Revision of Siting Criteria and Status of Emergency Planning Zone in Korea: Implications of Small Modular Reactors

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ABSTRACT

Small modular reactors (SMRs) are gaining increasing attention as a low-carbon and flexible energy source capable of supporting emerging applications such as data centers, hydrogen production, and industrial heat supply. Many SMR development concepts emphasize siting reactors near energy demand centers to improve system efficiency and economic viability. However, existing nuclear regulatory frameworks in many countries were originally developed for large conventional reactors and may impose constraints on such deployment strategies. This study examines how two key regulatory frameworks in Korea, nuclear facility siting criteria and emergency planning zone (EPZ) requirements, interact to influence the feasibility of near-demand SMR deployment. A regulatory policy analysis approach is applied through a review of relevant Korean statutes, administrative regulations, and legal interpretations, combined with a comparison to international regulatory practices including those of the International Atomic Energy Agency (IAEA) and the U.S. Nuclear Regulatory Commission (NRC). The analysis shows that siting criteria in Korea combine dose-based evaluation with fixed population-related distance requirements, including population center distance (PCD) and a regional population density limit within a 50 km radius of the plant site. At the same time, EPZ regulations define fixed EPZs of 3-5 km for the precautionary action zone (PAZ) and 20-30 km for the urgent protective action planning zone (UPZ). Although these frameworks pursue different regulatory objectives, their combined application may significantly limit the feasibility of siting SMRs near industrial demand centers or urban areas. Based on these findings, the study proposes several regulatory modernization options. These include conditional application of the PCD requirement based on accident consequence analysis, adoption of graded EPZ approaches reflecting reactor characteristics, and integrated risk assessment for multi-module SMR sites. In addition, the study highlights that the current population-density-based siting requirement may remains a major constraint event if EPZ regulations are modernized.

The results suggest that regulatory modernization incorporating risk-informed and performance-based approaches could enhance flexibility for SMR deployment while maintaining public safety objectives. Such improvements would be particularly important for enabling near-demand siting of SMRs in Korea.

Keywords: *small modular reactor, emergency planning zone, siting criteria, near demand center*

1 INTRODUCTION

Global changes in climate policy, industrial structure, and electricity demand are reshaping energy systems. Future energy systems must simultaneously provide low-carbon electricity, reliable baseload generation, and operational flexibility for emerging applications. The rapid expansion of data centers and artificial intelligence computing is further accelerating the demand for stable and low-carbon electricity supply [1]. International energy outlooks suggest that these new electricity demands could significantly reshape power systems. In this context, small modular reactors (SMRs), typically defined as reactors with electrical output below 300 MWe, are gaining attention worldwide due to their potential advantages such as standardization, modular construction, and flexible deployment [2]. The strategic role of SMRs extends beyond electricity generation when integrated with non-electric applications such as industrial process heat, hydrogen production, and district heating [3]. International organizations have identified nuclear energy as a viable energy source for high-temperature industrial heat and hydrogen production, particularly for advanced reactor concepts [4]. However, industrial heat applications require proximity between the reactor and the heat demand center due to heat transport limitations and economic considerations. Therefore, near-demand siting is often a necessary condition for the economic viability of SMR-based energy systems. Despite this potential, existing regulatory frameworks developed primarily for large conventional nuclear power plants may constrain such deployment concepts. This paper examines two regulatory frameworks in Korea that significantly influence SMR siting: nuclear facilities siting criteria and EPZ requirements.

The increasing interest in SMRs has also triggered regulatory discussions worldwide regarding the suitability of existing nuclear regulatory frameworks originally developed for large light-water reactors. Theses frameworks often rely on deterministic design assumptions and fixed distance requirements that may not adequately reflect the improved safety characteristics and smaller source terms of advanced reactors.

In particular, SMR deployment concepts frequently emphasize proximity to industrial energy demand centers such as hydrogen production facilities, desalination plants, and data centers. Theses deployment models challenge conventional siting approaches that assume large exclusion zones around nuclear facilities.

This paper addresses the following research questions: (1) what regulatory objectives and technical criteria underlie siting and EPZ in Korea? (2) How does the interaction between these two systems affect SMR deployment scenarios? (3) What regulatory modernization options could improve regulatory flexibility while maintaining safety objectives?

