppliers, including Doosan Enerbility and engineering partner Sargent & Lundy. Fabrication occurs in facilities holding ASME Section III accreditation and N-stamp authorization. Rather than establishing new dedicated SMR factories, NuScale relies on the existing nuclear-qualified industrial base.

Regulatory Pathway.

NuScale obtained Design Certification under 10 CFR Part 52 from the U.S. Nuclear Regulatory Commission in 2023. The Safety Evaluation Report addressed not only design features but also quality assurance frameworks and fabrication controls. Although manufacturers are not directly licensed, regulatory acceptance depends on compliance with ASME accreditation and Appendix B quality assurance programs. Manufacturing approval is therefore embedded within a layered system of design certification, supplier qualification, and licensee oversight.

(2) United Kingdom: Rolls-Royce SMR

The UK model, led by Rolls-Royce SMR, represents a more explicit integration of manufacturing approval into reactor licensing. The proposed design is a 470 MWe three-loop pressurized water reactor intended for standardized deployment.

Manufacturing Strategy.

Approximately 80% of plant volume is intended to be fabricated in factory settings. The concept of designated “SMR Design Points” envisions licensed, permanent manufacturing facilities dedicated to producing standardized modules. This product-oriented model emphasizes repeatability, serial production, and stable, regulator-approved production environments.

Regulatory Pathway.

The project is undergoing Generic Design Assessment (GDA) by the Office for Nuclear Regulation and the UK Environment Agency. Unlike traditional models relying primarily on procurement oversight, the GDA process evaluates manufacturing strategies, quality systems, supply chain governance, and digital traceability mechanisms as integral elements of the safety case. Consequently, manufacturing facility approval is increasingly aligned with design approval, reflecting the centrality of standardized factory processes to SMR safety assurance.

(3) Canada: GE Hitachi BWRX-300

The GE Hitachi Nuclear Energy BWRX-300 is a 300 MWe natural circulation boiling water reactor derived from the ESBWR design and is being advanced in multiple jurisdictions, including Canada.

Manufacturing Strategy.

The BWRX-300 leverages the established global supply chain for earlier boiling water reactors rather than creating entirely new SMR-specific factories. Components are fabricated in existing ASME- or CSA-qualified facilities in countries such as the United States, Japan, and Canada, and assembled into larger modules where feasible. This strategy minimizes technological and regulatory novelty by relying on proven manufacturing processes and experienced suppliers.

Regulatory Pathway.

The design is undergoing Vendor Design Review with the Canadian Nuclear Safety Commission (CNSC) for deployment at the Darlington site. Manufacturing approval relies on demonstrating the use of established codes, qualified suppliers, and mature quality assurance systems. Engagement with multiple regulators reflects a coordinated, multi-jurisdictional approach aimed at facilitating cross-border supply chains.

(4) China: CNNC Linglong One (ACP100)

China's ACP100, known as Linglong One, is a 125 MWe integral PWR designed explicitly for serial production.

Manufacturing Strategy.

The reactor module, weighing approximately 3,000 tonnes, is fabricated in a shipyard-like industrial environment. Development is led by the China National Nuclear Corporation (CNNC), which integrates design, manufacturing, construction, and operation within a vertically integrated state-owned structure. From inception, the reactor was engineered for modularization, transportability, and standardized factory production.

Regulatory Pathway.

Design approval was granted in 2016 by the National Nuclear Safety Administration. The first unit at Changjiang serves as a reference project validating both reactor design and fabrication processes. Manufacturing approval is incorporated into overall project authorization, and subsequent units are expected to benefit from streamlined approvals based on standardized replication.

(5) Comparative Implications

These case studies reveal distinct but converging regulatory strategies for SMR manufacturing approval:

- The United States embeds factory fabrication within existing code-based accreditation and design certification structures.
- The United Kingdom directly integrates manufacturing facility authorization into generic design assessment.
- Canada and multi-national deployments rely on vendor design review and established global supply chains to reduce regulatory novelty.
- China employs centralized, vertically integrated governance to standardize and streamline serial production approval.

Collectively, these approaches demonstrate that manufacturing approval is becoming a core dimension of SMR licensing. As nuclear construction transitions from site-built megaprojects to standardized factory production, regulatory systems are increasingly adapting to ensure that safety assurance extends beyond reactor design to encompass the integrity and governance of industrial manufacturing processes.

