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# Application of 10 CFR Part 53 to the Siting of Floating Nuclear Power Plants: A Risk-Informed and Performance-Based Approach

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## 1. Introduction

Floating Nuclear Power Plants (FNPPs) are emerging as an innovative and flexible energy supply alternative due to their ability to be deployed in any location with access to the sea, enabling the generation and distribution of electricity. FNPPs offer a stable power supply even in regions where the construction of land-based nuclear power plants is challenging, such as the Arctic or remote island communities. As a result, several countries, including the United States and Russia, have been developing and utilizing FNPPs in various forms, including military vessels and icebreakers, reflecting growing international interest in this technology [1]. Moreover, FNPPs, being deployed offshore, present advantages over land-based Nuclear Power Plants (NPPs), including reduced public opposition and fewer site selection constraints [2].

However, the domestic development of FNPPs is hindered by a lack of design and operational experience, as well as insufficient regulatory preparedness for licensing. Given that FNPPs operate in a unique maritime environment, dedicated regulatory requirements are necessary. However, the current nuclear safety regulations and licensing standards in Korea have been primarily established for land-based Light Water Reactors (LWRs). As a result, existing regulatory frameworks alone may not be sufficient to ensure the safety of FNPPs throughout their design and construction phases. Therefore, it is imperative to establish a legal and regulatory foundation to facilitate the safety validation, development, and operation of FNPPs.

This study examines the applicability of the newly proposed regulatory framework, 10 CFR Part 53, currently being developed by the U.S. Nuclear Regulatory Commission (NRC), to the siting evaluation of FNPPs [3,4]. 10 CFR Part 53 is a Technology-Inclusive (TI) framework that does not impose restrictions on specific reactor designs or technologies. Additionally, it adopts a Risk-Informed and Performance-Based (RIPB) approach, which enhances regulatory flexibility by addressing the limitations of traditional deterministic methods. In particular, for siting requirements, this framework shifts from a deterministic evaluation approach to a Probabilistic Risk Assessment (PRA) methodology, enabling a more quantitative assessment of potential accident scenarios and environmental risks. This shift is expected to introduce a significant transformation in the regulatory approach to nuclear facility siting.

However, the siting requirements outlined in 10 CFR Part 53 do not specifically address the unique operational conditions of FNPPs, nor do they include regulations tailored to floating structures in offshore environments. Therefore, additional modifications and detailed interpretations are essential to account for the specific floating design and maritime operating conditions of FNPPs.

This study aims to compare the PRA-based siting evaluation approach in 10 CFR Part 53 with conventional deterministic methods, identifying the key differences and determining the additional requirements that must be incorporated into the Safety Analysis Report (SAR) for FNPP licensing. Furthermore, regulatory challenges associated with establishing a licensing framework for FNPPs will be discussed, with the goal of ensuring that FNPPs can contribute to a stable energy supply within Korea's nuclear regulatory framework in the future.

## 2. Site Evaluation for FNPP Licensing and Need for New Framework

The site safety evaluation for nuclear power plant construction is addressed in Chapter 2 of the SAR, which includes a comprehensive assessment across five key areas: seismology and geology, site location, meteorology, hydrology, and man-made hazards [5]. The SAR preparation guidelines are based on Regulatory Guide (RG) 1.70, while site approval criteria are established in 10 CFR Part 100.

In the conventional site evaluation process, key aspects such as terrestrial geological and topographical conditions, seismic hazards, interactions with nearby industrial facilities, and population distribution are thoroughly assessed. However, these site criteria are exclusively designed for large land-based nuclear power plants. Therefore, for the siting and licensing of FNPPs, which are deployed offshore, the development of a new regulatory framework that accounts for marine environmental characteristics is essential [6].