2 RESEARCH METHODOLOGY

This paper adopts a regulatory policy analysis approach combining several analytical methods: (1) Analysis of relevant Korean statutes and administrative regulations, (2) review of authoritative legal interpretations, (3) comparison with international regulatory frameworks including IAEA guidance and U.S. NRC regulations, and (4) review of industrial deployment scenarios involving SMRs. The primary regulatory frameworks examined include: (1) Article 20-2 of the Korean Act on Physical Protection and Radiological Emergency, (2) Korean Siting Criteria for Nuclear Facilities, and (3) population-related siting criteria including LPZ and PCD definitions.

The study adopts a qualitative regulatory analysis framework consisting of three analytical steps. First, relevant Korean statutes and regulatory guidance documents are reviewed to identify the legal basis of siting criteria and EPZ requirements. Second, the regulatory objectives and functional roles of each framework are analyzed. Third, the interaction between the two frameworks in evaluated in the context of SMR deployment scenarios near energy demand centers.

3 INTERNATIONAL BACKGROUND OF SITING CRITERIA AND EPZ

Historically, nuclear power plant siting criteria were developed to ensure that public radiation exposure remains within acceptable limits during design basic accidents. Key spatial zones in conventional siting frameworks include: exclusion area boundary (EAB), low population zone (LPZ), and population center distance (PCD). In the United States, these concepts are codified in regulatory provisions such as 10 CFR 100.11 [5]. Historically, these spatial criteria were developed primarily for large light-water reactors with relatively large source terms.

The EPZ, however, are primarily intended for emergency preparedness and protective action planning rather than reactor design requirements. IAEA guidance defines two main emergency planning zones [6]: precautionary action zone (PAZ) up to 5 km and urgent protective action planning zone (UPZ) up to 30 km. Recent discussions in advanced reactor regulation consider the possibility of graded emergency planning approaches for smaller lower-risk facilities [7].

Recent regulatory discussions in the United States have explored the possibility of alternative EPZ approaches for advanced reactors. The U.S. NRC has acknowledged that smaller source terms and enhanced safety features may justify the use of performance-based EPZ sizing rather than fixed radius requirements. Similar discussions have also emerged within the IAEA regarding graded emergency preparedness approaches for advanced reactors.

4 ANALYSIS OF REGULATORY FRAMEWORK IN KOREA

In Korea, siting criteria are specified through administrative regulations that define population-related distance requirements. The PCD is defined as the distance from the reactor site to the nearest boundary of a densely populated area containing at least 25,000 residents. A key requirement is that the PCD must be at least four-thirds of the distance from the outer boundary of the LPZ. This framework combines two regulatory approaches: dose-based evaluation and fixed distance requirements. While dose-based criteria can reflect improvements in reactor safety design, fixed distance rules may limit the regulatory recognition of such improvements. The siting criteria of nuclear facilities in Korea is presented in Figure 1.

Under nuclear power plant siting regulations in Korea, a population center is defined as an area with a total population of 25,000 or more and a population density exceeding the national average. A nuclear power plant must be located such that the distance from the reactor to the outer boundary of the nearest population center is at least four-thirds of the distance from the reactor to the outer boundary of the low population zone. In addition, the average population density within a 50 km radius of the plant site must not exceed the national average during the plant's operating period. Because these requirements impose both minimum separation from population centers and a regional population density constraint, they make the siting of nuclear power plants near densely populated urban areas difficult under the demographic conditions of Korea.

Plus, under nuclear power plant siting regulations in Korea, the average population density within a 50 km radius of the plant site must not exceed the national average. Since national average population density in Korea is approximately 510 persons per km^2, the total population within a 50 km radius (approximately 7,850km^2) would need to be around 4 million people or fewer to potentially satisfy this criterion.

