Conceptual Design of a Floating Nuclear Power Plant in Eastern Indonesia: Strategic Site Selection in Remote Areas

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Abstract

Eastern Indonesia has considerable potential for clean energy development but continues to face limitations in electricity infrastructure and energy distribution across islands and remote areas. Floating nuclear power plants (FNPPs) are considered a potential solution because of their flexibility and ability to be deployed near remote islands. This study presents a conceptual design for an FNPP and examines strategic site selection in the waters of eastern Indonesia. The methodology involves analyzing secondary and satellite data on oceanographic conditions (waves, currents, and water depth), logistical accessibility, distance from population centers, potential connections to local electricity grids, and safety and environmental risk mitigation. Wave return-period analysis is used to help identify suitable locations for FNPP deployment and provide preliminary considerations for long-term energy planning in eastern Indonesia. This study is expected to serve as a strategic reference for supporting sustainable energy provision and strengthening national energy security.

Keywords: Eastern Indonesia, Floating Nuclear Power Plant, Oceanography, Remote Areas

INTRODUCTION

Indonesia, the world's largest archipelagic country with more than 17,000 islands [2], faces significant challenges in electrifying remote areas in the eastern region, where access to and the quality of electricity supply are often limited [14], [15]. With population growth and increasing energy demand [17], the need to develop reliable, clean, and sustainable energy sources has become critical. A Floating Nuclear Power Plant (FNPP) offers an innovative solution for improving electricity supply because its floating structure can be relocated to deliver electricity to areas in eastern Indonesia [3], [18]. However, one of the challenges is selecting an FNPP site in the eastern region, which involves considering the environmental conditions of archipelagic waters, limited infrastructure, and long distances from national energy centers. These factors may affect the efficiency of FNPP operations. Therefore, an appropriate assessment is required to determine a power plant location that can meet energy demand, account for technical and environmental aspects, and support sustainable development in the region [10], [16]. In response to these issues, this study focuses on identifying strategic locations for power plant development in eastern Indonesia and aims to recommend an optimal site to support decision-making in national energy infrastructure planning. The FNPP site is expected to meet the relevant criteria and enable efficient planning while maximizing its output [11], [12].

METHODOLOGY

This study collected environmental data, including waves, wind, bathymetry, and geological morphology, from secondary sources and satellite datasets. The data comprised 10 years of wave data from the ERA5 website, analyzed using the Gumbel method to estimate wave return periods [5]; a 29-year wind rose dataset from ERA5 [5]; bathymetric data from Ina-Geoportal, processed using ArcGIS to create mapping layouts [7]; and FNPP planning criteria obtained through a literature review [8], [11].

Two potential FNPP sites have been identified in eastern Indonesia: the waters of Dote and the waters of Warkori, as shown in Figures 1 and 2.

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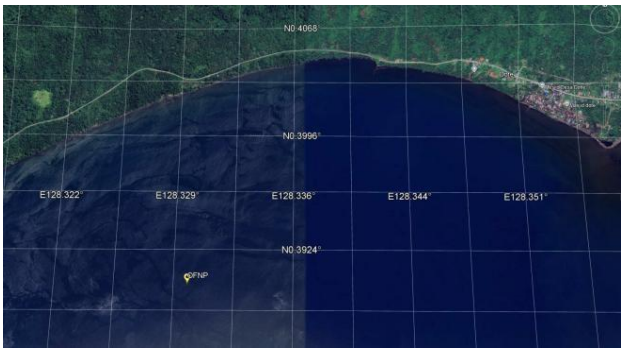


Figure 1. Location of the Floating Nuclear Power Plant in the Waters of Dote

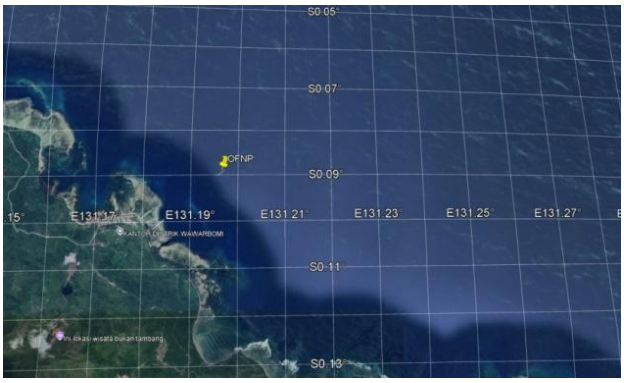


Figure 2. Location of the Floating Nuclear Power Plant in the Waters of Warkori

The coordinates of the proposed FNPP site in the waters of Dote (Figure 1) are E 128.33° and N 0.39°, whereas those of the proposed site in the waters of Warkori (Figure 2) are E 131.2° and S 0.09°.

