CLASSIFICATION REQUIREMENTS FOR FLOATING NUCLEAR POWER PLANTS (FNPPS)

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ABSTRACT

Increased interest in advanced nuclear technology for global decarbonization includes commercial floating nuclear power plants (FNPPs). Like all vessels today, FNPPs will be registered to a flag State, which usually delegates some responsibility to classification societies, such as the American Bureau of Shipping (ABS), to perform engineering reviews, inspections and surveys on their behalf. The role of classification is explained to provide an understanding of the marine regulatory framework and the integration with nuclear regulatory regimes.

Existing International Maritime Organization (IMO) regulations apply to nuclear merchant ships using pressurized water reactors but may not directly apply to FNPPs. To support the technology-agnostic production of FNPPs, the ABS *Requirements for Nuclear Power Systems for Marine and Offshore Applications* provide requirements for the vessel and supporting structure regardless of reactor type to obtain the Power Service (Nuclear) Classification Notation. The provisions for classification using these requirements are described, including the risk assessment, Interface Document, integration testing and in-service survey plans that are required to differentiate the verification activities of classification from the nuclear regulator for design and license approvals. These requirements may be used for FNPPs and leveraged later for nuclear ships, to guide the collaboration of the maritime and nuclear industries for successful implementation of commercial nuclear-maritime applications.

1. INTRODUCTION

Modern drivers for decarbonization are striving for a clean solution for future energy and fuel demands. This is especially true for the international shipping industries, which accounted for approximately 2% of global carbon emissions in 2020 [1]. Long-term emissions-free energy must be readily available, reliable and robust to support the decarbonization transition of hard-to-abate sectors such as shipping, which have conventionally relied upon the low costs and high availability of residual fuel oils. Nuclear power may be one of the few proven technologies offering a feasible technical solution, but it will face regulatory and economic challenges before full-scale implementation.

Nuclear propulsion may support international maritime decarbonization, as it has been used to power nuclear submarines and surface vessels since the 1950s. In 1961, the nuclear ship (NS) *Savannah* was commissioned and classified by the American Bureau of Shipping (ABS), beginning her decade-long cargo and passenger service under President Eisenhower's 'Atoms for Peace' program. Today, several large nuclear-powered icebreakers in the Arctic escort commercial traffic through the Northeast Passage without relying on fuel oils. Modern generation IV advanced nuclear technologies target smaller, modular power applications that may be well suited to power large commercial vessels. However, large-scale implementation of modular reactors for ships may be challenging to establish globally due to international nuclear regulations.

From a regulatory perspective, nuclear power service vessels, or commonly referred to as floating nuclear power plants (FNPPs), may be a less challenging application. These are expected to be stationary applications specially fitted with reactors whose generated power is transferred or distributed to adjacent (external or onboard) facilities. The U.S. Army Corps of Engineers implemented this to support Panama Canal operations in the 1970s, and later, the FNPP *Akademik Lomonosov* has been providing power to a remote Russian town since 2020.

Floating nuclear energy applications may be an ideal first step to supply energy to maritime industries to both demonstrate the feasibility of commercial floating nuclear technologies and provide clean, reliable electricity.

Some historical precedents and demonstration projects exist which demonstrated nuclear technologies for the commercial marine industry, but none achieved widescale adoption. As nuclear power is reconsidered for commercial maritime use, research and industry partnerships assist ABS in developing new classification Rules for non-nuclear propulsion use cases.

1.1. Maritime Demand for Decarbonization

In 2023, the International Maritime Organization (IMO) established ambitious targets to eliminate all greenhouse gas (GHG) emissions from shipping by 2050, compared to 2008 [2]. The IMO has implemented mandatory reporting of emissions performance through the Carbon Intensity Index (CII) for all vessels subject to IMO regulations, where higher emissions levels are subject to international fines and business consequences.

While originally focused on the direct emissions from ships (those produced on board for propulsion), future emissions reduction requirements can be expected to focus on the life-cycle emissions for ships, including the emissions created during the production of fuels. Since vessels' lifespans can reach up to 30 years, the uptake of carbon and GHG-free fuels must start long before the 2050 target.

Many strategies, technologies, or pathways may be implemented together or in series to decarbonize fleets, as seen in Fig. 1. However, efforts to eliminate emissions from using combustion fuels (e.g., LNG, biofuels and ammonia) suffer from diminishing returns. For example, onboard carbon capture and storage (OCCS) systems may help partially reduce emissions but capturing all emissions would be disproportionately challenging.