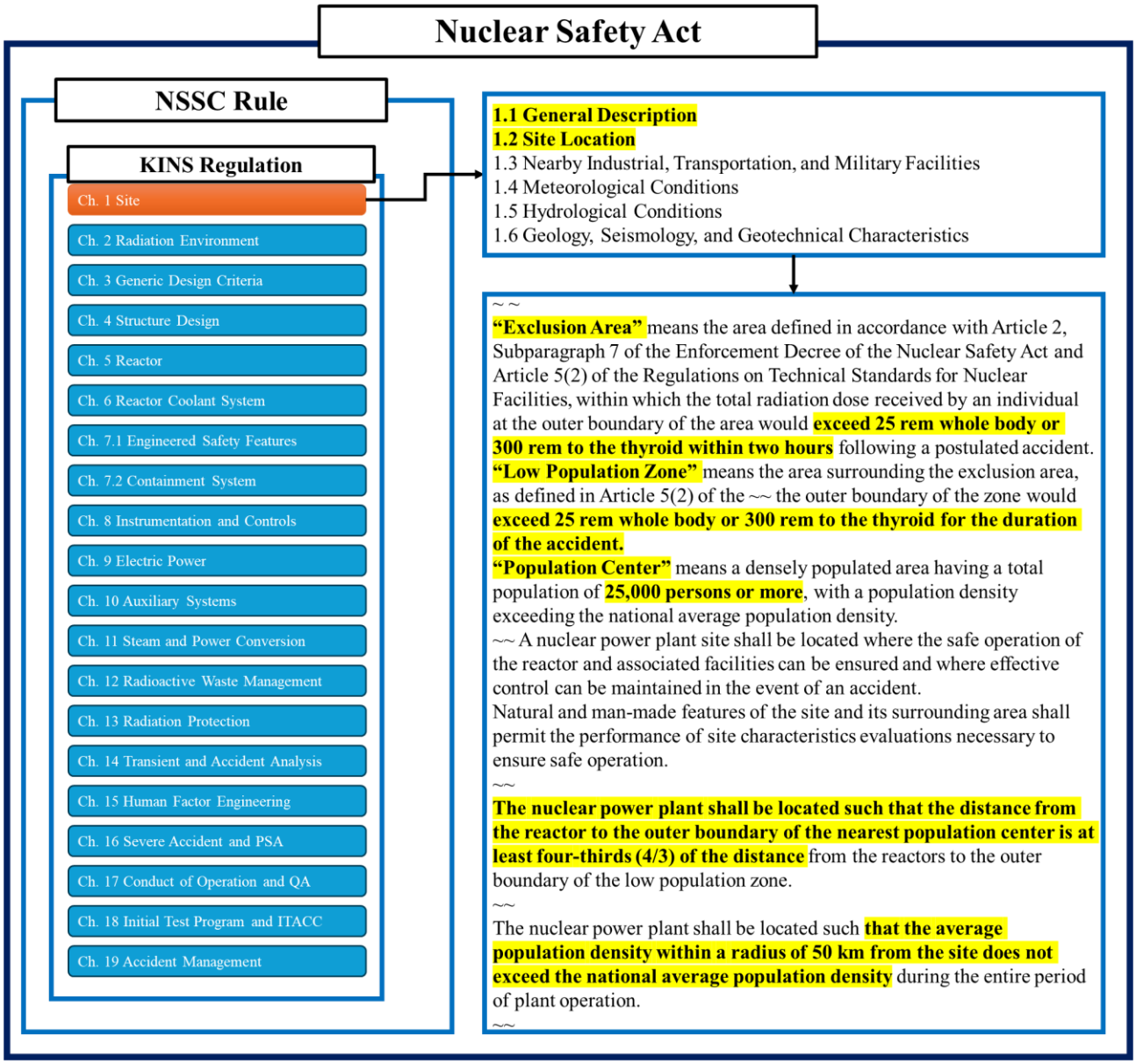

Figure 1: Siting Criteria of Nuclear Facilities in Korea

EPZ system in Korea is established under the *Act on Physical Protection and Radiological Emergency*. For nuclear power plants and related facilities, the following EPZs are defined: PAZ from 3 km to 5 km and UPZ from 20 km to 30 km. Legal interpretations indicate that operators cannot arbitrarily modify these ranges. Although the EPZ framework emphasizes emergency preparedness and coordination with local governments, fixed radius requirements may impose significant constraints on SMR deployment near demand centers.

Although the siting criteria and the EPZ framework pursue different regulatory objectives, their combined application creates spatial constraints that may significantly affect SMR deployment. The siting criteria focus on limiting potential public radiation exposure during design basic accident, whereas the EPZ framework aims to ensure effective emergency response and protective actions during both design basis accidents and severe accidents. When applied simultaneously, these two frameworks may lead to overlapping spatial restrictions. The EPZ regulation of nuclear facilities in Korea is presented in Figure 2.

Act on Physical Protection and Radiological Emergency

(1) The Nuclear Safety and Security Commission shall determine and announce an area that serves as a base for establishment of a radiological emergency planning zone by nuclear facilities (hereinafter referred to as "base area"). In such cases, if nuclear facilities consist of an electricity generating reactor and relevant facilities, the base area shall be determined in accordance with each of the following:

1. **Precautionary action zone**: **Area of a 3 to 5 kilometer radius** from the place in which the electricity generating reactor and relevant facilities are installed;
2. **Urgent protective action planning zone: Area of a 20 to 30 kilometer** radius from the place in which the electricity generating power reactor and relevant facilities are installed.

