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Technology-Neutral and Design-Responsive Safety Requirements for Maritime Nuclear Applications

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1. Introduction

Maritime nuclear applications have regained attention as a means of providing low-carbon propulsion for merchant shipping and firm low-carbon electricity for remote and offshore users. Government research programmes, commercial design projects, and classification reviews now address both nuclear-powered vessels and floating nuclear power plants (FNPPs) [1][2]. The applicable regulation, however, is distributed across instruments that differ in purpose and legal force: UNCLOS [3], SOLAS chapter VIII [4], the 1981 Code of Safety for Nuclear Merchant Ships [5], IAEA safety standards based largely on experience with land-based reactors [6], and class requirements and industry guidance without statutory force [7][8]. These regimes also differ in how they define nuclear ships and nuclear installations and in how they allocate responsibility between nuclear and maritime authorities. **Tables I** and **II** summarize the international instruments and the national approaches; taken together, they indicate that the difficulty lies not in an absence of rules but in the absence of an integrated and current framework for maritime nuclear applications.

A comparison of the instruments in **Tables I** and **II** indicates an inverse relationship between technology neutrality and maritime specificity. Frameworks developed for advanced reactors are intended to accommodate diverse technologies, but they rest largely on experience with land-based water-cooled reactors and treat marine-based transportable plants only at a preliminary level [6]. Maritime instruments, conversely, address marine conditions through assumptions derived largely from conventional light-water reactors [5]. Several States have established coordination mechanisms between nuclear and maritime authorities, but these mechanisms do not themselves establish requirements that respond to differences in reactor technology. Korea has neither a comprehensive technology-neutral framework nor a dedicated maritime licensing pathway, a situation that reflects the separate development of its nuclear and maritime regulation.

The time available for reconciling technology neutrality with maritime specificity is limited. Document MSC 110/6/4, co-sponsored by the Republic of Korea, identifies the 1981 Code as outdated [9]. SDC 12 subsequently established a work plan that targets adoption of the revised Code and the related SOLAS amendments in 2030 [10], and MSC 111 is reported to have endorsed this plan [11]. Because marine-suitable advanced reactors may reach the market at approximately the same time [9], the revised requirements might not be in effect when such reactors are first deployed. In addition, the technology-agnostic mandate for the revision [12] has not yet been translated into a defined structure of safety requirements.

Current development projects, several of them in Korea, already involve more than one reactor technology. ABS granted approvals in principle in 2025 for a nuclear-electric ship design and for floating SMR modules [13][14], and an application for standard design approval of the i-SMR was submitted in February 2026 [15]. BANDI, SMART100, and i-SMR are light-water designs, whereas the CMSR Power Barge [16] and the Norwegian NuProShip I project, which shortlisted molten-salt, helium gas-cooled, and lead-cooled reactors for merchant ships [17], indicate interest in non-light-water systems. The classification approvals are concept-level assessments; they are neither nuclear licences nor evidence that the regulatory framework is prepared for these designs.

These developments raise the question of how far the safety requirements for maritime applications must depend on the reactor design and on the application in which the reactor is deployed. To address this question, this study compares the applicable nuclear and maritime requirements, derives seventeen review criteria from them, and applies the criteria qualitatively to six reactor designs in four application types. On this basis, it distinguishes gaps that require new requirements, re-derived thresholds, or implementation criteria, and it identifies the physical parameters under which design features that are advantageous on land become less advantageous, or disadvantageous, at sea. Warships and submarines are outside the scope of the study. Section 2 reviews the existing technical requirements, Section 3 describes the review method, Section 4 presents the results, and Section 5 states the conclusions.

Table I. International Instruments and Bodies for Maritime Nuclear Applications

Instrument or body	Legal status	Coverage	Reactor-type stance
SOLAS ch. VIII (1974) [4]	Binding treaty	All nuclear ships except warships; procedural framework	Type-neutral; no self-propulsion condition in ch. VIII (cf. reg. I/3(a)(iii))
A.491(XII) Code (1981) [5]	Assembly resolution; non-binding	Nuclear merchant ships; detailed technical code	PWR-propulsion scope
IMO revision (MSC 110/6/4; SDC 12; MSC 111) [9][10][11][12]	In progress; adoption 2030	Revised Code and SOLAS VIII amendments	Technology-agnostic; structure pending
IAEA safety standards, incl. SRS No. 123 [6]	Used as a basis for national regulation	Land-based standards; modular and non-water-cooled applicability reviewed	LWR basis acknowledged
IAEA transportable-plant studies (NG-T-3.5; INPRO forum) [1][18]	Study level	Floating and transportable plants; jurisdiction and transport	No requirements set
Liability regime (Vienna Convention; INLEX, 2019) [18][19][20]	Vienna in force; 1962 ship convention not in force	Fixed-position (anchored, grid-connected) plants covered; propulsion outside the conclusions	Application-based exclusion
Class rules and guidance (ABS, 2025; LR, 2025) [7][21]	Mandatory class notation (ABS); advisory guidance (LR)	ABS: class notation required, propulsion excluded; LR: advisory, propulsion included	Prescriptive gaps remain
Industry reports (WNA CORDEL, 2025) [8]	Non-binding	Floating plants; propelled ships excluded	Harmonization advocated

Table II. National Regulatory Approaches to Maritime Nuclear Applications

State	Regulatory basis	Principal instruments	Position and gap
Republic of Korea [22][23][24]	Parallel nuclear and maritime regimes	Nuclear Safety Act; Ship Safety Act; Nuclear Ship Standards	Type-neutral reactor definition, but detailed technical rules are sparse and partly assume thermal reactors; FNPPs are not listed as ships
United States [25]	Nuclear	NRC rules; NRC-USCG memorandum (2026)	Review allocated by subject matter: reactor safety (NRC), vessel safety (USCG)
United Kingdom [26]	Maritime	Merchant Shipping (Nuclear Ships) Regulations 2022	IMO Code incorporated; power-only units excluded
Russia [27]	Nuclear; class rules incorporated	Federal Law No. 170-FZ, Arts. 3 and 40; ship classification and construction rules	Floating structures are nuclear facilities; class rules form part of compliance
China [28]	Not publicly specified	No dedicated public maritime instrument identified in this review	Reported FNPP programme; limited disclosure
Norway [17]	Class- and industry-led	SOLAS ch. VIII not yet implemented in national law; authority and class participate in NuProShip	Standard setting precedes regulation

2. Existing Technical Regulatory Framework and Safety Requirements

2.1. SOLAS Chapter VIII and Resolution A.491(XII)

SOLAS chapter VIII applies to "all nuclear ships except ships of war" [4]. The chapter is not expressly limited by reactor type or by self-propulsion, and its requirements are mainly procedural, covering safety assessment, operating manuals, surveys, certification, and port State control. Detailed technical provisions are set out instead in the 1981 Code of Safety for Nuclear Merchant Ships, adopted as Resolution A.491(XII), which comprises eight chapters and six appendices [5].

The Code quantifies several conditions specific to shipboard operation. Safety systems and power supplies must function at a static list of 30°, a roll of 45°, and a trim of 10° (§2.3.10), and inertial loads in six degrees of freedom must be assessed according to safety class (§§2.3.3–2.3.5). Capsizing is treated as a design-basis accident (§2.7.2). Reactivity control must maintain subcriticality during capsizing and sinking (§4.3.2), and shutdown must be initiated on flooding of the containment or on submergence (§4.3.1.4). The plant must also follow load and start without external assistance from a dead-ship condition (§2.4.3), and its design must facilitate salvage after a wreck (§3.1.4).

Although these provisions are specific to the marine environment, many of them are tied to a single plant architecture. Chapter 4, "Nuclear Steam Supply System," sets out its detailed requirements system by system, covering the reactor core, reactivity control, the primary pressure boundary, the secondary coolant system, and residual heat removal [5]; although Chapter 2 defines general safety functions, the detailed provisions are stated for the components of a PWR steam supply system. Safety class 4 includes the steam and feedwater systems and, where needed as heat sinks, the turbine and condenser, which presupposes a steam cycle. Section 4.12 similarly treats the interface between the nuclear plant and the ship mainly as a matter of piping isolation and leak detection, not as a functional allocation of review responsibility.

These provisions can be applied directly to pressurized water reactors (PWRs) with a steam cycle, but not to gas-cooled, molten-salt, or liquid-metal-cooled designs, whose pressure boundaries, heat-removal paths, confinement arrangements, and power-conversion systems differ. The limitation of the existing framework is therefore not an absence of marine

requirements but the alignment of a Code adopted forty-five years ago with one plant configuration. A goal-based revision should retain the physical content of these provisions where it remains valid, while stating the safety functions and performance outcomes that each design can demonstrate.

2.2. Classification Society Rules and Guidance

Classification societies have responded to the limitations of the Code in different ways. The ABS requirements (January 2025 edition) for the mandatory Power Service (Nuclear) notation do not apply where nuclear power is used for propulsion or auxiliary services on self-propelled vessels, and they state that the nuclear plant is not to be used for propulsion, positioning, or manoeuvring [7]. ABS describes A.491 as outdated and unsuitable for power-service vessels, yet recognizes it as the only international mechanism for the use of commercial nuclear technology on floating units [7]. The 2025 guidance of Lloyd's Register covers a wider scope, including offshore applications and propulsion, but it is advisory [21]. The ABS requirements are therefore mandatory but narrow in scope, the Lloyd's Register guidance is broad in scope but not mandatory, and no mandatory class rule for nuclear-propelled merchant ships was identified. The review described in Section 3 takes A.491 and these class documents as the existing reference and examines how their requirements apply to different reactor designs and applications.

3. Framework for Reviewing the Reactor-Type Dependence of Requirements

3.1. Unit of Analysis and Four Maritime Application Types

The review takes as its unit of analysis the combination of reactor design, application type, and review criterion, because the requirements applicable to a design change with the manner of its deployment. **Table III** defines the four application types used in the review. The distinction between application types also determines jurisdiction. SOLAS chapter VIII is neutral on reactor type and contains no self-propulsion condition, although regulation I/3(a)(iii) excludes ships not propelled by mechanical means unless expressly provided otherwise [4]; A.491 assumes PWR propulsion [5]; and ABS defines power-service vessels by their supply of power to adjacent facilities and excludes the use of nuclear power for propulsion [7]. National definitions diverge in a similar way: the United Kingdom limits nuclear ships to conventionally shaped, nuclear-propelled vessels and thereby excludes units that only supply power [26], whereas Russian law treats vessels and other floating structures as nuclear facilities [27].

Table III. Application Types used in the Review

Code	Application type	Self-propelled	Reactor part of the carrier	Regulatory approach
AP1	Moored FNPP	No	No; supplies external power	Cargo-oriented
AP2	Towed barge	No	No	Cargo-based
AP3	Nuclear-propelled merchant ship	Yes	Yes	Ship-based; least settled
AP4	Microreactor or offshore platform	No	No	Varies by design

Among the four application types, the nuclear-propelled merchant ship (AP3) is subject to the greatest regulatory uncertainty. It is excluded from the ABS rules [7], and its only detailed international instrument is specific to PWRs [5] and has not been revised since 1981 [9]. AP3 is therefore used as the common application for the cross-family comparison in Section 4.3.

3.2. Six Target Designs from Four Reactor Families

Table IV lists the six designs selected for the review and their principal specifications. The three PWRs are designs that the IAEA classifies as marine-based [29], and the three non-water-cooled designs are those ranked highest by the NuProShip project as candidates for merchant-ship propulsion [17]. Data for BANDI are taken from the IAEA design summary [29] and from a paper by the developer [30]. Because the non-water-cooled designs are intended for land-based power generation, they are assessed in their current configuration, without assumed changes for marine use.

Table IV. Target Designs and Principal Specifications

Design	Family	MWt / MWe	Pressure	Fuel, enrichment	Cycle
BANDI (KEPCO E&C)	A, semi-integral PWR	200 / 60	15.5 MPa	UO2, 4.95%	48–60 mo
RITM-200M (OKBM)	A, integral PWR	198 / 50	15.7 MPa	UO2 cermet, <20%	to 120 mo
ACP100S (CNNC)	A, integral PWR	385 / 125	15 MPa	UO2, <4.95%	24 mo
MMR (USNC)	C, prismatic HTGR	15–45 / 5–15	He, 6 MPa	TRISO in SiC, 9.99–19.75%	20 yr cartridge
KP-FHR (Kairos)	D, fluoride-salt-cooled	320 / 140	near atm.	TRISO pebbles, n/a	online
SEALER-55 (Blykalla)	E, lead-cooled fast	140 / 55	atmospheric	U nitride, 19.9%	once, no reload

