Regulatory Considerations for Floating Nuclear Power Plants: Implications for Indonesia

Utomo Kevin Erianto and Juyoul Kim*
Department of Nuclear Power Plant Engineering, KEPCO International Nuclear Graduate School,
658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan 45014
**Corresponding author: jykim@kings.ac.kr*

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1. Introduction

Floating nuclear power plants (FNPPs) are emerging as a potential option for supplying reliable low-carbon electricity to remote coastal regions and islands where conventional land-based nuclear power plants face infrastructure or siting constraints. This concept is particularly relevant to Indonesia, an archipelagic country with geographically dispersed energy demand. However, an FNPP cannot be regulated simply as a conventional nuclear power plant installed on a floating platform. Its regulatory framework must integrate nuclear safety with maritime engineering and classification, environmental protection, emergency preparedness, and the responsibilities of nuclear, maritime, and port authorities [1,2,3].

This nuclear–maritime interface also introduces radiation-protection considerations that are less prominent in land-based NPPs. Although fundamental principles such as dose limitation and optimization remain unchanged, the conditions for demonstrating compliance can differ. Land-based plants generally rely on fixed structures, stable source–shield–receptor geometries, and spatial separation between radiation sources and occupied areas. In contrast, FNPPs involve compact and weight-constrained layouts, adjacent occupied compartments, numerous penetrations, marine motion and structural loading, and seawater interfaces. These characteristics require additional consideration of shielding and radiation streaming, radiological zoning and occupancy, monitoring, radioactive releases, and marine-specific exposure pathways. The regulatory distinction therefore lies not in establishing separate radiation-protection criteria, but in demonstrating compliance with existing criteria under marine-specific design and operating conditions.

International frameworks address different parts of this interface. The International Atomic Energy Agency (IAEA) provides the nuclear-safety and radiation-protection baseline, while the Atomic Technologies Licensed for Applications at Sea (ATLAS) initiative, launched in August 2026, is intended to connect the nuclear and maritime communities for civilian applications at sea [1]. The International Maritime Organization (IMO) has initiated revision of the 1981 Code of Safety for Nuclear Merchant Ships and SOLAS Chapter VIII, with the Maritime Safety Committee assigning nuclear-related work to the Ship Design and Construction Sub-Committee [4]. The American Bureau of Shipping (ABS) and Lloyd's Register (LR) provide complementary marine classification, interface, safety-case, and lifecycle guidance [2,3], while the U.S. Nuclear Regulatory Commission (NRC) is examining how existing licensing frameworks can be applied to maritime nuclear applications [5].

Indonesia already has a general regulatory framework for nuclear installations, but Government Regulation (GR) No. 2 of 2014 was formulated primarily for land-based installations [6]. Reference [7] examined revisions to Indonesia's FNPP licensing process, particularly siting, construction, commissioning, and the possibility of different licensing locations. In 2026, BAPETEN also initiated FNPP-specific coordination involving nuclear, energy, maritime, environmental, and transport stakeholders [8,9]. Distinct from Ref. [7], this study focuses on the substantive radiation-protection and nuclear-maritime compliance demonstrations that must be embedded within the licensing framework, particularly shielding and streaming, zoning and occupancy, monitoring, marine releases, lifecycle states, and regulator-classification interfaces. Accordingly, this study comparatively reviews major international nuclear and maritime frameworks and identifies priority implications for Indonesia.

2. Methods and Results

2.1 Regulatory Frameworks and Review Method

A structured qualitative regulatory review was conducted using purposive source selection. Sources were included when they were: (i) authoritative nuclear or maritime regulations, regulator documents, or classification guidance directly relevant to nuclear installations, floating/offshore units, or maritime nuclear applications; (ii) current instruments or active revision initiatives available through 31 August 2026; or (iii) peer-reviewed technical studies providing evidence on marine-specific phenomena not explicitly addressed in regulatory texts. General energy or economic commentary, duplicate summaries, and non-traceable secondary sources were excluded. Primary regulations and official regulator documents were prioritized, followed by classification guidance and peer-reviewed technical studies. The resulting source groups are summarized in Table I.