(2) Each nuclear licensee shall establish a radiological emergency planning zone on the basis of a base area announced by the Nuclear Safety and Security Commission after consulting with the Mayor/Do Governor having jurisdiction over the base area, taking into consideration the following:

1. Population distribution, road networks, topography, and other area-specific features;
2. Effectiveness of emergency measures to protect residents, etc. in cases of any radiological emergency or radioactive disaster that occurs in the nuclear facilities.

(3) Where a nuclear licensee intends to establish a radiological emergency planning zone, he or she shall obtain approval therefor from the Nuclear Safety and Security Commission. The same shall also apply where he or she intends to alter or cancel it.

(4) Each nuclear licensee shall reflect a radiological emergency planning zone established under paragraph (2) in formulating a radiological emergency plan under Article 20.

(5) Matters necessary for public announcement by the Nuclear Safety and Security Commission under paragraph (1), procedures for holding consultations under paragraph (2), etc. shall be prescribed by Presidential Decree.

Category		PAZ	UPZ
Power Reactors and Associated Facilities		3 – 5 km	20 – 30 km
Research Reactors and Associated Facilities	2 MWth ≤ P < 10MWth	N/A	0.5 km
	10 MWth ≤ P< 50MWth	N/A	1.5 km
	50 MWth ≤ P< 100MWth	N/A	5 km
Spent Fuel Storage/Treatment/Disposal Facilities	Treatment facilities not intended for testing or research (Evaluated individually by facility)	To be determined by facility-specific evaluation	5 km
	Storage and disposal facilities	N/A	1.5 km
	Treatment facilities for testing or research purposes	N/A	Site Boundary
Other Nuclear Facilities		N/A	Site Boundary

Figure 2: Siting Criteria of Nuclear Facilities in Korea

5 INDUSTRIAL APPLICATION AND NEAR-DEMAND SITING

The increasing electricity demand from data centers and AI computing infrastructure has led major technology companies to explore nuclear energy partnerships. For example, Microsoft has pursued long-term electricity supply agreements associated with nuclear generation project [8]. Amazon has also announced collaborations with advanced reactor developers to secure carbon-free electricity supply through SMR technologies [9]. In addition to electricity generation, nuclear reactors are increasingly considered for industrial heat supply and hydrogen production [10]. For these applications, proximity to demand centers becomes economically important due to heat transport limitations and system integration requirements.

6 PROPOSED REGULATORY IMPROVEMENTS

Several regulatory improvement options are proposed. First, the PCD requirement could be applied conditionally rather than as a rigid distance rule, if accident consequence analysis demonstrates limited offsite impact. Second, the EPZ framework could incorporate graded emergency planning reflecting reactor power level, frequency, and source term characteristics. Third, regulatory frameworks should address multi-module SMR sites through integrated risk assessment considering module independence, shared systems, and potential common cause failures.

The current regulation requires that a nuclear power plant be located in an area where the average population density within a 50 km radius of the site does not exceed the national average population density. This criterion functions as a site suitability requirement independent of the EPZ designation. Therefore, even if the EPZ is reduced, the 50 km population density requirement may still restrict siting near large metropolitan areas. In particular, areas surrounding major metropolitan regions in Korea generally have population densities significantly higher than the national average, which may make it difficult to site nuclear facilities, including SMRs, near urban centers. Consequently, expanding the feasibility of siting SMRs closer to urban areas would require not only adjustments to EPZ regulations but also a review of the population-density-based siting criteria.

7 CONCLUSION

This paper examined how nuclear facility siting criteria and emergency planning zone requirements in Korea interact to influence the deployment potential of SMRs. Although the two regulatory systems serve different purposes, their combined implementation may significantly constrain SMR siting flexibility for near-demand SMR deployment. To address these challenges, the study proposes regulatory modernization measures based on RIPBR principles, including conditional siting criteria, graded EPZ implementation, and integrated risk management for multi-module SMR sites. Future research should develop quantitative methodologies for evaluating SMR accident consequences and assess the economic and social implications of EPZ flexibility.

Quantitative methodologies, to evaluate accident consequence distances for SMRs using PSA and source term analysis, should be provided by further researches. Such studies could support regulatory decision-making for graded EPZ implementation and near demand centers.

This paper suggests that regulatory modernization integrating risk-informed approaches may play an essential role in enabling flexible SMR deployment while maintaining public safety and health in Korea.

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