Hydrogen and ammonia may be consumed in fuel cells to produce emissions-free electricity. However, the production, storage and availability of these alternative energy sources raise concern, especially when considering the need to use fuels derived from renewable energy sources.

While the maritime industry already implements many near- and medium-term decarbonization and GHG reduction measures, we can expect a mix of decarbonization solutions to achieve the targets.

Fig. 1: Decarbonization Solutions for Shipping

With mixed solutions for decarbonizing international shipping, the global market will be under additional stress to supply decarbonized energy solutions. Nuclear technology, advertising modular, deployable, reliable, energy-dense power solutions, may be available to deploy to local areas of demand, such as remote ports without reliable fuel sources or those struggling to provide electricity for onshore power supply (OPS) to ships.

Many opportunities may arise under new economic arrangements, supporting national energy security and essential international trade activities. However, installing commercial nuclear power plants on floating platforms has not been accomplished at scale, and many uncertainties exist surrounding the regulatory framework for maritime and international nuclear implementation.

1.2. Marine Regulatory Framework

Nuclear regulators are expected to continue managing the licensing activity for nuclear technologies and a facility's handling of nuclear materials. However, this activity must be carried out in conjunction with the maritime regulatory framework for nuclear maritime applications. An introduction to the marine regulatory framework is provided to establish a basic understanding of how ships and offshore unit designs are reviewed, approved, and verified for national and international compliance schemes.

1.2.1 International Maritime Organization (IMO)

The United Nations (U.N.) formed the IMO in 1958 to standardize safety, security and environmental standards for shipping. Today, it comprises 174 member States and various non-governmental organizations (NGOs) representing marine industry stakeholders. The IMO codes and standards typically apply to merchant vessels traveling through international waters. International codes and regulations are developed by various IMO assemblies, committees or working groups and are endorsed and implemented by member States.

The U.N. Convention on the Law of the Sea (UNCLOS) and local laws require vessels to be registered with a recognized flag Administration and to carry a Certificate of Registration. Vessels flagged by IMO member States must adhere by statute to the IMO regulations endorsed by their flag Administration and those adopted by the member States of destination ports. Any port State finding a visiting vessel out of compliance with local law has the right to deny entry or detain the vessel until deficiencies are addressed.

1.2.2 Role of Classification Societies

Classification societies, such as ABS, are NGOs that establish and administer standards for the design, construction, and periodic survey of commercial vessels and other marine structures. Flag Administrations can authorize classification societies to act on their behalf to carry out statutory certification work [3].

Vessels must hold a Certificate of Compliance issued by a class society to show compliance with international application requirements. Certificates of Compliance may be revoked if the unit does not adhere to the related codes, regulations or standards.

Classification societies also develop class Rules to assist flag Administrations and shipowners in implementing mandatory requirements according to their type of vessel or offshore unit. They also offer optional provisions for marine applications to showcase additional safety or performance features. As shown in Fig. 2, ABS carries out the development of class Rules with transparency to industry. Mandatory class Rules are often associated with notations indicated in the vessel's classification record, indicating compliance with a specified set of requirements. Once Rules are established, engineers will conduct reviews to approve the design to the appropriate requirements. Once the design is approved, classification society surveyors attend equipment and vessels during construction and throughout the unit's lifetime to verify compliance with Rules and statutory requirements. Continuous updates and modernization of the class Rules result from direct feedback by operators and surveyors. Additional feedback is received from industry to ensure the Rules are suitable for novel and innovative processes and technical equipment.

Fig. 2: ABS Classification Model

1.2.3 The International Association of Classification Societies (IACS)

Accredited classification societies form IACS, which contributes to developing IMO codes and regulations as an NGO at the IMO. The group further assists in harmonizing international codes and standards by providing Unified Interpretations (UIs) to assist in implementing IMO codes and regulations and Unified Requirements (URs), which are mandatory for classification societies to incorporate into class Rules.

To assist in understanding and complying with the matrix of international, regional and local maritime requirements, classification societies often work as Recognized Organizations (ROs) on behalf of flag Administrations to verify compliance of vessels and offshore units.

2. REGULATIONS FOR COMMERCIAL NUCLEAR MARITIME APPLICATIONS

It is anticipated that future nuclear maritime applications will not be regulated by an entirely new licensing and certification framework. Mechanisms originating from the time of the NS *Savannah* may be modified or partially applied to modern applications today. However, due to international regulatory complexities, FNPPs are likely to be implemented before nuclear-powered commercial vessels.

2.1. International Maritime Organization (IMO)

The Convention for the Safety of Life at Sea (SOLAS) was one of the first international conventions produced by the IMO to harmonize safety and lifesaving measures for crew and passengers on international voyages. It has been updated many times since it was first established in 1914, including the addition of Chapter VIII: Nuclear Ships in 1961. This chapter applies to merchant ships propelled by pressurized water reactors (PWRs) and contains high-level design goals and functional requirements for nuclear-powered vessels.

In 1981, Resolution A.491(XII): the Safety Code for Nuclear Merchant Ships was adopted by the IMO Assembly to accompany SOLAS Ch. VIII. This provided more detailed provisions for PWR-powered vessels than SOLAS Chapter VIII. Both SOLAS Chapter VIII and Resolution A.491(XII) explain that they may be updated to consider different nuclear technologies when developed. However, no update has been prepared to date.

2.2. Classification Societies

ABS published the 1962 *Guide for the Classification of Nuclear Ships* to support the NS *Savannah* classification but was retired when the NS *Savannah* was decommissioned. Still, it reflected many of the provisions of the SOLAS Chapter VIII, supplemented by detailed information on risk assessments, damaged condition cases from collision, and other requirements focused on addressing risks as identified in specific operational hazards and safety identification assessments. This document offers ABS a helpful precedent for future class Rules.

The Russian Maritime Register of Shipping[1] offers Rules for Nuclear Ships and Floating Facilities, applicable to nuclear-powered vessels and floating nuclear power facilities, and the Italian Classification Society Registro Italiano Navale (RINA) offers a Guide for Nuclear Installations on Marine Units for design and technical considerations of nuclear maritime applications. Unlike classification Rules, the RINA Guide offers technical recommendations and functional criteria but does not impose mandatory provisions for classification.

All incidents of past or present class Rules or Guides include provisions from or are based on SOLAS Chapter VIII and A.491(XII) and only apply to PWR applications with a focus on nuclear propulsion. They do not consider alternative types of reactors.

3. ABS REQUIREMENTS FOR NUCLEAR POWER SYSTEMS FOR MARINE AND OFFSHORE APPLICATIONS (ABS NUCLEAR REQUIREMENTS)

ABS *Nuclear Requirements* address the needs of maritime and nuclear regulators looking for a technology-agnostic approach for classification approval, where any reactor type may be used for power service. The requirements can also guide shipowners and shipyards during the early design stages. The early establishment of requirements assists designers and shipyards by reducing the risk of redesign or modifications in later design stages.

3.1. Scope of Applicability

The ABS *Nuclear Requirements* apply to marine applications fitted with a nuclear power plant for power generation, such as providing electricity to a shore-based power grid or offshore industrial facilities. These may be stationary units such as power barges or offshore units (e.g., semisubmersibles, tension-leg platforms) intended for temporary or permanent service in a single location or they may be conventionally powered self-propelled units with onboard nuclear power plants. The ABS *Nuclear Requirements* do not apply to nuclear-powered vessels arranged with nuclear propulsion. It should be noted that shipyards, port equipment, or maintenance facilities do not fall under the scope of classification but would be subject to the local nuclear regulator's approval or certification.

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[1] Russian Register of Shipping voted out of IACS in 2022 after EU noted them as a sanctioned state-owned entity [4].

For FNPPs, the division of structures, systems and components (SSC) by function allows designers to differentiate the systems intended for nuclear power service and nuclear safety from those for essential marine services and safety.

An important prerequisite for final class Certification is for the nuclear power plant to have the appropriate license from its designated nuclear regulator. Engineering review and verification for the purpose of nuclear license may occur concurrently with activities for classification review and approval. It is anticipated that ABS will need to collaborate with the nuclear licenser.

3.2. Goal-Based Standards

The IMO established a goal-based standards approach[2] to help users interpret the intention of the regulations, allow for alternative design arrangements, and enable engineers and surveyors to verify that an alternative design achieves equivalent levels of safety. Detailed prescriptive requirements may not be necessary when applying a goal-based standard approach, so proposed new equipment or novel arrangements may not be subject to mandates related to specific equipment types and arrangements. ABS incorporates the goal-based standards framework by using goals and functional requirements (FRs), shown in Fig. 3.

Goals within Tier I define the highest-level objectives that must be met according to applicability. All ABS Goals are provided in the ABS *Conditions of Classification* Part 1D Chapter 3. FRs provide more details about the specific criteria for meeting the associated goal.

Tier III provisions address the verification of conformity and provides specific instructions to confirm the design meets the Goals and FRs. Tier IV and V items indicate existing prescriptive requirements for conventional systems.