FNPPs are fundamentally exposed to different environmental conditions compared to land-based nuclear power plants. As such, the licensing process for FNPPs must consider additional marine-specific factors, including wave impacts from ocean winds, tsunami risk assessments, corrosion or structural degradation due to saltwater exposure, and the stability of mooring systems. Furthermore, FNPPs differ significantly from land-based nuclear power plants in terms of the establishment of Exclusion Area Boundaries (EAB) and Low Population Zones (LPZ), as well as the assessment of radiological impacts. These distinctions necessitate the establishment of new regulatory criteria tailored to FNPPs [7].

*2.1. 10 CFR Part 53 Rulemaking in the U.S.*

Recently, the NRC has been shifting away from the traditional deterministic, large Light Water Reactor (LWR)-centric regulatory approach. Instead, it is developing a technology-neutral, risk-informed, and flexible regulatory framework under 10 CFR Part 53, designed to accommodate a wide range of advanced reactors, as illustrated in Figure 1 [8].

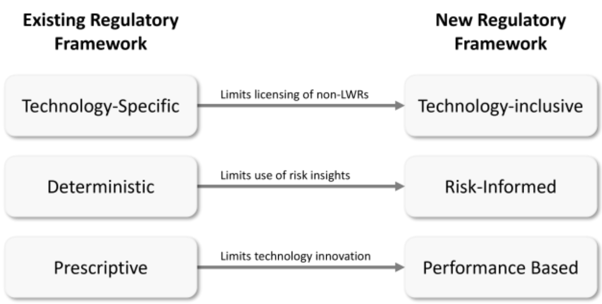


Figure 1 Comparison of Existing and Future Regulatory Frameworks for Advanced Reactor Licensing

The primary objective of 10 CFR Part 53 is to accommodate the diverse technological characteristics of innovative advanced reactors while addressing the limitations of traditional rigid regulatory frameworks. This is achieved through PRA-based external hazard evaluations and performance-based design requirements.

As illustrated in Figure 2 [9], 10 CFR Part 53 is structured into 11 subparts (Subpart A to Subpart K).

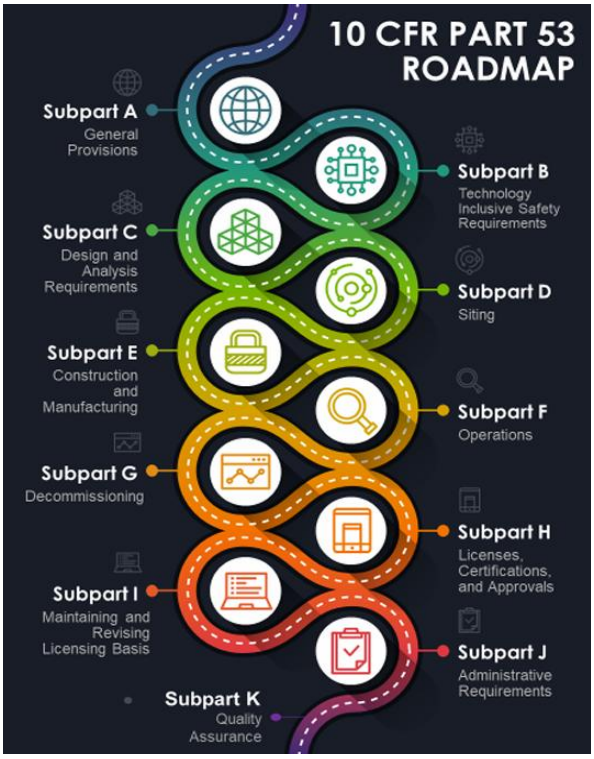


Figure 2 10 CFR Part 53 Roadmap

Compared to the deterministic approach adopted in the 10 CFR Part 50 and Part 52 regulatory frameworks, 10 CFR Part 53 introduces the following key distinctions:

First, 10 CFR Part 53 adopts a Technology-Inclusive (TI) approach, meaning it is not limited to specific reactor technologies. Traditional regulatory frameworks have been established based on deterministic design criteria, which posed challenges in licensing advanced reactors with innovative technological characteristics. In contrast, 10 CFR Part 53 defines performance objectives that are universally applicable to all reactor technologies, enabling designers to focus on performance and safety rather than adhering to prescriptive technology-specific requirements. This approach facilitates the development and deployment of diverse reactor designs.