3.3. Derivation of Seventeen Review Criteria

The seventeen review criteria were derived in three steps. First, SOLAS chapter VIII and A.491 were mapped chapter by chapter. Second, areas specific to the marine environment that classification societies and the IAEA have identified, but that were absent from this map, were added. Third, each candidate criterion was cross-referenced to A.491. Of the resulting criteria, six have explicit quantitative counterparts in the Code (M1, M5, M6, M7, M12, and M14), six have partial counterparts (M3, M4, M8, M9, M11, and M13), two have indirect counterparts (M10 and M15), and three have no counterpart (M2, M16, and M17). The criteria are arranged in four groups: physical conditions imposed by the marine environment, sources and barriers, operation and life cycle, and regulatory interface and transport. For each design and application, the review assessed qualitatively what maritime deployment requires, whether current rules address that requirement, and what evidence the characteristics of the design make necessary; no scores or rankings were assigned. The criteria, their assessment areas, and the results of the review are presented together in **Table V** in Section 4.1.

4. Reactor-Type Dependence of Maritime Safety Requirements

4.1. Common Framework Gaps and Design-Dependent Criteria

Table V presents each review criterion, the area assessed under it, and the result of applying it to the six designs. Three patterns can be identified. First, the differences between designs are largest for M8–M10 and for the coolant-dependent criterion M13, not for the criteria that A.491 quantifies most precisely. Second, the criteria without a Code counterpart, M2, M16, and M17, apply to all designs; they therefore represent gaps in the regulatory framework rather than characteristics that distinguish one technology from another. M14 similarly leaves the dual qualification of personnel under nuclear and maritime regimes unresolved. Third, M3 could not be assessed for any design in the AP3 application, because public information does not define the ultimate heat sink in sufficient detail. Section 4.2 examines the divergences within one reactor family, and Section 4.3 examines those across reactor families.

Table V. Review Criteria, Assessment Areas, and Results for the Six Designs

#	Criterion	Assessment area	Result across the six designs
Group I — Physical conditions imposed by the marine environment			
M1	Motion, list and acceleration loads	Core thermal-hydraulics and void response under motion and list	A.491 sets limits [5], but the function protected by the limit differs by reactor type, so a single value lacks a common physical basis.
M2	Natural circulation and passive safety	Gravity-driven flow sensitivity; two-phase instability	No Code counterpart; all designs credit passive safety or natural circulation, but public data do not quantify sensitivity to motion and list.
M3	Ultimate heat sink	Seawater, corrosion, biofouling, temperature, and standby power	Not assessable for AP3: public data omit corrosion, biofouling, and standby-power details of the heat sink.
M6	Protection against external impact	Collision, grounding, fire, extreme seas, mooring, and testability	Collision and grounding provisions exist [5], but the feasibility of full-scale testing varies considerably with unit size.
M13	Mass, volume and vertical centre of gravity	Stability, trim, layout, and metacentric height	Coolant density affects stability; no rule links coolant inventory to the stability of the carrier.
Group II — Sources and barriers			
M4	Source term and inventory	Inventory, chemical form, retention, and seawater behaviour	Fuel form is the dominant factor; criteria for crediting encapsulation and for circulating fuel inventory are absent.
M5	Pressure boundary and containment	Internal/external pressure; hull-containment integration; flooding	Pressure ranges from 15.7 MPa [29] to near atmospheric; the Code requires the containment to withstand pressure differences during sinking and flooding [5].
M7	Response to sinking and flooding	Deep-water integrity, recriticality, cooling, and monitoring	The Code and ABS require analysis [5][7], but no criterion specifies how boron-free or non-water-cooled designs demonstrate compliance.
M8	Recoverability	Recovery plan, module separation, timing, and flotation	Deployment area is the governing factor; the Code requires design provisions that facilitate salvage [5], but responsibility, funding, and deadlines are not specified.
M9	Fuel form and enrichment	Fuel type and enrichment relative to the 5% transport branch	The 5% enrichment branch for transport separates designs within and across families.
Group III — Operation and life cycle			
M10	Operating cycle and refuelling	Cycle length, refuelling location, and unit movement	The ratio of fuel cycle to survey interval ranges from 0.4 to 4.0, and online and no-reload designs also occur; current standards address neither extreme.
M11	Spent fuel and end of life	Storage, return, decommissioning, hull disposal, and funding	Cartridge and once-through designs shift spent-fuel storage to the return of modules; online refuelling requires continuous fuel handling.
M12	Power manoeuvring and load following	Propulsion response, starts and stops, and restart	For AP3 the Code requires load response comparable to that of a conventional steam plant and an unaided dead-ship start [5]; external heating for one design conflicts with the latter.
M14	Human factors and operating regime	Manning, remote and shore support, and dual licensing	All designs share an unresolved need for dual licensing as reactor operator and seafarer.
M15	Maturity and licensing record	Readiness, demonstration, review, supply chain, and inspection	Lead cooling has naval submarine experience only, and none of the selected non-water-cooled designs has been applied at sea [17].