RESULTS AND DISCUSSION

Hydro-Oceanographic Analysis of the Waters of Dote

Wind

According to ERA5 wind data, winds in the waters off Dote Village predominantly blow from the south to the southwest, with a high frequency (>10%) and speeds commonly ranging from 6 to 9 km/h. This pattern indicates the influence of the southwest monsoon [5], as illustrated in Figure 3.

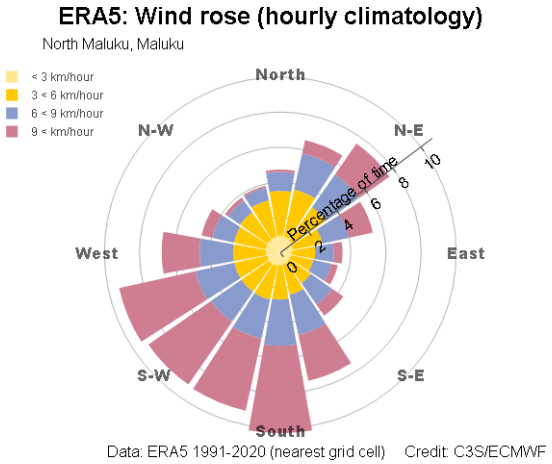


Figure 3. Wind Data for 29 Years (1991–2020) in the Waters of Dote

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Waves

Analysis of wave data obtained from ERA5 [5] yielded the 100-year return-period wave conditions in the waters of Dote. The extreme wave height reaches 1.16 m, with a peak period (Tp) of 7.16 s, as shown in Figure 4.

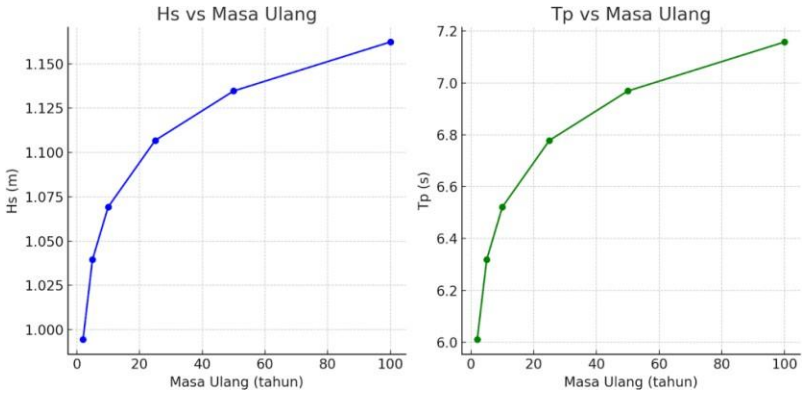


Figure 4. Wave Return Period in the Waters of Dote

Bathymetry

Secondary bathymetric data from observations by Erik Febriarta were used to characterize the waters of Dote, with point B–B′ representing the FNPP site [6]. Figure 5 indicates that the seabed depth at the FNPP site, located 1.45 km from the shoreline, averages 166 m, with a relatively gentle slope of 7.3°.

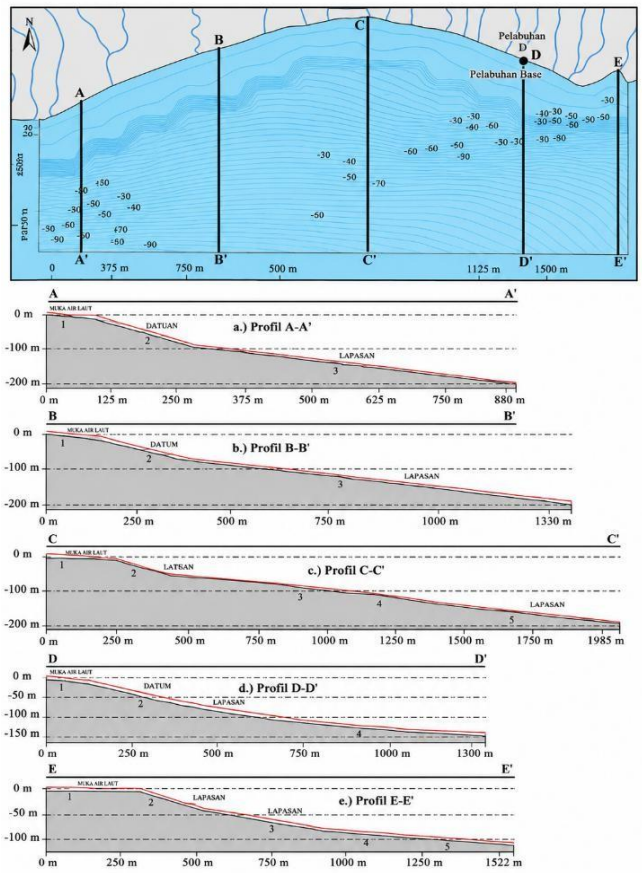


Figure 5. Seabed Relief (Topography) in the Waters of Dote (Halmahera Sea) [12]

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Geological Morphology

Identification of the seabed sediments indicates the presence of a thick layer of soft soil, as shown in Figure 6. This is an important factor to consider in the design of the mooring system [13].

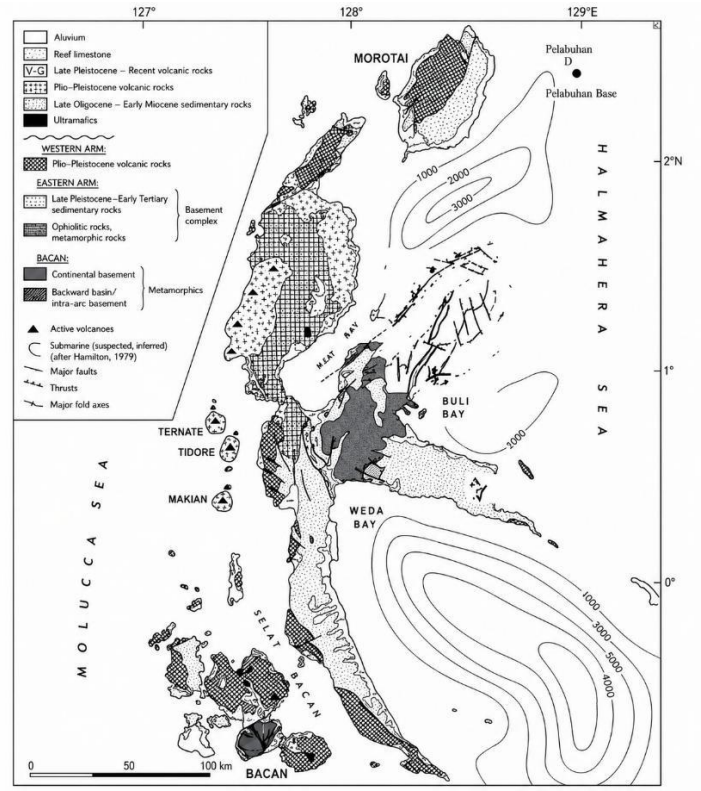


Figure 6. Geological Map of Halmahera Island, Modified from Apandi and Sudana

Hydro-Oceanographic Analysis of the Waters of Warkori

1. Wind

According to the ERA5 wind rose in Figure 7, winds in the waters of Warkori predominantly come from the south, with speeds below 15 km/h [5].

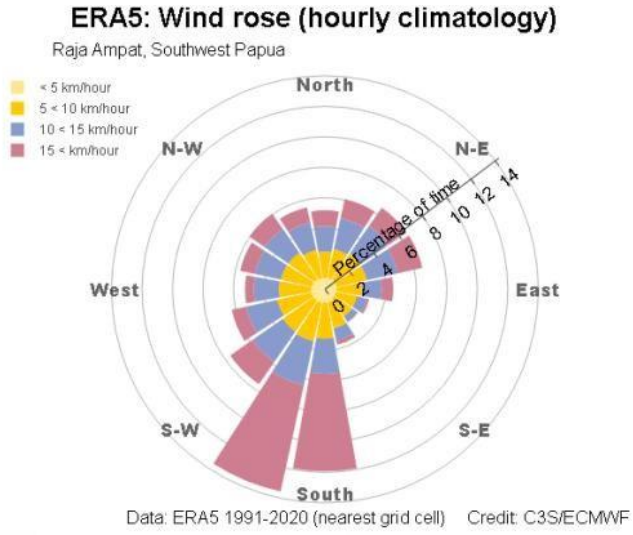


Figure 7. Wind Data for 29 Years (1991–2020) in the Waters of Warkori

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2. Waves

Figure 8 shows that the maximum wave height exceeds 2.05 m, with a period of more than 14 s. These conditions may pose a risk to the FNPP structure because high waves with long periods can cause resonance. Therefore, the FNPP design must account for its natural period to prevent it from coinciding with the wave period [3], [13].