To achieve a technology-agnostic approach to classification, the ABS *Nuclear Requirements* Goals and FRs highlight the primary safety and functional criteria while allowing for various technologies or solutions to be proposed. The technical differences between different types of reactors may add complexity to the regulatory regime. However, by implementing goal-based standards, any nuclear technology may be used as long as classification can verify that it meets equivalent levels of safety.

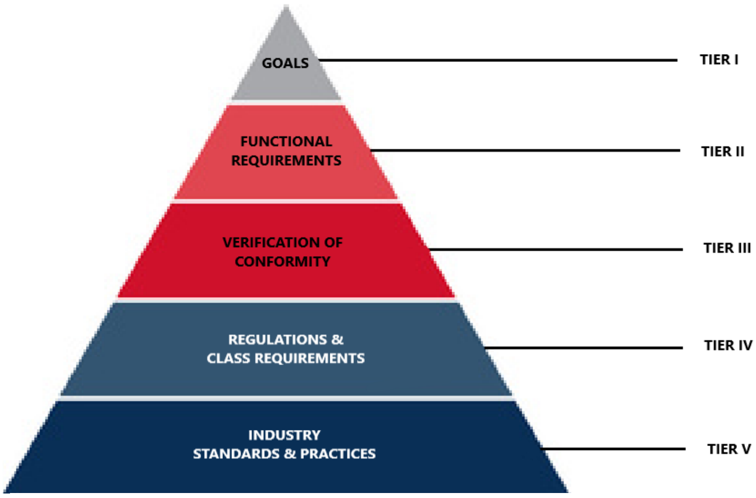

Fig. 3: The ABS Goal-Based Standards Framework

3.3. Roles

Flag Administrations are national authorities that register vessels and work closely with designers and classification societies to verify compliance with all applicable requirements. They also have the specific authority to impose additional regulations and approve final design decisions. Nuclear regulators are independent agencies of national authorities that have authority over the approval and licensure of nuclear reactors and related systems. The technology provider will identify the nuclear regulator to license their design. Port States or coastal State Administrations are the appropriate authority in the country where the nuclear unit is stationed or laid up for service and maintenance.

In addition to regulations and provisions required by flag Administrations, nuclear regulators and port State Administrations may impose additional requirements on the unit.

3.4. Risk Assessments

To facilitate a technology-agnostic approach to nuclear technology on marine applications, it will be

[2] The IMO Guidelines for Developing Goal-Based Standards [5] were adopted 8 July 2019, supporting the Guidelines for the Approval of Alternatives and Equivalents [6], 24 June 2013.

necessary to investigate and assess all technical and operational hazards the unit may encounter over its lifetime. For classification, it is essential that documentation of any risk assessment methodology carried out (e.g., risk inventories, probabilistic risk assessments, hazard identification assessments, etc.) be submitted to ABS to show how risks are addressed in design and construction, as well as indicate how Goals and FRs are met.

3.5. Interface Definition

An essential aspect of nuclear licensing and classification is clearly defining the interface between nuclear and marine systems, including physical boundaries between structures or systems and conceptual interfaces related to control, monitoring, and administrative controls or processes, as indicated in Fig.4.

While the nuclear regulator is expected to review and approve the design and operation of the nuclear power plant (NPP), including the nuclear reactor, related safety systems, and systems indicated within and around the nuclear power plant in Fig.4, the flag Administration and classification society are expected to provide analogous services for marine systems. It is anticipated that some overlap may exist between the scope of review and approval of nuclear and marine systems, especially for functions passing into and out of the nuclear power plant. To simplify the approach of regulatory oversight, an interface document will be necessary to describe the marine and nuclear systems, the stakeholders whose approvals are necessary, and the responsibilities assigned to the Stakeholders. In addition to the interface document, onboard system integration test plans and in-service inspection plans are necessary to define the roles of inspectors and surveyors to be able to verify SSCs according to requirements throughout the unit’s lifetime.

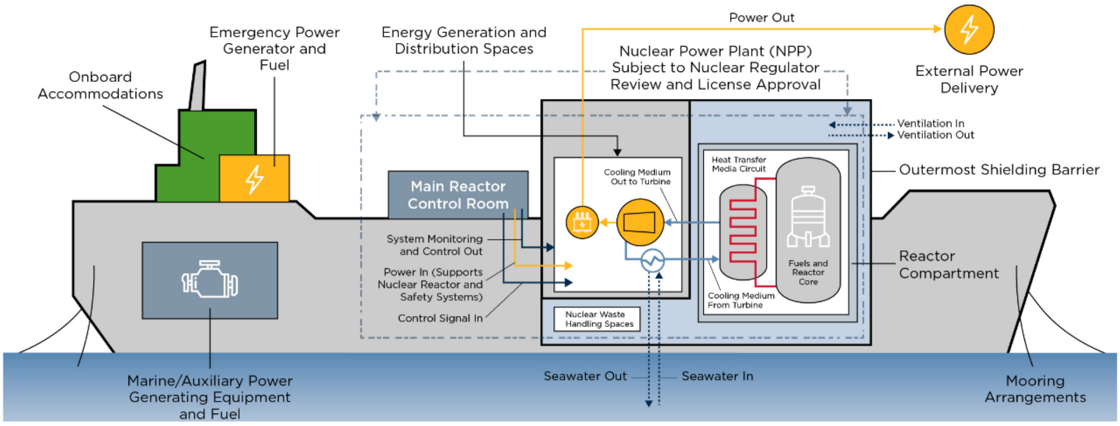

Fig. 4: Schematic of Interface between Nuclear Power Plant and Marine Systems

Marine systems subject to classification reviews are to be differentiated from nuclear systems according to their functional purpose to support primary essential marine services or secondary marine services, as shown in Table 1, or services essential to operate during emergency conditions.

The interface is relatively straightforward for FNPPs not using the nuclear power plant for essential marine services. However, safety equipment “whose loss or failure would create an immediate hazard or risk to the marine unit” may include nuclear equipment essential to maintain reactor safety, shielding from radiological hazards, or systems that may directly affect the safe control of the reactor. Specifically, the essential services that may fall under the responsibility of both the nuclear regulator and the classification society must be closely considered and responsibilities for approval established within the interface document, shown in the last row of Table 1.

TABLE 1. Summary of Primary and Secondary Marine Services

	Primary Essential Marine Services	Secondary Essential Marine Services
Typical marine services	— Continuous operation to maintain (non-nuclear) propulsion and steering in self-propelled units, or continuous operation to maintain station-keeping, including dynamic positioning, anchoring or	— Non-continuous operation to maintain (non-nuclear) propulsion and steering for self-propelled units, or non-continuous operation to maintain stationkeeping, anchoring or mooring for non-self-propelled units.

	Primary Essential Marine Services	Secondary Essential Marine Services
	mooring equipment for non-self-propelled units, or — Any systems whose loss or failure (other than nuclear reactors) would create an immediate hazard or risk.	— Non-continuous operation to maintain a minimum level of safety for navigation or for the carriage of dangerous cargoes, radioactive material and waste. — Any systems whose loss or failure would create a potential hazard to the unit.
Services that may be subject to classification and nuclear regulator's review	— Services considered necessary to maintain hazardous spaces in a safe condition. — Ventilation and filtration systems or any services necessary to maintain radiation doses to within the dose limits in all normally manned areas.	— Radiation detection and alarm systems. — Control, monitoring and safety systems for nuclear waste handling systems, as applicable. — Electric equipment and other equipment for security monitoring, security doors and other security closing appliances.

The interface document will be unique according to the type of nuclear technology chosen, onboard arrangements, and unit operational functions. The complexities of breaking down all SSCs and assigning responsible roles will require intense technical collaboration between nuclear and maritime regulators, supported by designers, integrators and manufacturing facilities.

4. CONCLUSION

The maritime regulatory paradigm is mature and has worked effectively to support global commerce for decades. It is not likely to change significantly with the introduction of nuclear reactors for power generation or propulsion. Likewise, the nuclear regulatory regime is equally mature in developing regulations and issuing licenses for the operation of reactors. Unfortunately, it has been over a half-century since these two regulatory regimes have worked together closely.

With the dramatic push by the IMO to reduce GHG emissions from international shipping and a global cry for clean energy, nuclear power is a viable solution. It is up to industry stakeholders and the various regulatory agencies that will govern these operations to collaboratively create a pathway for the practical and safe application of nuclear technology in the commercial maritime industry.

Based on the research that has been conducted to date, it is clear that the most effective way to achieve the goal stated above is for the maritime industry to continue to focus on the marine aspects of the new designs and for the nuclear regulators to focus on the overall safety of the design and operation of the nuclear reactor. With this approach, the only area of complexity is the interface between the marine and nuclear systems. ABS has developed an approach to this complexity but will only be successful if the key stakeholders in both industries closely collaborate on the practical application of this methodology.

It is recommended that key nuclear regulators, flag Administrations, coastal States, and class societies collaborate to understand the interactions described in this paper to support the initiatives at IMO and to reduce the global release of GHGs.

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