Council on Competitiveness Nippon (COCN) 2022 Project Final Report

Offshore Floating Nuclear Power Plant

February 9, 2023

Executive Summary

1. Features and Advantages of Floating Nuclear Power Plants

Background

To achieve a carbon-neutral society, it is essential to transition the entire power generation sector, which accounts for 40% of Japan's CO2 emissions, to zero-emission energy sources. Currently, approximately 80% of the nation's electricity generation relies on fossil fuels. Converting these to zero-emission energy sources by 2050 will require the construction of new power generation facilities at a pace exceeding that of Japan's period of rapid economic growth. Moreover, as transportation and various industries shift to electrification to achieve carbon neutrality, the demand for electricity will increase further. Therefore, while significantly expanding renewable energy sources such as solar and wind power, the use of nuclear power will also be unavoidable.

However, the extensive improvement of safety, based on lessons learned from the Fukushima Daiichi Nuclear Power Plant accident, is an absolute prerequisite for utilizing nuclear power. To address this, the Council on Competitiveness Nippon (COCN) has been investigating the feasibility of offshore floating nuclear power plants (as proposed by Professor Michael Golay of the Massachusetts Institute of Technology and others) since 2020, focusing on their potential to enhance safety during events such as tsunamis or loss of offsite power.

Mechanism of Floating Nuclear Power Plants

Floating nuclear power plants involve mounting nuclear power generation facilities on a cylindrical floating structure, a design already proven for offshore drilling rigs. These plants are positioned over 30 km offshore, connected to existing power grids via undersea cables, and transmit electricity to demand areas. (Fig.1, Fig.2)The technologies for nuclear power generation, floating structures, and undersea cables are already well-established, meaning the development and design phase will not require extended periods. The floating structure features a double-hull design, ensuring it remains watertight even in the event of external damage. Its large size and low center of gravity minimize motion caused by ocean waves.

Advantages of Offshore Deployment

Placing the plant offshore offers several advantages. First, it significantly mitigates the impact of tsunamis. Second, the surrounding seawater facilitates natural convective heat exchange, enabling prolonged cooling without the need for active power. The reactor equipment is positioned below sea level to enable efficient heat dissipation using natural circulation forces. Furthermore, by situating the plant more than 30 km offshore, the "Urgent Protective Action Planning Zone (UPZ)" will not include residential areas. This reduces the impact on nearby residents and minimizes the burden of evacuation in the unlikely event of an accident.

The table below summarizes the safety features and additional advantages identified during the study:

① Reduced Impact from Tsunamis and Earthquakes

Being located in deep offshore waters minimizes the impact of tsunamis and reduces the effects of seismic activity (marine quakes) compared to onshore installations. Additionally, utilizing offshore areas broadens the range of potential installation sites.

② Continuous Cooling with Natural Seawater Circulation

The large volume of surrounding seawater can be used for cooling decay heat from the reactor indefinitely without requiring external power.

③ Reduced Burden of Evacuation for Nearby Residents

Positioned far offshore, the plant significantly reduces the burden of evacuation on residents in the event of an accident.

④ Increased Construction Efficiency

Manufacturing the plant in industrial zones enhances construction efficiency and shortens the construction period.

⑤ Risk Mitigation Through Mobility

The plant's mobility allows it to relocate if new environmental risks (e.g., active faults or volcanic activity) are discovered after operations have begun.

⑥ Safe Power Supply for High-Risk Regions

The technology can provide a safe power supply to regions with high tsunami and earthquake risks, such as Southeast Asia.

⑦ Simplified Export Process

Offshore nuclear plants can be built domestically and transported via towing, eliminating the need for on-site construction, which is often a challenge when exporting nuclear plants.

⑧ Synergy Between Nuclear Plant and Shipbuilding Technologies

The fusion of Japan's nuclear plant manufacturing expertise and shipbuilding technologies strengthens industrial competitiveness.

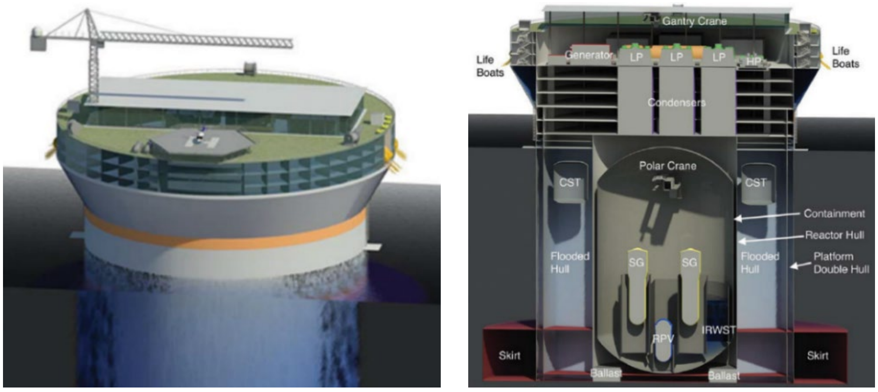

Fig 1　Image of OFNP Structure[1]

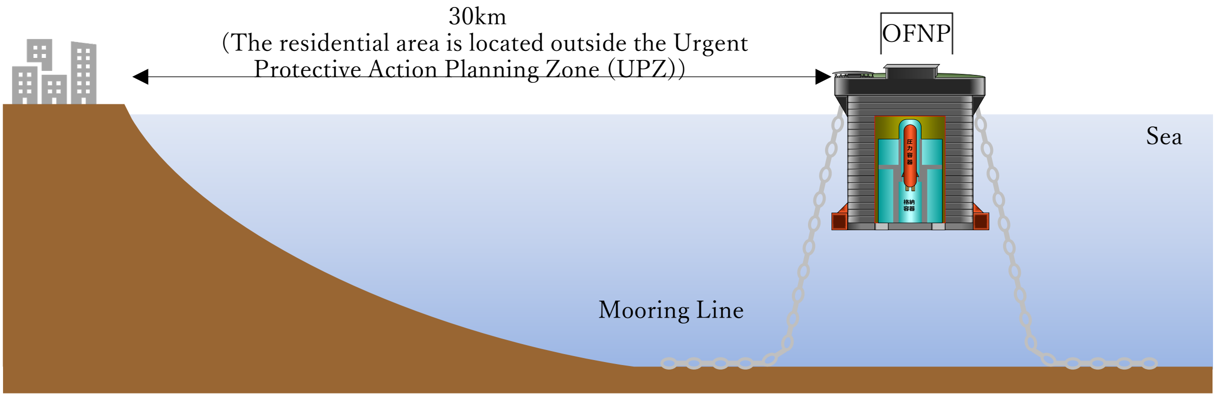

Fig 2　Placement Image of OFNP

This project was based on existing Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) designs. However, it is believed that the safety-enhancing benefits would also be significant for any new reactor types utilizing water-cooled systems that may be developed in the future.

2. Perspectives and Scope of the Study

Fiscal Year 2020

During FY2020, the team focused on understanding the basic structure of the floating nuclear power plant proposed by MIT and confirmed the following points:

- **Identifying Challenges for Offshore Installation**: No critical factors were found that would fundamentally hinder the feasibility of offshore floating nuclear power plants.
- **Heat Dissipation During Severe Accidents**: The ability to continuously dissipate

[1] J. Buongiorno et al., “The Offshore Floating Nuclear Plant (OFNP) Concept,” Nucl.Tech., vol.194, pp.1-14 2016.

decay heat using surrounding seawater without external power significantly enhances safety.

- **Tsunami Risk Mitigation**: While the risk from tsunamis is substantially reduced, further evaluation of the impact of marine seismic activity (seismic waves propagating through the ocean) is required.
- **Oscillation Effects**: It was confirmed that even with a BWR installed, oscillation effects would not obstruct feasibility.

Fiscal Year 2021

During FY2021, the study expanded to include construction schedules, costs, safety systems, maintenance, lessons from the Fukushima Daiichi Nuclear Power Plant accident, international cooperation, and past findings. Key points confirmed include:

- **Construction Timeline**: The construction of the first unit, including legal preparations and permits, would take approximately 14.5 years.
- **Construction Costs**: Costs are estimated to be comparable to onshore nuclear power plants.
- **Maintenance**: While most maintenance tasks can be conducted offshore based on knowledge from oil drilling rigs, a dock would be needed for repainting or significant repairs of the floating structure.
- **Positioning Method**: The catenary mooring system, commonly used in offshore wind farms, was identified as a strong candidate for anchoring the floating structure.
- **Heat Dissipation During Oscillation**: Changes in heat dissipation from nuclear fuel during oscillation were found to be within acceptable limits (confirmed for BWR).
- **Safety Measures Based on Fukushima Lessons**: Safety measures, such as improved accident management systems, were examined based on lessons learned from the Fukushima accident (confirmed for BWR).
- **Radioactive Material Release**: Releases during operation would remain within permissible limits and would not constitute marine dumping under the London Convention and Protocol.
- **Global Interest**: Interest in offshore nuclear power plants is growing internationally, as confirmed through communications with the IAEA and OECD-NEA.
- **Past Knowledge**: Insights from marine reactors and artificial island nuclear power plants were collected.

Fiscal Year 2022

In FY2022, the study covered various aspects such as safety systems, oscillation, construction and maintenance sites, operational areas, long-term operational impacts, nuclear security, operational frameworks, and necessary legal reforms. Additional activities included:

- **Safety Systems**: Requirements for severe accident response, dynamic vs. static safety systems, and countermeasures for sinking scenarios were organized.
- **Oscillation**: The impact on reactors, safety systems, spent fuel pools, turbines, power transmission lines, and mooring systems was analyzed. Solutions will be refined after determining the magnitude of oscillations. Past studies (e.g., MIT analysis and cylindrical oil drilling rigs) suggest minimal oscillation except during severe storms like typhoons.
- **Construction Sites**: Domestic shipbuilding docks were surveyed, and deep draft requirements were identified as a challenge.
- **Maintenance Sites**: Considerations for delivery and maintenance work were compiled.
- **Operational Areas**: External factors like wave patterns at offshore locations 30 km from the coast were reviewed for site selection.
- **Operational Framework**: An estimated crew size of around 300 was derived, considering online maintenance and referencing onshore reactor systems.
- **Long-Term Use**: Fatigue and corrosion in key materials were identified as potential issues, with strategies proposed for easy replacement.
- **Nuclear Security**: Threats such as terrorism were analyzed, and countermeasures like reinforcing the outer hull were considered.
- **Legal Reforms**: While existing nuclear reactor and maritime safety laws can be applied, clarifying definitions for special-purpose vessels, captain's authority, and sea area usage under national property laws is necessary.
- **Social Acceptance**: Safety concerns and benefits vary among stakeholders. Residents of municipalities bordering the floating nuclear plant's marine area were defined as key stakeholders, though detailed surveys were not completed in time for the final report.
- **Information Dissemination**: Efforts to raise awareness about floating nuclear power plants included presentations at the Atomic Energy Society of Japan, newspaper interviews, and public lectures.
- **International Collaboration**: Information sharing with MIT researchers and discussions with overseas organizations interested in the project were conducted. Discussions with JINED explored the potential introduction of floating nuclear plants in Southeast Asia.
- **Insights from the "Mutsu" Nuclear Ship**: Team members visited the Mutsu Science and Technology Museum to gather insights and conduct field research.
- **Other Efforts**: The Electric Power Central Research Institute leveraged the Ministry of Economy, Trade, and Industry's NEXIP initiative to deepen research on oscillation

effects.

3. Proposals and Policies for Strengthening Industrial Competitiveness

At the request of the Council on Competitiveness Nippon (COCN) in early 2020, a three-year study was conducted to explore the feasibility of floating nuclear power plants, which are expected to significantly enhance safety for future nuclear energy utilization. The study involved participation from electric utilities, reactor manufacturers, and shipbuilding companies, enabling a thorough evaluation of the novel concept combining nuclear reactor systems with floating structures. Additionally, cooperation from research institutes such as the Japan Atomic Energy Agency (JAEA) and universities provided valuable insights into the feasibility of floating nuclear power plants.

In December 2022, toward the end of this project, the GX (Green Transformation) Executive Meeting declared a government policy to develop and construct next-generation innovative reactors with new safety mechanisms. The timing of this project aligned with the government's new direction, which raises strong expectations for floating nuclear power plants to contribute to achieving GX goals.

However, current circumstances require electric utilities and manufacturers to focus on restarting existing reactors and extending their operational periods, leaving limited resources for this project. Delaying progress until these priorities are resolved risks further loss of skilled personnel experienced in nuclear power plant design and construction.

While the construction of a floating nuclear power plant is expected to take about 10 years, encompassing basic design, detailed design, permitting, and construction, the need for large-scale engineering on the reactor system is reduced when using existing light water reactors. The basic design phase could be handled by a team of approximately 20–30 members.

To ensure a smooth transition into the basic design phase after the conclusion of this project, the following proposals are made:

Proposals for the Industry

1. **Establish a Startup Organization for Basic Design**
    - A new organization should be formed to advance the basic design of floating nuclear power plants, including requirements, reactor system specifications, floating structure design, and performance evaluations.
    - The organization should consist of rehired retirees from electric utilities and manufacturers, graduate students participating in job-based internships, and a small number of dispatched staff from utilities and manufacturers.
    - Funding for personnel costs and design outsourcing should be secured

through investments in the organization.

    - The floating structure design should be outsourced to ship design companies for further development.
    - The basic design phase should be completed within approximately three years, after which the outcomes will be handed over to a detailed design organization.
2. **Promote Collaboration**
    - Electric utilities should recommend collaboration with the Electric Power Central Research Institute.
    - Reactor manufacturers should grant access to design information of existing reactors for review by the new organization.

Proposals for Universities

1. Encourage student participation in the new organization and foster collaboration through these students.

Proposals for the Ministry of Economy, Trade, and Industry

1. Provide financial support for the basic design conducted by the new organization.
2. Recommend collaboration between the new organization and the Institute of Energy Economics, Japan (IEEJ).
3. Strengthen international cooperation frameworks with organizations such as the OECD-NEA and IAEA.

Proposals for the Ministry of Education, Culture, Sports, Science, and Technology

1. Provide financial support for personnel costs associated with knowledge transfer activities by the new organization.
2. Recommend collaboration between the new organization and JAEA.

Proposals for the Ministry of Land, Infrastructure, Transport, and Tourism

1. Develop laws related to floating structures and marine utilization for floating nuclear power plants.
2. Establish methods for environmental impact assessments.
3. Strengthen cooperation frameworks with international organizations such as the IMO.

Proposals for the Nuclear Regulation Authority

1. Develop safety review guidelines for floating nuclear power plants.
2. Consider applying a type certification system for floating nuclear power plants, which

are less dependent on site-specific factors.