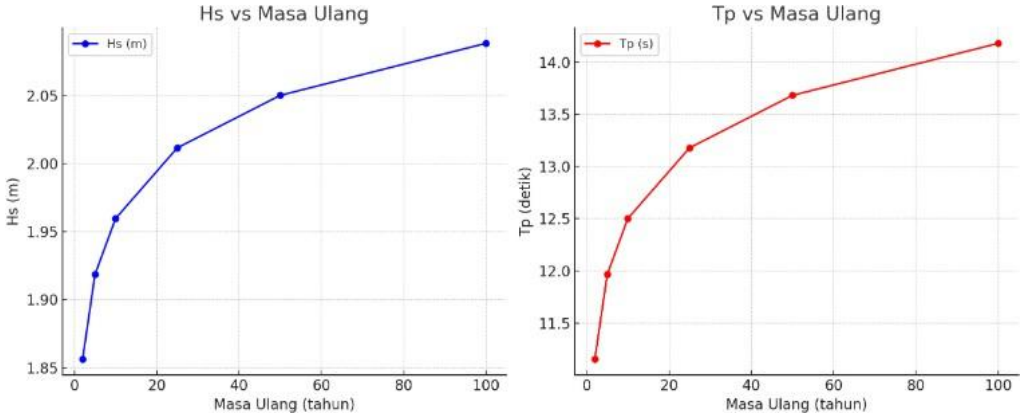


Figure 8. Wave Return Period in the Waters of Warkori

3. Bathymetry

The seabed profile must be understood when designing a Floating Nuclear Power Plant (FNPP) to ensure that the floating structure can operate safely in the waters around Warkori [11]. Figure 9 presents bathymetric data for the waters off Warkori Village. The seabed depth at the proposed FNPP site approaches 200 m, and the site is approximately 2.17 km from the shoreline [7].

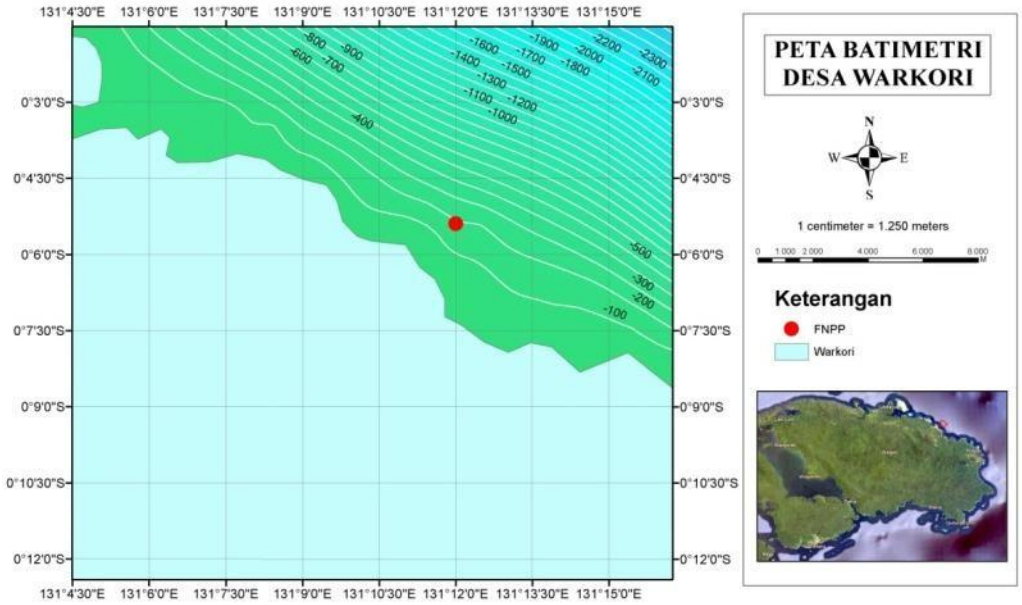


Figure 9. Bathymetric Map of Warkori Village (Ina-Geoportal)

Criteria for Recommending an FNPP (Floating Nuclear Power Plant) Site

The hydro-oceanographic analysis provides the criteria used to recommend a location for the Floating Nuclear Power Plant (FNPP), as summarized in Table 1 [10], [16].