Second, 10 CFR Part 53 incorporates a RIPB regulatory approach. Traditional deterministic methods restrict accident scenario assessments and environmental factors within a limited predefined scope. However, a Risk-Informed approach leverages PRA results, allowing for a more quantitative evaluation of various accident scenarios and environmental impacts throughout the design and operational phases. Instead of mandating specific compliance methods or technologies, this framework prioritizes the achievement of safety performance objectives, thereby enhancing technological flexibility and fostering innovation in design and operation.

As outlined above, 10 CFR Part 53 extends the application of PRA beyond design evaluation to include site selection, population density considerations, and environmental conditions, introducing a more flexible evaluation framework that overcomes the limitations of traditional deterministic approaches.

*2.2. Changes and Discussions on PRA-based Siting Requirements*

According to the proposed rule of 10 CFR Part 53 released to date, Subpart D addresses Siting Requirements and is structured as shown in Table 1.

Table 1 Subsections of Subpart D in 10 CFR 53 as Drafted by the NRC

| Section number | Section title |
|---|---|
| § 53.500 | General siting and siting assessment |
| § 53.510 | External hazards |
| § 53.520 | Site characteristics |
| § 53.530 | Population-related considerations |
| § 53.540 | Siting interfaces |

Unlike RG 1.70 and 10 CFR Part 100, which have traditionally employed a deterministic approach focused on large land-based nuclear power plants, the newly proposed rule introduces a more quantitative and site-specific assessment framework. It mandates the evaluation of natural and human-induced external hazards, as well as geological and seismic characteristics, through site-specific assessments rather than relying solely on predefined deterministic criteria.

This new framework enables risk-informed evaluation of Licensing Basis Events (LBEs), ensuring that external site hazards are assessed in a quantitative, risk-based manner. Table 2 presents a comparison of conventional site criteria and the proposed rule, highlighting key changes in siting requirements.

Table 2 Difference in Site Requirements Specified in 10 CFR 100 and 10 CFR 53

| Category | Existing Site Criteria (10 CFR 100) | Proposed rule (10 CFR 53) |
|---|---|---|
| Approach | Deterministic | Risk-informed and performance-based approach |
| Applicable Reactors | Regulation focused on LWRs | Technology-inclusive, covering advanced reactors (e.g., SMRs, MSRs) |
| Evaluation Methodology | Deterministic, applying fixed criteria (e.g., seismic hazards, flooding) | Actively utilizes PRA, systematically considering external hazard probabilities and variations |
| Site-Specific Assessment | Specifies fixed technical criteria for individual risks such as seismic hazards, geological characteristics, and flood risks | Site-specific PRA, assessing external hazards and site-specific characteristics while providing flexibility for achieving safety design objectives |
| Population and Exclusion Area (EA) | Fixed criteria for EA and LPZ settings | The PRA-based approach provides regulatory flexibility by allowing the integration of the EA and LPZ into the site boundary, provided that radiation dose criteria are met. |

This represents a significant shift in site requirements, indicating that the RIPB approach enables a more comprehensive integration of the uncertainties and unique environmental conditions associated with FNPPs' offshore deployment.

## 3. Ensuring Flexibility in FNPP Siting Regulations through a RIPB Approach

As discussed thus far, the RIPB approach of 10 CFR Part 53 extends beyond traditional design criteria by systematically analyzing risks based on actual operating conditions and accident scenarios. By focusing on achieving safety performance objectives, this framework serves as an important reference for the siting evaluation and licensing of FNPPs, which operate under fundamentally different environmental conditions compared to land-based nuclear power plants.

The unique operational environment of offshore deployment introduces additional external hazards, such as waves, ocean currents, and typhoons, which are not typically encountered by land-based nuclear power plants. Furthermore, unlike fixed terrestrial plants, FNPPs must account for micro-displacements and stability concerns caused by waves and tidal forces [10].

To comprehensively address these challenges, a risk-based approach that quantitatively assesses the likelihood and impact of each hazard scenario is more effective than a purely deterministic methodology.

Additionally, the performance-based approach of 10 CFR Part 53 enables regulatory flexibility, allowing safety requirements to focus on achieving performance objectives rather than prescribing specific technologies or systems. This is particularly advantageous for FNPPs, as they can be designed and operated in various configurations depending on deployment location, intended use, and reactor type. A performance-based framework allows for the optimization of safety criteria tailored to each FNPP deployment scenario.

However, despite these advantages, specific criteria and evaluation parameters for offshore siting have yet to be fully established. Therefore, a key challenge moving forward is the development of quantitative risk metrics and qualitative assessment methodologies to ensure the rigorous evaluation of offshore risks and performance objectives for FNPP licensing.

The NRC has actively discussed the establishment of a flexible regulatory framework through various reports and white papers, aiming to maintain fundamental site requirements while incorporating design and environmental characteristics [11]. For instance, if PRA results demonstrate compliance with the 25 rem Total Effective Dose Equivalent (TEDE) criterion, the proposed framework allows for the integration of the Exclusion Area (EA) and LPZ within the site boundary, thereby significantly enhancing regulatory flexibility.

Unlike conventional deterministic approaches, this framework explicitly permits the consolidation of EA and LPZ into a single radiological protection zone, provided that the TEDE 25 rem dose criterion is met. Table 3 presents a comparison of dose requirements specified under 10 CFR 100 and 10 CFR 53.

Table 3 Dose criteria required by 10 CFR 100 and 10 CFR 53

| | **10 CFR 100 (Existing)** | **10 CFR 53 (Newly Proposed)** |
|---|---|---|
| EA | In the event of an accident, an individual within the exclusion area must not receive a dose exceeding 25 rem (250 mSv) over 2 hours. | If the 25 rem TEDE dose criterion is met within 2 hours, the EA and LPZ may be integrated into the site boundary. |
| LPZ | An individual must not receive a dose exceeding 25 rem (250 mSv) over the entire duration of the passing radioactive plume. | |
| Population Center Distance | The minimum distance from the reactor to the outer boundary of the nearest population center must be at least 1⅓ times the EA boundary distance. | Same standard applies. |
| TEDE | 25 rem (250 mSv) | 25 rem (250 mSv) |

The detailed assessment of site safety for nuclear power plant construction is addressed in Chapter 2 of the SAR, which is structured based on extensive investigations across five key areas: Geography and Population (2.1), Nearby Industrial, Transportation, and Military Facilities (2.2), Meteorology (2.3), Hydrology (2.4), and Geology, Seismology, and Geotechnical Engineering (2.5).

Currently, SAR preparation follows the guidelines established in RG 1.70 by the NRC. However, as RG 1.70 was developed primarily for land-based nuclear power plants, modifications are necessary for each chapter to appropriately reflect the unique characteristics of FNPPs. The following adjustments are therefore considered essential.

*3.1. Geography and Demography: Population impact assessment considering marine environment and establishment of offshore EAB*

Given the offshore deployment of FNPPs, it is essential to establish a new site evaluation framework that extends beyond traditional land-based site assessment methods and incorporates maritime environmental conditions and operational characteristics. Achieving this requires clear delineation of roles among developers, regulators, and regulatory agencies, along with close collaboration between these stakeholders.

First, developers must conduct a comprehensive PRA that thoroughly accounts for the unique hazards of the marine environment during the FNPP design and site selection stages. This includes analyzing external events specific to the deployment location, such as typhoons and tsunamis, and assessing the dynamic behavior of floating structures under operational and accident conditions. Developers should also prepare detailed safety justification materials to support regulatory approval, particularly regarding the potential mobility of FNPPs and their structural responses to environmental forces.