Seven comparison axes were selected because together they cover the regulatory control chain: protection criteria (regulatory objective), shielding and

barriers (design control), zoning and occupancy (exposure control), monitoring (compliance verification), waste and releases (source and environmental control), emergency and lifecycle conditions (non-stationary states), and the nuclear-maritime regulatory interface (allocation of responsibility). Each axis recurs across multiple reviewed frameworks or is necessary to demonstrate marine-specific compliance [1-6]. Table III is an author-derived qualitative priority order, not a numerical risk ranking. Items are placed earlier when they map to an existing Indonesian obligation, present a marine-specific compliance challenge supported by multiple sources or technical evidence, or are prerequisites for downstream lifecycle/interface controls; ties follow the sequence from acceptance criteria to design/operation and then lifecycle/institutional integration. Cited statements describe source content, whereas the terms 'gap', 'priority', and 'should' represent the authors' interpretation unless explicitly attributed to a source.

Table I: Regulatory frameworks and their relevance to FNPPs.

Group	Role and key contribution
IAEA	Nuclear safety and radiation-protection baseline, harmonization
IMO	International maritime safety and regulatory context
ABS	Marine classification and design assurance
NRC	National radiation-protection and maritime licensing practice
Lloyd's Register	Safety-case and lifecycle assurance
Indonesia	National licensing basis and FNPP regulatory preparation

2.2 Comparative Regulatory Considerations for Land-Based NPPs and FNPPs

The comparative assessment indicates that the fundamental radiation-protection principles applied to land-based NPPs remain applicable to FNPPs. National dose limits and optimization principles therefore provide the regulatory basis for both. The principal difference lies in how compliance is demonstrated under marine-specific conditions. Unlike land-based NPPs with fixed structures, relatively stable shielding geometries, and well-defined occupancy patterns, FNPPs may involve compact and weight-constrained layouts, adjacent occupied compartments, marine structural loads, and seawater interfaces [2,3]. These characteristics do not necessarily require separate dose criteria, but they require additional consideration in design assessment, verification, and regulatory oversight.

Shielding and radiological barriers are particularly affected by these conditions. Compact FNPP arrangements may place occupied compartments close to radiation sources, while hatches, piping, cable transits, ventilation ducts, and other penetrations can create radiation-streaming pathways. Shielding assessment should therefore address barrier continuity, penetration configuration, adjacent-compartment occupancy, and marine loading in addition to conventional bulk and local shielding [2]. Technical studies further show that ocean conditions can affect reactor response and penetration integrity, while containment leakage can influence airborne radioactivity in surrounding compartments [10-12].

Radiological zoning and monitoring should likewise account for compartment-specific occupancy, access and maintenance routes, and temporary configurations during refueling or waste handling [2,3]. Monitoring arrangements should integrate area and process monitors, portable instrumentation, individual dosimetry, and effluent monitoring for normal and relevant abnormal conditions. Radioactive waste and environmental releases also require marine-specific consideration. In addition to conventional control of gaseous, liquid, and solid radioactive waste, assessments should address atmospheric, coastal, and aquatic transport pathways and marine receptors [13,14]. The surrounding marine environment should therefore be explicitly evaluated rather than treated simply as a dilution medium.

Finally, FNPP regulation must address lifecycle conditions that are less prominent for stationary land-based plants. Transport, deployment, operation, refueling, possible relocation, and decommissioning may change facility configurations, surrounding receptors, and regulatory responsibilities [1,3]. Clear coordination is therefore required among nuclear regulators, maritime and environmental authorities, operators, port stakeholders, and classification societies [4,5]. Table II summarizes the principal differences between land-based NPP requirements and the additional regulatory considerations associated with FNPP deployment.

Table II: Comparison of regulatory considerations for land-based NPPs and FNPPs.

Regulatory area	Land-based NPP baseline	Additional FNPP consideration
Protection criteria	Dose limitation and optimization/ALARA	Same dose criteria, with compliance demonstrated under marine-specific conditions
Shielding and barriers	Fixed structural shielding and relatively stable geometry	Compact/weight-constrained geometry, penetrations, streaming, marine structural loads
Zoning and occupancy	Controlled/supervised areas with relatively fixed occupancy	Adjacent compartments, accommodation spaces, maintenance routes, changing

		occupancy
Monitoring	Area, individual, process and effluent monitoring	Marine-specific locations, operating states and emergency availability
Radioactive waste and releases	Controlled solid, liquid and gaseous releases	Coastal/aquatic pathways, seawater interface and marine receptors
Emergency and lifecycle	Predominantly stationary-site emergency arrangements	Transport, deployment, refueling, relocation and port interfaces
Regulatory interface	Primary nuclear regulatory authority	Nuclear–maritime–environmental–classification coordination

2.3 Priority Regulatory Considerations for Indonesia

Indonesia's licensing baseline is GR No. 2 of 2014. Article 4 establishes site, construction, commissioning, operation, and decommissioning licensing stages, while Articles 8-11 require site-evaluation, safety-analysis, radiation-protection, environmental, emergency-preparedness, and related technical documentation [6]. However, several provisions are explicitly land-based: Article 1(9) defines a site (Tapak) as a location on land, Article 1(11) defines construction as building the installation at the predetermined site, and Article 7(b)(1), incorporated into the site-license application through Article 18, requires proof of land rights [6]. In the authors' interpretation, these provisions do not explicitly cover an FNPP fabricated or commissioned away from its deployment location, transported to a berth, moored in a port or coastal area, or relocated during its lifetime. The concrete gap is therefore not the absence of a nuclear licensing basis, but the absence of explicit marine-specific acceptance and verification criteria.

Reference [7] previously examined revisions to Indonesian licensing definitions and stages, including the possibility of different locations for siting, construction, and commissioning. The present study does not repeat that procedural proposal. Instead, it uses the existing licensing stages as the national baseline and asks what additional evidence must be demonstrated for radiation protection and the nuclear-maritime interface. Based on Section 2.2, the main needs are marine-specific shielding and streaming assessment, compartment-based zoning and occupancy control, integrated radiation monitoring, ship-to-shore waste and marine-release control, emergency arrangements for onboard and port conditions, and verification across transport, deployment, refueling, relocation, and decommissioning [1-3,10-14].

Responsibilities for safety-significant functions should also be allocated among BAPETEN, maritime and environmental authorities, the operator, port stakeholders, and relevant classification societies [4,5,8,9]. Table III applies the qualitative ordering defined in Section 2.1. Bracketed references in each row provide the traceable source basis for the identified consideration, while the ordering itself is the authors' comparative interpretation. This converts the identified gaps into a practical sequence for adapting GR No. 2 of 2014 without changing its fundamental licensing logic.

Table III: Priority regulatory considerations for FNPP deployment in Indonesia.

Regulatory area	Priority consideration for Indonesia
Radiation protection criteria	Apply national dose limits and optimization principles with marine-specific compliance and verification requirements [2,6].
Shielding and streaming	Address compact layouts, penetrations, adjacent compartments, streaming paths, and marine structural conditions [2,10-12].
Zoning and occupancy	Establish compartment-specific zoning based on dose rates, occupancy, access, and maintenance activities [2,3].
Occupational protection	Integrate dosimetry, work planning, contamination control, and temporary shielding for onboard activities [2,3].
Radiation monitoring	Provide fixed, portable, personnel, process, and effluent monitoring appropriate to marine operating conditions [2,3].
Radioactive waste and releases	Control solid, liquid, and gaseous waste, including ship-to-shore interfaces and marine discharge pathways [2,3,13].
Marine environment	Assess atmospheric, coastal, hydrological, and aquatic exposure pathways and receptors [13,14].
Emergency protection	Integrate onboard response with national, local, maritime, and port emergency arrangements [1,3,6].
Lifecycle conditions	Address transport, deployment, operation, refueling, relocation, and decommissioning [1-3,7].
Regulatory interface	Clearly allocate responsibilities among BAPETEN, maritime/environmental authorities, operators, port stakeholders, and classification societies [4,5,8,9].

3. Conclusions

This study compared nuclear and maritime regulatory frameworks to identify FNPP-specific compliance issues and their implications for Indonesia. Existing radiation-protection principles and GR No. 2 of 2014 can remain the baseline, but compliance must be demonstrated under marine-specific geometry, structural loading, occupancy, seawater and environmental pathways, port interfaces, and changing lifecycle states. GR No. 2 of 2014 also contains concrete land-based assumptions, notably the definition of Tapak as a location on land, construction at a predetermined site, and land-right documentation for

site licensing [6]. These provisions do not explicitly address floating deployment, which creates a need for marine-specific acceptance and verification criteria rather than separate radiation dose limits. Priority areas are shielding and streaming, zoning and occupational protection, radiation monitoring, waste and marine releases, emergency arrangements, lifecycle transitions, and nuclear-maritime regulatory interfaces. Unlike Ref. [7], which focused on revision of the licensing process and stages, this work provides a comparative radiation-protection and marine-interface basis for the substantive evidence to be demonstrated within those stages. The Table III ordering is an author-derived qualitative priority based on source convergence, linkage to existing Indonesian obligations, and regulatory dependency. This approach can support future BAPETEN rulemaking while retaining consistency with established nuclear-safety principles.

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