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Table 1. Criteria for Recommending an FNPP Site

FNPP Criteria	Waters of Dote	Waters of Warkori
Wind	Wind speeds in the waters of Dote reach 6–9 km/h, generating relatively small waves and helping maintain the stability of the floating structure under excitation forces	Wind speeds reach <15 km/h, potentially generating waves with larger amplitudes at least greater than those in the waters of Dote
Waves	Based on the wave return-period analysis, the probability of an extreme wave of 1.16 m occurring in the waters of Dote is 1%.	Based on the wave return-period analysis, the probability of an extreme wave exceeding 2.05 m occurring in the waters of Warkori is 1%.
Bathymetry	The FNPP site in the waters of Dote meets the depth criterion, with a water depth of up to 100 m.	The FNPP site in the waters of Warkori also meets the depth criterion, with a water depth of up to 100 m.
Geological morphology	The seabed in the waters of Dote consists of soft soil.	-

Based on Table 1, the waters of Dote are selected as the proposed location for the Floating Nuclear Power Plant (FNPP) because the wave-excitation forces in Dote are lower than those in Warkori. FNPP safety must be assessed against international standards because an FNPP houses a reactor whose malfunction could cause environmental damage and threaten public safety. One relevant safety measure is the protection zone, shown in Figure 10 [8], [11].

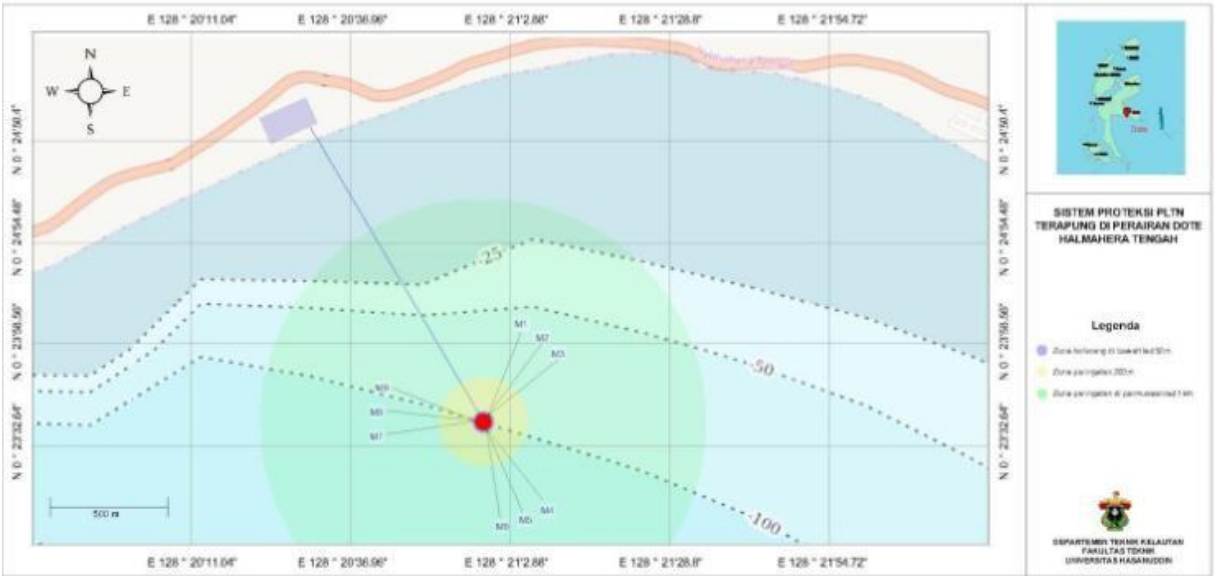


Figure 10. FNPP Protection Zones in the Waters of Dote

As shown in Figure 10, the exclusion zone extends 50 m underwater, the warning zone extends 200 m, and the surface-water warning zone extends 1,000 m from the operational location [11].