Meanwhile, regulators can reference the RIPB framework of 10 CFR Part 53, currently under discussion by the NRC, when formulating site approval criteria for FNPPs. It is advisable to incorporate PRA-based risk assessment methodologies, considering factors such as geographic conditions, maritime transport routes, port facilities, and interactions with military vessels. This approach would enable a more comprehensive regulatory framework that accounts for the unique maritime context of FNPP deployment. Additionally, it would support discussions on establishing an Offshore Exclusion Zone within the site boundary, specifically tailored to the operational characteristics of FNPPs.

Furthermore, regulatory agencies must progressively adapt evaluation methodologies and institutional frameworks to accommodate the distinct characteristics of FNPPs, which differ significantly from conventional land-based nuclear plants. Leveraging PRA-based site assessment approaches will be critical to effectively evaluating the diverse factors influencing FNPP site selection and licensing. To this end, it is necessary to systematically refine evaluation criteria and licensing procedures tailored to FNPP-specific design and operational attributes, while also enhancing regulatory expertise in offshore nuclear technologies.

*3.2. Nearby Industrial, Transportation, and Military Facilities: Analysis of maritime transportation routes, port activities, military vessel operations, and their mutual interactions*

In conventional RG 1.70-based SARs, the assessment of nearby industrial facilities and transportation routes has been conducted using fixed distance criteria and deterministic evaluations of Design Basis Accidents (DBAs) to analyze potential interactions with the NPP site.

However, under the 10 CFR Part 53 regulatory framework, PRA-based risk-informed assessments are actively incorporated into the evaluation of man-made hazards. This approach allows for a probabilistic analysis of accident scenarios at nearby industrial facilities, enabling a quantitative evaluation of potential risks. Consequently, site-specific risk levels must be clearly defined and justified by integrating design features and programmatic controls, ensuring that risks remain within an acceptable threshold.

Furthermore, FNPPs deployed offshore may be exposed to additional hazards, such as maritime traffic routes, offshore resource extraction facilities, and military operational areas, which could increase the risk of collisions or military-related incidents. Therefore, continuous monitoring of vessel traffic, fishing activities, and military exercises in the vicinity of the FNPP is essential. Additionally, regulatory frameworks should require the establishment of risk mitigation measures, such as navigational avoidance protocols and safety buffer zones, to ensure that potential hazards are systematically managed.

*3.3 Meteorology: Analysis of maritime-specific weather phenomena such as marine layer, precipitation, mixing height, and marine boundary layer inversion.*

In conventional SARs, extreme weather conditions have been assessed using a conservative and deterministic approach, relying on meteorological data from the past 100 years. However, under the 10 CFR Part 53 regulatory framework, PRA-based meteorological assessments will be implemented. Particularly, when defining design-basis external hazard levels, uncertainties and variabilities in the frequency and intensity of meteorological phenomena are expected to be systematically incorporated.

This shift allows for a more realistic and risk-informed approach to establishing design criteria, especially for critical meteorological factors in offshore environments, such as strong winds, storm surges, and typhoons. By quantitatively evaluating the potential frequency and intensity of these weather events, FNPP designs can be optimized to better reflect actual environmental conditions.

*3.4 Hydrology: Assessment of tsunamis, seabed strata and stability, and impacts on the marine ecosystem.*

In conventional SARs, hydrological evaluations have been conducted deterministically, focusing on land-based factors such as rainfall, river flooding, and inland inundation. However, since FNPPs are deployed and operated offshore, greater emphasis must be placed on marine hydrological characteristics, including tsunamis, tides, waves, and ocean currents.

For instance, it is critical to assess how dynamic loads acting on the floating structure may impact safety systems and cooling water intake. Additionally, the potential effects of sudden seawater temperature fluctuations, sea level rise or fall, and extreme oceanographic events on radiation management and operational stability must be comprehensively evaluated.

Furthermore, under the 10 CFR Part 53 regulatory framework, hydrological hazard assessments will adopt a probabilistic approach, allowing for a systematic evaluation of uncertainties and variations in potential offshore hazard scenarios. This shift is expected to facilitate the development of site-specific, risk-informed design criteria for hydrological events, ensuring that assessments are quantitative and reflective of actual marine conditions.

