# Concept Design and Risk Assessment of Nuclear Propulsion Ship

Youngmi Gil [a*], Seongjin Yoo [a], Yeontae Kim [a], June Oh [a], Yoonchul Byun [a], Ilguk Woo [a], Jiho Kim [b], Suhn Choi [b]
[a]*Daewoo Shipbuilding & Marine Engineering Co., Ltd, Seoul, Republic of Korea*
[b]*Korea Atomic Energy Research Institute, Daejeon, Republic of Korea*
[*]*Corresponding author: gil@dsme.co.kr*

## 1. Introduction

The nuclear energy is emerging as an alternative to the fossil fuels, which is applied to the propulsion of ships. The nuclear propulsion ships (hereinafter referred to as "nuclear ships") have been considered as an eco-friendly ship. There have historically been warship and submarine with the source of nuclear power. The use of nuclear ships has been recently extending to the icebreaker, the deep-water exploration ship, and the floating nuclear power plant.

Prior to developing the new ship, we evaluated the economics of various types of ships and concluded that the container ship could be appropriate for the nuclear propulsion [1]. In order to verify its safety, we performed the ship calculation based on the optimal arrangement of the nuclear reactor. Finally, we verified its safety by the HAZID.

## 2. Concept design of nuclear propulsion ship

### *2.1 Estimation of propulsion type and nuclear reactor power*

The mechanical propulsion is generally preferred over the electric propulsion for a large merchant ship. In addition to its high efficiency, the mechanical propulsion offer many advantages over the electric propulsion. Nevertheless, we chose the electric propulsion in this study because of the arrangement of the nuclear reactor. The nuclear reactor is generally located in the middle of ship. In this case, the propulsion section is far from the nuclear reactor and the mechanical propulsion is not proper.

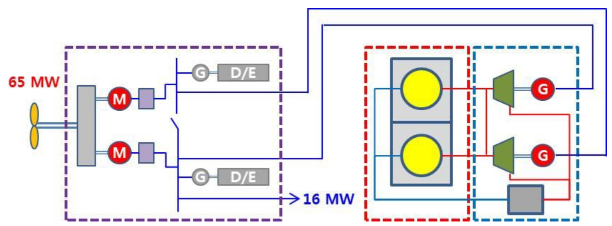


Figure 1 Concept of electric propulsion

The thermal power required by the nuclear reactor is estimated based on the propulsion power of the reference ship and is as follows:

1) Propulsion power: 65 MW
 - Reduction gear: 99%
 - Motor efficiency: 98%
 - Transformer efficiency: 98%
 → Required electric power: 68 MWe
2) Auxiliary power: 16 MWe
3) Total required power: 68 + 16 = 84 MWe
 - Generator efficiency: 98%
 - Steam turbine efficiency: 24%
 → Total required reactor thermal power: 360 MWt

The thermal power required by the nuclear reactor is 360 MWt. In this study, two reactors of 180 MWt were installed for redundancy.

### *2.2 Arrangement of nuclear reactor and BOP*

In this study, we considered the container ship of 14,000 TEU in size. In case of the existing ships, the deckhouse is located in the stern with the funnel, whereas the deckhouse in this study is located in the middle of the ship; that is the concept of the twin island. Consequently, the cargo cannot be loaded under the deckhouse and this area is used for the fuel oil tank. We intend to install the nuclear reactor and BOP in this area, which enables the nuclear ships to minimize the loss of container without changing the shape and the dimension of the ships.

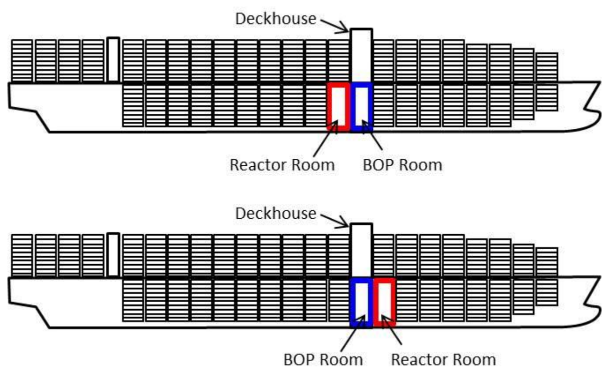


Figure 2 Arrangement of reactor and BOP

### *2.3 Optimization of nuclear shielding structure and weight estimation*

Radiation protection is one of the most important factors in the nuclear ships as well as the nuclear power plant on the ground, which is guaranteed by a multi-layered shielding. In addition to safety aspects, there are other issues in the nuclear ships. That is, limitations of space and weight. In order to overcome this limitation, the shielding structure in the ship has to be installed more effectively than on the ground.

In the former research, we optimized the shielding structure composed of concrete between steel, which is 36% lighter than the existing shielding of the nuclear power plant on the ground [2].

In this study, the unnecessary shielding wall between two reactors was removed [Fig. 3], which enables the shielding weight to be reduced from 12,051 ton to 10,507 ton and took the shielding optimization research a step further. Finally, figure 4 shows the optimized reactor and BOP structure.