8. Proposed Amendments to the Legal Framework f or SMR Factory Fabrication and Transport

8.1. Necessity of Legislative Reform under the Nuclear Safety Act

The transition from site-built large reactors to factory-fabricated SMRs reveals structural limitations in Korea's current legal framework under the Nuclear Safety Act (NSA). Existing provisions are primarily equipment-centered and site-specific, developed for single-unit construction projects. They do not adequately address serial production, integrated module fabrication, digital manufacturing systems, or the transport of large, unfueled nuclear modules.

To ensure safe and efficient SMR deployment, systematic amendments to the NSA and its subordinate regulations are required. Reform should pursue three core objectives: (i) establishment of a facility-based manufacturing approval system; (ii) clarification of transport authorization and inspection authority; and (iii) integration of manufacturing, transport, and site licensing into a coherent regulatory pathway.

8.2. Reform of Manufacturing Approval and Inspection

(1) Structural Limitations of the Current Framework

Under the current NSA, design safety review and construction permits are linked to site-specific licensing, while manufacturing approval provisions focus on individual items of "nuclear equipment." Although the Act provides authority for manufacturing inspection and approval of manufacturing methods, it does not explicitly authorize certification of manufacturing facilities or serial production lines for identical modules.

Under the current NSA:

- Article 10 (Construction Permit) is tied to site-specific licensing.
- Article 15-2 (Reporting of Contracts for Safety-Related Facilities) requires approval of contracts for safety-related facilities or equipment.
- Article 16 (Inspection) is tied for inspection to the installer of a power reactor, the supplier, and the performance verification institution with respect to the construction of the power reactor and its related facilities, and matters concerning the material accountancy of specific nuclear material.

As a result, the framework lacks a legal mechanism to approve a factory for repetitive production of standardized reactor modules or to recognize that units produced under an approved production system satisfy design requirements by default. This equipment-based approach is misaligned with the industrial logic of SMR serial fabrication.

(2) Introduction of Serial Manufacturing Approval

To address this gap, a new statutory provision should establish a facility-based serial manufacturing license. Such a provision would authorize the approval of:

- The designated manufacturing facility;
- Production processes and quality assurance systems;
- The number of units and validity period of authorization;
- Surveillance and audit requirements.

Modules manufactured under an approved serial production license would be deemed to satisfy design approval requirements, subject to compliance verification. This reform would shift the regulatory paradigm from item-by-item approval to production-line certification while preserving inspection authority through periodic audits and performance monitoring.

A new statutory provision should be introduced under the NSA to establish a facility-based manufacturing licensing system.

Proposed amendment Article 10 (Construction Permit)

③-1 Any person intending to serially manufacture identical nuclear facilities or major components thereof in a designated manufacturing facility may obtain approval from the Nuclear Safety and Security Commission (NSSC) for the manufacturing facility, production processes, and quality assurance system.

Such approval shall specify:

- The number of units authorized for manufacture,
- The validity period,
- Applicable conditions and surveillance requirements.

③-2 Nuclear facilities or modules manufactured in accordance with an approved serial manufacturing license shall be deemed to satisfy the design approval requirements under Article 12 (Standard Design Approval) for each identical unit, subject to compliance verification.

⑤-1 A person who intends to obtain approval for manufacture pursuant to paragraph ③-1 shall submit to the Commission an application for approval accompanied by design documents for the reactor and related facilities, safety analysis reports, a quality assurance program, and such other documents as prescribed by Ordinance of the Prime Minister.

⑥-1 Where a person who intends to manufacture a power reactor and its related facilities (hereinafter referred to as a "Reactor Manufacturer") obtains approval for manufacture pursuant to paragraph ③-1 and intends to manufacture safety-related facilities, if the design documents under Article 11 (3), as referred to in Article 15-2 (1) of this Act, are submitted to the head of the relevant administrative agency, such person shall be deemed to have obtained a building permit under Article 11 of this Act.

8.3. Dedicated Enforcement Decree for Factory Fabrication

Implementation of serial manufacturing approval requires a specialized Enforcement Decree for Factory Fabrication of Nuclear Facilities. The Decree should define "factory-fabricated nuclear module" and establish criteria for:

- Certification of manufacturing facilities;
- Quality assurance requirements for serial production;
- Digital recordkeeping and configuration management;
- Mandatory inspection and witness points;
- Change management and nonconformance reporting.