*3.5 Geology, Seismology, and Geotechnical Engineering: Seabed Geological and Seismological Assessment for FNPP*

Since FNPPs are not installed on terrestrial ground but are instead moored and docked to the seabed, a comprehensive geological and geotechnical site investigation may not be necessary. Instead, the assessment can primarily focus on the stability of the mooring system and provide supporting justifications accordingly. Specifically, the analysis should prioritize the potential impacts of seismic events originating from adjacent land areas or the seabed on mooring structures, while evaluating key geotechnical properties such as liquefaction potential, shear strength, and settlement behavior. Demonstrating that structural integrity can be maintained over extended operational periods under extreme conditions would be sufficient for regulatory approval. This approach is expected to significantly reduce the scope of geological and seismic investigations compared to land-based nuclear power plants, thereby providing substantial advantages in the FNPP design and licensing process.

Additionally, it is crucial to assess the dynamic effects of seabed fault activity and earthquakes on FNPP buoyancy and mooring stability, and to implement appropriate design measures to mitigate these risks.

Therefore, under the 10 CFR Part 53 regulatory framework, a customized geotechnical and seismic evaluation framework tailored to FNPPs' offshore deployment is required, rather than applying conventional land-based reactor site assessment criteria. To achieve this, a site-specific, PRA-based evaluation methodology must be systematically incorporated into the licensing process.

## 4. Conclusions

As discussed throughout this study, the development and implementation of 10 CFR Part 53 mark a transition from traditional deterministic evaluation methods to a more flexible, risk-informed, and performance-based regulatory framework. This shift is particularly significant for the licensing of FNPPs, which operate in a fundamentally different environment compared to conventional land-based nuclear power plants.

In terms of site evaluation, unlike the criteria established under RG 1.70 and 10 CFR 100, the new regulatory framework actively incorporates PRA methodologies across all evaluation areas, including industrial and transportation hazards, meteorological conditions, hydrological events, and seismic stability assessments.

For FNPPs, ensuring long-term structural stability and operational safety requires a comprehensive assessment of seabed geology, mooring and docking structures, and hydrodynamic forces. Moreover, by accounting for the uncertainties and variabilities associated with maritime-specific hazards, a more realistic and adaptable licensing process can be established. Consequently, the PRA-based regulatory approach under 10 CFR Part 53 can serve as a critical reference for FNPP licensing, contributing to the development of site-specific evaluation frameworks and risk management strategies for offshore deployment.

Particularly in the context of FNPP siting evaluation, a key advantage is the significant reduction in site investigation requirements compared to land-based nuclear plants. However, achieving this requires the systematic development of PRA guidelines tailored to offshore sites, safety validation criteria for mooring and docking systems, and regulatory frameworks addressing external hazard uncertainties. Given that FNPPs operate in an environment fundamentally different from land-based reactors, regulatory requirements should not merely be adapted from existing criteria but rather be optimized to reflect the unique characteristics of offshore deployment.

To ensure the effective implementation of this approach, it is essential to establish FNPP-specific evaluation metrics, external event scenarios, and risk quantification models. Additionally, regulatory authorities and industry stakeholders must develop a common framework for applying these methodologies in licensing assessments. Ultimately, a comprehensive regulatory framework must be established to balance safety regulations and industrial requirements, ensuring that FNPPs become a reliable and sustainable energy source while addressing the unpredictable challenges of offshore environments.

In this study, we analyze the format and content of SARs to derive site evaluation criteria applicable to FNPPs, considering both existing national nuclear regulatory requirements and offshore environmental factors. Furthermore, we outline chapter-specific applications of current regulatory provisions to FNPP site permitting. Given that the regulatory framework for FNPP siting must be developed at a national level, this study is expected to serve as a foundational reference for future regulatory discussions on FNPP site evaluation and licensing frameworks.

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