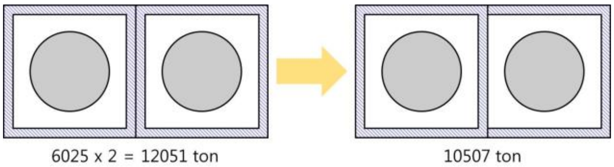


Figure 3 Shielding optimization

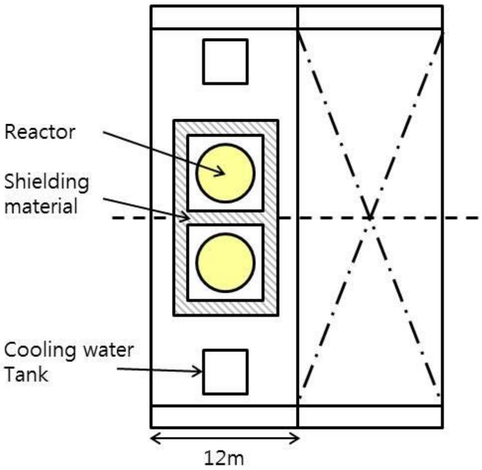


Figure 4 Arrangement of reactor and BOP

*2.4 Ship calculation*

In order to verify the safety, we performed the ship calculation under the ballast departure condition and the homogeneous design departure condition. The check list is as follows:

- T: 14 m
- Trim: stern trim, less than 1% LBP
- GM value: more than 1 m (0.5 m ~ 1.2 m)
- Propeller Top Height: 9.35 m
- Allowable Bending Moment: 890,000 T-m
- Allowable Shear Force: 11,400 T

Figure 5 and 6 show that the safety factors such as draft, trim, GM, depth of propeller, shear force, and bending moment are kept under acceptable levels.

By additional calculation, we confirm the result as follows:

- When the reactor and the BOP system weigh less than 7,000 ton, the stability of ship with the reactor and the BOP installed in the middle is guaranteed.
- When the reactor and the BOP system weigh less than 5,000 ton, the stability of ship with the reactor and the BOP installed in the stern is guaranteed.
- When the reactor and the BOP system are installed in the middle of the ship, the loss of container is 392 TEU.
- When the reactor and the BOP system are installed in the stern of the ship, the loss of container is 754 TEU.

From the results described above, we concluded that the installation of the reactor and the BOP system in the middle is the optimal way in the aspect of safety and economics.

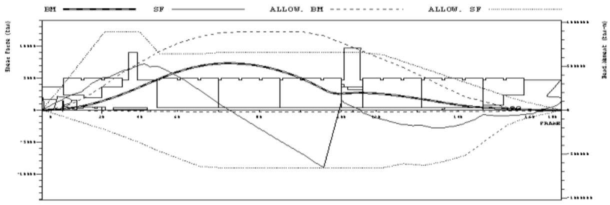


Figure 5 Stability result of ballast departure condition

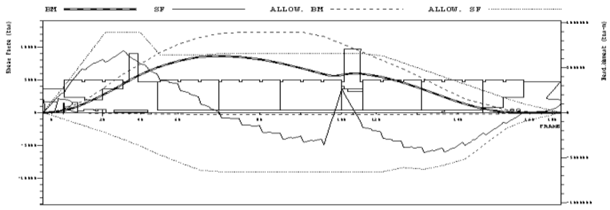


Figure 6 Stability result of homogeneous design departure condition

### 3. Risk assessment of nuclear propulsion ships

In this study, we used the HAZID(HAZard Identification) technique to confirm the safety and the reliability. The HAZID is the process of identifying hazards in order to mitigate the risk. It is the important step for the qualitative risk assessment.

At first, the major risk factor is identified. The each factor is evaluated the risk sensitivity according to human, environment, ship, cargo. Finally, Risk Index is quantified based on Frequency Index and Severity Index as follows:

$$\text{Risk Index(RI)} = FI \times SI \quad (1)$$

The FI is Frequency Index, the frequency in which the damage takes place. The SI is Severity Index, the severity of damage. The RI is classified as Low, Medium, and High according to the frequency and the severity.

Figure 7 shows the final result of the HAZID analysis. The hazards are divided into four categories such as reactor compartment, BOP compartment, unlawful act, general arrangement.

In this study, we considered the SMART reactor. Its safety is secured by PSA (Probabilistic Safety Assessment) so that the fetal risk was not found out. We suggest, however, that the risk analysis of the large motion was performed in our future work because it was not considered in the stage of the reactor design.

| ID | Failure Mode | Failure causes | Failure effects | RI |
|---|---|---|---|---|
| 1. Reactor Compartment | | | | |
| 1.1 | 원자로 출력 이상 | large motion에 의한 제어봉 구동장치 손상 및 오작동 | 원자로 노심 내 불균일한 온도 분포 | M |
| | | large motion 에 의한 냉각수 유속 변화 | 원자로 압력용기 온도 변화 | M |
| 1.2 | 원자로 및 차폐체 손상 | motion 에 의한 피로파괴 | 방사능 누출 | M |
| | | collision | 방사능 누출 | M |
| | | impact 에 의한 손상 (Slamming 등) | 방사능 누출 | L |
| 1.3 | compartment 손상 | drop object | 방사능 누출 | L |
| 1.4 | compartmet 내부 monitoring 시스템 이상 | 화재 및 폭발 (수소가스) | compartment 손상 | M |
| 1.5 | compartment 침수 | collision | 제어 기능 상실 | M |
| | | grounding | 제어 기능 상실 | M |
| | | open hatch | 제어 기능 상실 | M |
| | | capsize | 원자로 기능 상실 / 인명 및 재산 피해 | M |

Figure 7 Result of HAZID for container ship powered nuclear reactor

## 4. Conclusions

In the former research [1, 2], we confirmed the applicability of the nuclear propulsion system for the large container ship. In this study, we verified the safety of the nuclear ships according to the HAZID analysis.

We expect that this research will lead to safe design of the nuclear ships

## REFERENCES

[1] Youngmi Gil *et al*., Feasibility Study on Nuclear Propulsion Ship according to Economic Evaluation, Transactions of the Korean Nuclear Society Spring Meeting, Gwangju, Korea, 30-31 May 2013.

[2] Seongjin Yoo *et al*., A study on the applicability of nuclear propulsion system for large container ship. *The Society of Naval Architects of Korea, Ulsan*, Republic of Korea, 7-8 November 2013.