Particular attention should be given to advanced manufacturing technologies—such as additive manufacturing, robotic welding, and automated inspection systems. Secure digital traceability of materials, welding data, inspection results, and deviations should form part of a legally recognized digital compliance record, enabling data-driven oversight.

8.4. Reform of Transport Authorization and Inspection

(a) Legal Gaps in Current Transport Provisions

Current NSA transport provisions primarily regulate radioactive materials and do not explicitly address the transport of unfueled reactor modules or massive pressure-retaining components. This creates uncertainty regarding definitional scope, jurisdictional coordination among ministries, applicable safety standards, emergency preparedness, and protection of sensitive nuclear technology.

Given the size, weight, and strategic sensitivity of SMR modules, explicit statutory clarification is necessary.

Proposed Article 15-2 (Notification of Contracts for Safety-Related Structures, Systems, and Components)

② A person who has submitted an application for a license pursuant to Article 10 (3) 1, or a reactor manufacturer, shall likewise comply with paragraph (1) with respect to safety-related structures, systems, and components. In such cases, the term "design related to construction" in subparagraph 1 of paragraph (1) shall be deemed to mean "design related to manufacture."

Proposed Article 15-3 (Approval of Reactor Module Transport)

① Any person intending to transport nuclear facility modules exceeding prescribed size or weight thresholds shall obtain transport approval from the NSSC in consultation with relevant transportation authorities.

② The transport approval shall include:

- Approved route and schedule,
- Transport equipment specifications,
- Structural integrity verification,
- Emergency response and security plan,
- Coordination mechanisms with local authorities.

③ The NSSC may conduct inspections before and during transport to verify compliance with approved conditions.

Proposed Article 15-4 (Notification of Factory Fabrication and On-Site Transportation of Reactors)

① The act of fabricating or assembling, in whole or in part, the reactor vessel, systems, structures, and major appurtenant equipment (hereinafter referred to as "nuclear system facilities") at a factory shall include the following activities:

- Fabrication and assembly in accordance with the design of reactor constituent modules;
- Functional testing, quality inspection, and safety verification of fabricated modules;
- Packaging, securing, and protective measures for transportation.

② On-site transportation pursuant to paragraph (1) shall include the following activities:

- Establishment and approval of a transportation plan in accordance with relevant statutes and regulations;
- Loading, transportation, and unloading of fabricated reactor modules;
- Management and supervision to ensure safety and prevent accidents during transportation.

③ The factory fabrication and on-site transportation of reactor facilities shall be regarded as procedures independent from the installation and operation of a reactor; provided, however, that with respect to nuclear safety and radiation protection, the relevant statutes and regulations applicable to the installation and operation of a power reactor shall apply mutatis mutandis.

This provision would clarify jurisdictional authority for nuclear safety aspects of module transport.

A new provision should require prior approval for the transport of nuclear facility modules exceeding specified size or weight thresholds. Such approval should include:

- Authorized routes and schedules;
- Transport equipment specifications;
- Structural integrity verification;
- Emergency response and security planning;
- Coordination with relevant transportation and local authorities.

(b) Establishment of Nuclear Module Transport Inspection Framework

To ensure comprehensive regulatory oversight of SMRs, the nuclear regulatory authority should explicitly retain the authority to conduct inspections both before and during transport of nuclear modules.

Given the distinctive characteristics of SMRs, particularly for the off-site factory fabrication and modular installation approach, a tailored regulatory inspection system should be established under the existing nuclear safety legislative framework as shown I Table 1 [10]. This system should reflect the full lifecycle of SMR modules, from manufacturing through decommissioning.

(a) Scope of the Regulatory Inspection System

The proposed inspection framework would encompass:

- Module manufacturing and transport inspections
- Preoperational inspections following module installation
- Quality assurance inspections
- Vendor inspections
- In-service inspections, including in-service testing
- Periodic inspections
- Decommissioning inspections

This integrated inspection structure would ensure coherent and continuous oversight of nuclear safety and security throughout the lifecycle of SMR modules, while also enabling coordination with relevant infrastructure and maritime authorities where transportation is involved.

(b) Subordinate Decree Requirements

To operationalize the transport inspection regime, a subordinate decree should further specify:

- Technical standards applicable to module transport
- Route survey and risk assessment requirements
- Structural load and stress analysis requirements
- Public notification procedures
- Insurance and liability provisions
- Physical protection and security measures

Such subordinate regulations would provide technical clarity while maintaining consistency with overarching nuclear safety objectives.

