

Graded Approach-Based Regulatory Framework for Implementing PSA in Research Reactor Licensing

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1. Introduction

Unlike nuclear power reactors, research reactors are operated primarily for neutron utilization, radioisotope production, materials irradiation, education and training, and various experimental purposes rather than for electricity generation. Consequently, research reactors vary considerably not only in rated thermal power but also in nuclear fuel and radioactive material inventories, configuration of experimental facilities, operating modes, and site conditions. These characteristics make it difficult to assess the potential risk of a research reactor solely on the basis of reactor power and highlight the need for safety assessments commensurate with each facility's characteristics.

Under the Korean Nuclear Safety Act and its subordinate regulations, separate provisions are established for the construction and operation of nuclear power reactors and research reactors. However, many requirements concerning the obligations of research reactor operators and Periodic Safety Review (PSR) are applied *mutatis mutandis* from provisions originally established for nuclear power reactors. