A Literature-Based Review of Design Characteristics and Considerations for Nuclear-Powered Ships

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1. Introduction

Fossil fuels, which are predominantly used as propulsion fuels for ships, are subject to considerable price volatility due to changes in international conditions and crude oil prices. In addition, greenhouse gases and air pollutants emitted during combustion are increasingly subject to environmental regulations. Accordingly, the maritime industry has been investigating environmentally friendly propulsion systems based on alternative energy sources as alternatives to conventional fossil fuels. Nuclear energy has been considered a potential alternative because of its high energy density, near-zero direct carbon emissions during operation, and relatively low dependence on fossil fuel price fluctuations [1].

Nuclear propulsion has already been applied to submarines, icebreakers, and several merchant ships. Earlier nuclear-powered merchant ships employed relatively large reactor plants and associated systems, resulting in significant onboard space and weight requirements. Recently, the potential application of smaller and more modular reactor systems has been investigated as an alternative to conventional large reactors. Reactor systems for marine applications must be designed by comprehensively considering not only safety but also various factors associated with shipboard installation [2].

Therefore, this study reviews existing nuclear-powered ship cases and related literature and identifies and classifies the major design characteristics and considerations for nuclear-powered ships into the Planning, Construction, and Operation stages. In addition, based on the derived considerations, a literature-based conceptual design of a 15,000 TEU nuclear-powered containership is presented to examine how these considerations can be applied to ship design.

2. Design Characteristics and Their Application

2.1 Design Characteristics and Considerations

Based on the reviewed literature and previous nuclear-powered ship cases, major design issues were identified and classified according to the stage in which they primarily affect ship design and operation.

In the Planning stage of nuclear-powered ship design, the Ship Type, Reactor Selection, and Propulsion System Selection should be determined based on the intended mission and operating conditions of the vessel, and the Principal Particulars should subsequently be established. For this purpose, previous experience in the development and operation of nuclear-powered ships should be reviewed to identify technical and operational issues encountered during actual service [2].

In addition, because nuclear-powered ships generally involve high initial construction costs, Economic Feasibility, including initial capital costs and expected operating costs, should be considered. Reactor Arrangement and Regulatory Requirements should also be addressed during this stage in accordance with the design and operational conditions of the vessel.

In the Construction stage, including detailed design and shipboard integration, detailed consideration is required to integrate the reactor and propulsion systems determined during the Planning stage into the actual vessel.

Unlike land-based nuclear power plants, marine reactors are subject to onboard space and weight constraints and must also account for ship motions such as roll and pitch. Accordingly, Hull Structures, Reactor Compartment Shielding, System and Equipment Arrangement, and Emergency Safety System Arrangement should be considered to ensure that the reactor and associated systems can maintain safe and reliable functions under marine operating conditions [3,4].

In the Operation stage, periodic Maintenance of the reactor and propulsion systems is required to ensure safe vessel operation and long-term reactor performance. Nuclear Fuel and Radioactive Waste Management should include the management of refueling intervals and the storage and treatment of radioactive waste generated during operation. In addition, Crew requirements, including the assignment of qualified nuclear personnel and appropriate training and certification, should be considered together with Emergency Response procedures [5]. At the end of the vessel's operational life, Decommissioning should also be addressed, including vessel decommissioning or conversion, removal of nuclear fuel, and dismantling of reactor systems.

Table I summarizes the major design characteristics and considerations for nuclear-powered ships derived from the review and analysis of 20 relevant studies and classifies them according to the Planning, Construction, and Operation stages.

Table I: Design characteristics and considerations for nuclear-powered ships by planning, construction, and operation stages

Stage	Considerations	Design Characteristics
Planning	Ship Type	Power requirements, space constraints, and operational characteristics for different ship types
	Reactor Selection	Reactor characteristics according to reactor type, generation, and design concept
	Propulsion System Selection	System configuration and arrangement for electric propulsion and steam-turbine-driven mechanical propulsion
	Reactor Arrangement	Shipboard arrangement of the reactor compartment considering protection against collision and grounding
	Principal Particulars	Effects of reactor power, dimensions, and weight on ship size, displacement, and stability
	Regulatory Requirements	Integrated consideration of maritime and nuclear regulatory requirements
	Economic Feasibility	Initial capital costs and expected operating costs
Construction	Hull Structures	Structural dimensions and requirements for major hull structures, including the double bottom, bulkheads, and decks
	Reactor Compartment Shielding	Radiation shielding performance for different shielding materials and configurations; shielding weight and volume
	System and Equipment Arrangement	Interface and arrangement of the reactor and propulsion systems; arrangement of auxiliary power systems, including batteries and diesel generators
	Emergency Safety System Arrangement	Configuration and arrangement of safety systems for emergency conditions such as collision, fire, and flooding
Operation	**Maintenance**	Inspection and maintenance planning for the reactor and propulsion systems
	Nuclear Fuel and Radioactive Waste Management	Refueling intervals; radioactive waste storage and treatment methods
	Crew	Assignment of qualified nuclear personnel; training and certification requirements
	Emergency Response	Emergency response procedures, including reactor shutdown, decay heat removal, and mitigation of radioactive material release
	Decommissioning	Vessel decommissioning or conversion options; removal of nuclear fuel and dismantling of reactor systems

2.2 Application to the Conceptual Design of a Containership

Based on the design characteristics and considerations summarized in Table I, a conceptual design of a nuclear-powered containership was carried out in this study. Containerships require stable, high power output over long periods to sustain high-speed, long-distance operation. Nuclear propulsion systems are well suited to these operational characteristics because their high energy density allows long-term operation without refueling. In addition, the port entry and operation of nuclear-powered ships require relevant licensing and port support infrastructure for radiation safety. Containerships, which operate on fixed routes with regular ports of call, are advantageous for establishing and operating such infrastructure in advance.