<u>*Proposed Amended Article 16 (Inspection)*</u>

② In cases where all or part of the reactor vessel, systems, structures, and major appurtenant equipment are fabricated or assembled at a factory or equivalent manufacturing facility other than the reactor installation site, transported to the site, and installed thereat, an inspection shall be conducted on the following matters prior to the use or operation of the reactor:

1. Whether the factory fabrication and transportation processes conform to the approved design and technical standards;
2. Whether structural integrity, functions, and performance have been maintained notwithstanding transportation and on-site installation;
3. Whether the applicable standards concerning reactor safety, radiation protection, and quality assurance have been satisfied;
4. The adequacy and traceability of inspection and test results performed during the factory fabrication stage.

③ In conducting the regulatory inspection pursuant to paragraph (2), the Commission may substitute all or part of the inspections or tests performed during the factory fabrication stage with inspections conducted after on-site installation, or may integrate them; provided, however, that on-site confirmatory inspections shall be conducted for matters having a significant impact on safety.

9. Conclusion

Factory-based manufacturing of nuclear facilities and major components constitutes one of the most transformative innovations introduced by SMR technology. By shifting significant portions of fabrication from construction sites to controlled industrial environments, SMRs aim to achieve cost reduction, schedule predictability, enhanced quality control, and scalability through serial production. However, as this study has demonstrated, existing nuclear licensing frameworks, site-built light-water reactors, remain only partially aligned with the product-oriented and factory-centric nature of SMR deployment.

This paper has identified structural issues within current regulatory systems, including the absence of facility-based manufacturing licensing, insufficient integration between design certification and production approval, regulatory fragmentation in transport authorization, and limited recognition of digital manufacturing and data-driven oversight mechanisms. While many jurisdictions have begun adapting their frameworks through risk-informed regulation, vendor design reviews, or integrated design assessments, further systematic reform is required to accommodate serial factory production of nuclear modules.

To address these challenges, this study proposed a multi-dimensional reform strategy. Core elements include the introduction of manufacturing-based licensing systems, clearer allocation of regulatory responsibilities across manufacturing, transport, and installation phases, adoption of graded and risk-informed approaches tailored to safety significance, and closer integration of design certification with production-line approval. In addition, strengthened international regulatory cooperation and harmonization were emphasized as essential for enabling global SMR supply chains and avoiding duplicative regulatory burdens. Therefore, enabling legislation should be drafted to provide an explicit legal basis for type licensing of standardized nuclear facilities, factory manufacturing approvalsfor serial production, and an integrated multi-stage licensing pathway encompassing manufacturing, transport, and site installation.

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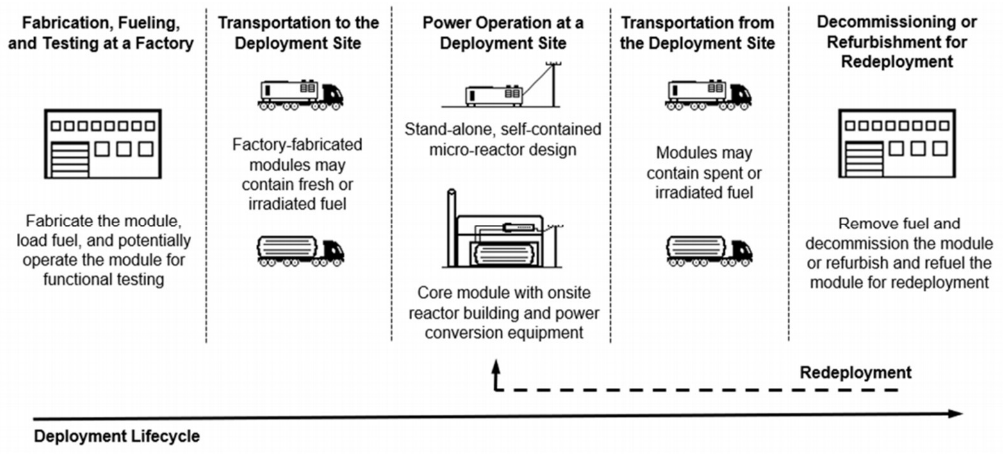

Figure 1: Generic factory-fabricated micro-reactor deployment model [9]

Table 1. Proposed Regulatory Inspection System for SMRs [10]