FNPP Dimensions

The Floating Nuclear Power Plant (FNPP) is designed as a cylinder with a diameter of 45 m, a total height of 73 m, and a draft of approximately 48.5 m. These dimensions are intended to accommodate extreme 100-year return-period wave conditions (Hs = 1.16 m, Tp = 7.16 s), while providing a minimum freeboard of 15 m to prevent overtopping and ensure safety [3], [13]. The design model is shown in Figure 11.

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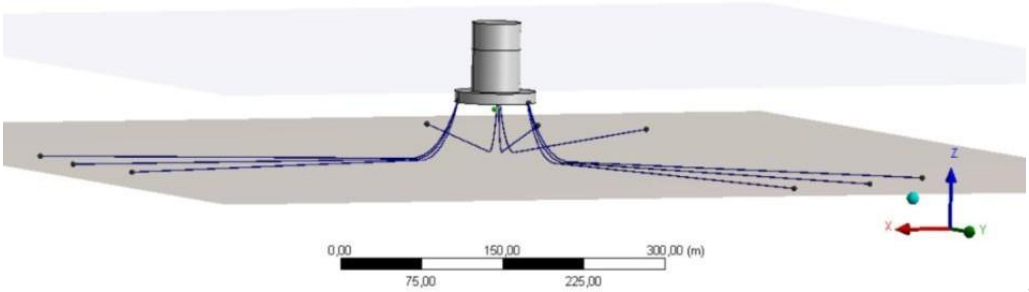


Figure 11. FNPP Structural Design

The FNPP structure is planned to be manufactured at Cosco (Qidong) Offshore Co., Ltd., in Shanghai, China. This shipyard was selected because of its large-scale modular assembly facilities and experience with offshore projects. The transportation route to the installation site is designed to avoid congested waters, with an estimated transit duration of 12 days, as illustrated in Figure 12.



Figure 12. FNPP Transportation Route

In addition, the FNPP installation process is planned to proceed in parallel, allowing the reactor and supporting systems to be fabricated while the floating structure is being prepared. This approach can shorten construction time by up to 33% compared with land-based nuclear power plants [11]. The installation scheme is shown in Figure 13.

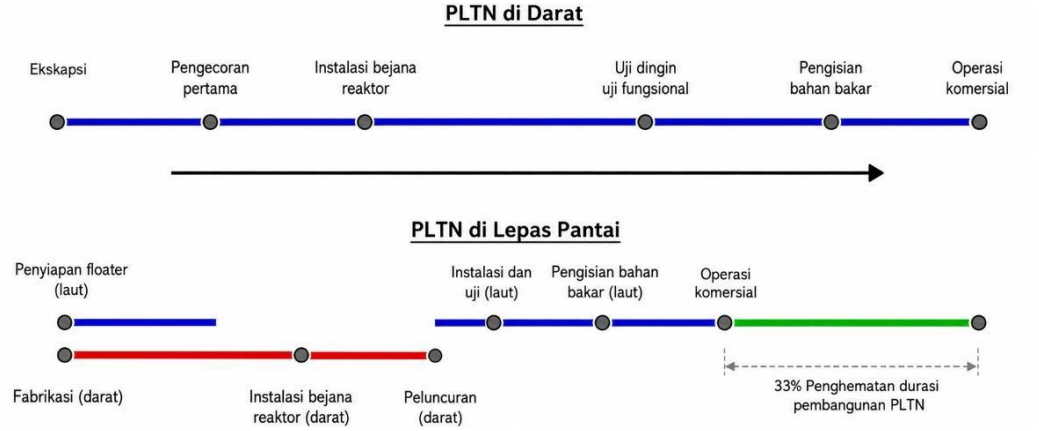


Figure 13. FNPP Installation Scheme

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CONCLUSION

The waters of Dote represent a strategic location for power plant planning because the hydro-oceanographic analysis indicates relatively calm conditions. In addition, the bathymetry in Dote meets the FNPP depth criterion, reaching 100 m, while the gentle seabed slope facilitates FNPP mooring-system design [6], [16]. The transportation distance to Dote is also relatively short compared with Warkori, which may improve vessel fuel-cost efficiency. A Floating Nuclear Power Plant (FNPP) was selected as an energy source for eastern Indonesia because a single FNPP reactor can generate substantial electrical power. It also offers several advantages over land-based nuclear power plants, including a parallel installation process that can improve installation-time efficiency by 33% [3], [11].

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