#	Criterion	Assessment area	Result across the six designs
Group IV — Regulatory interface and transport			
M16	Regulatory interface boundary	Nuclear-maritime review boundary; circulating fuel and shared power	No Code counterpart; ABS assigns review responsibility through an interface document [7], whereas the NRC-USCG memorandum allocates it by subject matter, assigning reactor and radiological safety to the NRC and vessel and maritime safety to the USCG [25].
M17	Safety state in transport or tow	Fuel state, standby systems, decay heat, monitoring, and approvals	No Code counterpart; the fuel state and approvals during transit vary with the design and with M9 enrichment.

4.2. Divergence among Pressurized Water Reactors of One Family

The three PWRs, BANDI, RITM-200M, and ACP100S, belong to family A. If the reactor family alone determined the applicable requirements, these designs would be treated identically; criteria M8–M10, however, lead to different and in some cases opposing implications for them (**Table VI**).

Table VI. Review Criteria that Diverge within Reactor Family A

Criterion	BANDI	RITM-200M	ACP100S
M9 fuel, enrichment	4.95% LEU; below 5% branch	<20% HALEU; added protection and transport approval	<4.95% LEU; below branch
M10 operating cycle	48–60 mo; near survey cycle	120 mo; decoupled from survey	24 mo; 2–3 refuellings per survey interval
M8 recoverability	Site unset; recovery conditions undetermined	Arctic; seasonal access limits	Shallow coastal; salvage practicable

○ Enrichment and Transport Approval (M9)

Under M9, all three designs use solid oxide fuel, but their enrichment levels impose different burdens for physical protection, non-proliferation, and transport approval. The IAEA identifies RITM-200M as a design using high-assay low-enriched uranium (HALEU) [29]. Because an enrichment of 5% serves in practice as a branch point for transport requirements, designs within a single PWR family follow different regulatory paths.

○ Fuel Cycle and Survey Interval (M10)

Under M10, the fuel cycles of the three designs [29] relate differently to the five-year dry-docking survey [17]. The 120-month cycle of RITM-200M is independent of the docking schedule, whereas the 24-month cycle of ACP100S requires two or three refuellings between dockings. International rules do not clearly address refuelling at sea or in foreign ports; in Korea, the loading or rearrangement of fuel in a ship reactor also requires an occasional survey [23].

○ Deployment Area and Recoverability (M8)

Under M8, the deployment area is more significant than the reactor type. Shallow coastal waters may permit salvage and a clear allocation of responsibility, whereas Arctic ice can restrict access. A.491 permits less severe seaway design requirements for special ships operating only in restricted areas (§2.3.6) [5], but it does not differentiate requirements systematically by sea area. Severe-accident features also do not cover every marine phenomenon: the in-vessel retention and double containment of RITM-200M [29] may limit releases after sinking, but they do not directly address recriticality caused by increased moderation.

○ Design Disclosure and the Scope of a PWR Standard

The extent of public disclosure also affects the confidence with which a design can be reviewed. BANDI could be assessed against all criteria because its developer has published the design parameters and safety features [30], whereas designs with less published information could not be evaluated to the same extent.

Reactor-family designations therefore do not capture differences in enrichment, fuel cycle, deployment area, accident response, or available evidence, and a single maritime safety standard for PWRs would not distinguish between designs that these criteria separate.

4.3. Conflicts across Reactor Families in Nuclear-Propelled Ships

Whereas Section 4.2 held the reactor family constant, the comparison in this section holds the application constant at AP3 and varies the reactor family: BANDI (A), MMR (C), KP-FHR (D), and SEALER-55 (E). Most of the issues identified could be addressed through design changes or licence conditions, but two cases, online refuelling and lead-coolant freezing, require changes to the regulatory or operating model. The remainder of this section then examines the physical parameters that govern land-based advantages at sea.

○ Online Refuelling and Discrete Survey Requirements

In KP-FHR, pebbles are continuously removed during operation, their burnup is measured, and they are reinserted or placed in storage [17]. This arrangement improves availability and burnup in land-based operation, but continuous fuel handling while the ship is under way or in a foreign port raises issues of acceptance and security. It is also inconsistent with the Korean occasional-survey requirement [23], which presupposes refuelling as a discrete event. The incompatibility is therefore regulatory as well as technical: compliance requires inspection and authorization procedures to be redefined for continuous refuelling and cannot be achieved by modifying the plant alone.

○ Lead-Coolant Freezing and Merchant-Ship Operation

In SEALER-55, the lead coolant may solidify when power is reduced below 30–40% of nominal power [17]. Merchant ships repeatedly operate at low power or shut down during manoeuvring and berthing, and A.491 §2.4.3 requires rapid load response and unaided startup from a dead-ship condition [5]. Preventing coolant freezing may therefore require changes to the reactor, to the operating profile of the vessel, or to external heating arrangements, and reliance on a continuous supply of auxiliary heat may itself conflict with the dead-ship requirement.

○ Land-Based Advantages Governed by Maritime Parameters

These two cases follow a more general pattern in which a feature that is advantageous on land may lose its value, or may become a burden, at sea. **Table VII** lists seven such features together with the physical parameter that governs each of them at sea. The comparison does not imply that advanced reactors are inherently less safe at sea; it indicates that maritime deployment changes the quantity or condition against which each feature must be demonstrated.

Table VII. Land-Based Advantages and Governing Maritime Parameters

Feature	Advantage on land	Governing quantity at sea, with values	Effect on the requirement
Low primary pressure	Smaller containment design pressure	External hydrostatic load, about 10 kPa/m depth, versus internal design pressure: 15–15.7 MPa (A), 6 MPa (C), near atmospheric (D, E)	External-pressure and buckling resistance require separate demonstration; low internal pressure is insufficient.
Dense coolant at low pressure	Large thermal inertia	Coolant mass affects displacement and vertical centre of gravity.	Inventory becomes a stability as well as thermal input.
Coolant that solidifies on release	Passive confinement of a leak	Minimum sustainable power; lead may solidify below 30–40% power [17].	Potential conflict with manoeuvring, berthing, and dead-ship start [5].
Long or single-batch fuel cycle	Fewer outages	Fuel cycle / five-year survey: 0.4 (ACP100S), 0.8–1.0 (BANDI), 2.0 (RITM-200M), 4.0 (MMR), no reload (SEALER-55)	Below one, refuelling falls between dockings; above one, inspection must be demonstrated without opening the boundary.
Online refuelling	No shutdown; higher burnup	Inspection events per cycle: zero online versus one per batch refuelling.	Korea's occasional-survey ground is defined per fuel-loading event and does not address continuous loading [23].
Higher enrichment	Compact core; longer cycle	Enrichment relative to 5%: ≤4.95% (BANDI, ACP100S); 9.99–19.75% (MMR); <20% (RITM-200M); 19.9% (SEALER-55)	Three designs exceed the branch and one is undeclared; AP3 repeats the burden at each port State.
No moving parts	Simplicity; fewer failure modes	Function protected by 45° criterion: rod insertion (A), helium distribution (C), circulation path (D), sloshing (E)	A single 45° rolling criterion, not differentiated by reactor design [5], lacks a common basis across types; the limit should be derived by type.

○ External Pressure and Inclination Thresholds

Primary pressure illustrates how an advantage on land may change under marine conditions. NuProShip excludes designs that cannot guarantee that accident pressure remains below the limit the ship structure can sustain [17], while A.491 design class 2 (DC-2) also requires the containment shell to withstand the pressure differences that arise during sinking and subsequent flooding [5]. Hydrostatic pressure increases by approximately 10 kPa per metre of depth. A low internal pressure therefore does not in itself provide a larger margin at sea, because near-atmospheric boundaries may instead be governed by external buckling or collapse. High-pressure vessels may have greater structural stiffness, but qualification for internal pressure does not demonstrate resistance to external pressure; each design must therefore be assessed separately for external loading.

The inclination criterion shows why a single threshold may not suit all reactor technologies. Under the 45° criterion of §2.3.10, the limiting phenomenon may be control-rod insertion, pump performance, or the driving head of passive systems in a PWR; helium-flow distribution in a prismatic gas-cooled reactor; distortion of circulation paths in a pebble-bed reactor; and coolant sloshing in a lead-cooled reactor. The value may reflect assumptions made for light-water reactors, but the Code does not state its physical basis. The applicable limit should therefore be derived from the safety function or phenomenon that inclination degrades in each design. ABS adopts the inclination angles of A.491 and its requirement for shutdown capability at inclinations of up to 90° [7], but no evidence was identified that the basis of these values has been reassessed for different reactor types.

○ Boron-Free Operation and Recriticality on Flooding

Boron-free operation illustrates a third type of gap, which requires neither a new requirement nor a revised threshold, but an implementation criterion. BANDI-60S uses soluble-boron-free operation, internal control-rod drives, and a secondary shutdown system [30]; in land-based reactors such features are generally regarded as advantages. During seawater ingress, however, the colder and denser moderator could insert positive reactivity, while soluble-boron injection would not be available. This study does not quantify the effect, but the governing requirement already exists: A.491 §4.3.2 requires subcriticality under ship-accident conditions, including capsizing and sinking [5], and ABS recommends that the Interface Document address reactivity insertion associated with sinking or water intrusion [7]. What is absent is guidance on how boron-free water-cooled reactors, or non-water-cooled designs with different density feedback, should demonstrate

compliance with this requirement. The distinction is relevant to the revision of the Code: a missing requirement calls for new regulatory text, whereas a missing implementation criterion calls for interpretive guidance or design-specific acceptance criteria.

5. Conclusions

This study compared the nuclear and maritime requirements applicable to maritime nuclear applications, derived seventeen review criteria from them, and applied the criteria qualitatively to six reactor designs in four application types. The review assessed what maritime deployment requires, whether current rules address each requirement, and how the characteristics of each design change the evidence required; no scores or rankings were assigned.

The review produced three findings. First, the reactor family and the application type do not by themselves determine the applicable requirements: PWRs of the same family in the AP1 application diverge in enrichment, fuel cycle, and recoverability. Second, the comparison across reactor families identifies structural conflicts between continuous refuelling and inspection based on discrete refuelling events, and between the freezing limits of lead coolant and the operating profile of merchant ships. Third, features that are advantageous on land may lose their advantage or become burdens at sea according to measurable parameters: the ratio of fuel cycle to survey interval, enrichment, coolant melting point and density, hydrostatic pressure, frequency of fuel handling, and response to inclination.

These findings indicate that the revised Code should combine two layers of requirements. The first layer would contain obligations common to all designs, covering recriticality on flooding, sinking depth, recovery, regulatory interfaces, the safety state during transport or towing, and personnel qualification. The second layer would contain thresholds derived from the governing parameters identified above, covering pressure, inclination, coolant freezing and inventory, refuelling mode, and enrichment. This combination of goal-based and prescriptive requirements is consistent with the technology-agnostic approach of MSC 110 [12] and would supply prescriptive criteria for the functional requirements of ABS that currently lack them [7]. Because the review relied on publicly available design information, criteria for which that information was insufficient, such as M3 in the AP3 application, remain to be assessed with design-specific data.

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REFERENCES

[1] International Atomic Energy Agency, 24th INPRO Dialogue Forum on the Sustainable Deployment of Floating Nuclear Power Plants for Transitioning to Net Zero, Vienna, 19-23 May 2025.
[2] World Nuclear Association, "Nuclear-Powered Ships," Information Library, updated 18 May 2026.
[3] United Nations Convention on the Law of the Sea, 1982, UNTS Vol. 1833, I-31363.
[4] International Convention for the Safety of Life at Sea (SOLAS), 1974, ch. VIII, UNTS 1184, I-18961.
[5] International Maritime Organization, Code of Safety for Nuclear Merchant Ships, Assembly Resolution A.491(XII), 1981.
[6] International Atomic Energy Agency, Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Small Modular Reactors, Safety Reports Series No. 123, 2023.
[7] American Bureau of Shipping, Requirements for Nuclear Power Systems for Marine and Offshore Applications, January 2025.
[8] World Nuclear Association, CORDEL Working Group, Facilitating Global Deployment of Floating Nuclear Power Plants, Report 2025/001, June 2025.
[9] Republic of Korea et al., Revision of the Code of Safety for Nuclear Merchant Ships, IMO Doc. MSC 110/6/4, 9 April 2025.
[10] International Maritime Organization, SDC 12 Meeting Summary, 19-23 January 2026.
[11] DNV, IMO MSC 111: New MASS Code adopted, 22 May 2026.
[12] International Maritime Organization, MSC 110 Meeting Summary, 18-27 June 2025.
[13] American Bureau of Shipping, Nuclear-Electric Propelled Vessel Design from HD KSOE Earns ABS Approval, 19 February 2025; Nuclear Concept from HHI and HD KSOE Receives ABS Approval, 18 June 2025.
[14] Korea Atomic Energy Research Institute, press release on the ABS approval in principle for the SMART100-based floating nuclear power platform with Samsung Heavy Industries, 16 December 2025 (in Korean).
[15] Nuclear Safety and Security Commission, NSSC Begins Preparations for the Review of the Standard Design Approval of the Innovative Small Modular Reactor (i-SMR), press release, 4 March 2026 (in Korean).
[16] Samsung Heavy Industries, SHI Speeds Up Development for Nuclear Power Plant On the Sea, press release, 4 January 2023.
[17] J. Emblemsvåg et al., Final Report of the Nuclear Propulsion for Merchant Ships I (NuProShip I) Project, Norwegian University of Science and Technology, 15 January 2025.
[18] International Atomic Energy Agency, Legal and Institutional Issues of Transportable Nuclear Power Plants: A Preliminary Study, Nuclear Energy Series NG-T-3.5, 2013.
[19] International Atomic Energy Agency, Nuclear and Radiation Safety, GOV/2019/27-GC(63)/4, 17 July 2019, paras. 153-154.
[20] Convention on the Liability of Operators of Nuclear Ships, Brussels, 25 May 1962 (not in force).
[21] Lloyd's Register, Global Nuclear Security Partners and NorthStandard, Navigating Nuclear Energy in Maritime, 16 October 2025.
[22] Republic of Korea, Nuclear Safety Act No. 21679 and Enforcement Decree No. 36664 (in Korean).

[23] Republic of Korea, Ship Safety Act No. 19134 and Enforcement Rule No. 813 (in Korean).
[24] Ministry of Oceans and Fisheries, Nuclear Ship Standards, Notice No. 2025-14, 20 January 2025 (in Korean).
[25] U.S. Coast Guard and U.S. Nuclear Regulatory Commission, Memorandum of Understanding regarding Civilian Maritime Nuclear Projects, signed 18 and 22 June 2026, ADAMS ML26096A081.
[26] United Kingdom, The Merchant Shipping (Nuclear Ships) Regulations 2022, S.I. 2022/1169.
[27] Russian Federation, Federal Law No. 170-FZ, On the Use of Atomic Energy, 21 November 1995, as amended.
[28] J. Deemer, O. Pimentel, M. J. Ryu, M. Yamada and E. Jenner, Uncharted Waters: Assessing China's Intentions to Deploy Floating Nuclear Power Plants in the South China Sea, Center for Global Security Research, Lawrence Livermore National Laboratory, June 2023.
[29] A. Constantin and H. Subki, Overview of SMR Designs for Maritime-based Nuclear Power Plants, 24th INPRO Dialogue Forum on Sustainable Deployment of Floating Nuclear Power Plants for a Net-Zero Transition, IAEA, Vienna, 19-23 May 2025.
[30] I. H. Kim et al., Development of BANDI-60S for a Floating Nuclear Power Plant, KNS Autumn Meeting, Goyang, 24-25 October 2019.