In terms of structure, containerships do not require liquid or gas cargo tanks, unlike oil tankers and LNG carriers, which makes it relatively easier to secure space for the reactor, shielding, and propulsion systems. Because the reactor and shielding systems of a nuclear-powered ship must be arranged within limited onboard space and allowable weight, efficient use of space is an important design factor. Furthermore, the burden of considering fire and explosion hazards from the cargo itself together with reactor safety design is relatively small. Considering these operational and arrangement characteristics together with the shipbuilding experience of the Korean shipbuilding industry and market demand, a 15,000 TEU containership was selected as the Ship Type, reflecting the principal particulars of the Neo-Panamax (NPX) class, for which market demand is high.

Reactor types include liquid metal-cooled reactors, gas-cooled reactors, heavy water reactors, molten salt reactors, and light water reactors. Molten salt reactors have attracted attention as next-generation reactors capable of low-pressure operation; however, their technology readiness has not yet been sufficiently established, and they have not been installed and operated on ships. In contrast, light water reactors have been installed and operated on ships, including naval vessels and submarines, and have also been applied to a containership. Although this experience has established a technical foundation, conventional light water reactors require considerable weight and space owing to their complex system configuration. Therefore, an integral pressurized water reactor (iPWR) with a compact and modular design was selected. The design referred to the specifications and configurations of SMART and BANDI, both developed in Korea. In both reactors, major components such as the core, steam generators, and pressurizer are integrated within the reactor pressure vessel.

For Reactor Arrangement, the reactor compartment was planned to be located at midship or slightly aft of

midship to reduce the effects of collision and grounding. The engine room, which houses the steam turbine and generator, was arranged adjacent to and aft of the reactor compartment. In this arrangement, the reactor compartment may be located far from the propeller at the stern; therefore, electric propulsion was selected to reduce arrangement constraints on the propulsion system. In electric propulsion, the power produced by the generator driven by the steam turbine is supplied to the propulsion motor through cables. Because the generator does not need to be directly connected to the propulsion motor by a long shaft line, the major equipment can be arranged more flexibly.

The required power was estimated based on existing ships with similar principal particulars and compared with the power output of the reference reactors. In addition, two reactors were planned to be installed to address the shutdown of a single reactor. Storing surplus electric power produced by the reactors in batteries for use when needed was also considered. The crew accommodation was located at the bow, sufficiently separated from the reactor compartment for radiation safety, and to secure visibility for ship navigation.

Accordingly, this study performed a conceptual design of a nuclear-powered ship by applying two iPWRs and an electric propulsion system to a 15,000 TEU containership, considering the compartment arrangement of the reactor compartment, engine room, and crew accommodation.

3. Conclusion

This study analyzed the major design characteristics and considerations for nuclear-powered ships, which are being considered as an alternative for reducing carbon emissions, by classifying them into the Planning, Construction, and Operation stages. These design stages are not independent but are closely interconnected; therefore, the results of the preceding stage and their effects on subsequent stages should be considered together. In particular, reactor selection can affect shipboard arrangement, shielding, principal particulars, and propulsion configuration, indicating the need for integrated ship–reactor design.

Based on these considerations and design characteristics of the Planning stage, a conceptual design of a 15,000 TEU nuclear-powered containership was performed. Through this conceptual design, it was confirmed that the Ship Type, Reactor Selection, Propulsion System Selection, and Reactor Arrangement are closely related to one another.

In addition, compared with conventional fossil-fuel-powered ships, nuclear-powered ships require additional considerations related to reactor safety, radiation shielding, emergency response, and radioactive material management, which may require design procedures and considerations that differ from those of conventional ships.

In particular, the Construction stage involves strong interactions among reactor, propulsion, hull, shielding, and arrangement requirements and therefore requires detailed design to integrate the reactor and propulsion systems determined during the Planning stage into the vessel. Further research is needed to refine the conceptual design presented in this study by considering the design characteristics and considerations of the Construction and Operation stages, and to investigate detailed design criteria and production design for the practical construction of nuclear-powered ships.

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REFERENCES

[1] S. E. Hirdaris, Y. F. Cheng, P. Shallcross, J. Bonafoux, D. Carlson, B. Prince, and G. A. Sarris, “Considerations on the potential use of Nuclear Small Modular Reactor (SMR) technology for merchant marine propulsion,” Ocean Engineering, Vol. 79, pp. 101–130, 2014.

[2] L. O. Freire and D. A. de Andrade, “Historic survey on nuclear merchant ships,” Nuclear Engineering and Design, Vol. 293, pp. 176–186, 2015.

[3] S. Park, S. Kim, G. A. R. Bari, and J. H. Jeong, “Fundamental understanding of marine applications of molten salt reactors: Progress, case studies, and safety,” Journal of Marine Science and Engineering, Vol. 12, No. 10, 1835, 2024.

[4] M. Drosińska-Komor, J. Głuch, N. Ziółkowska, Ł. Brenkacz, K. Brzezińska-Gołębiewska, J. Blaut, and P. Ziółkowski, “Integrating fourth-generation reactors into maritime transport,” Ocean Engineering, Vol. 342, 122891, 2025.

[5] J. Jang, “A Study on the Revision of Korean Nuclear Safety Act under the Assuming the Introduction of Nuclear Ships: Reference to Russian Nuclear Safety Law,” Transactions of the Korean Nuclear Society Autumn Meeting, Changwon, Korea, October 30–31, 2025.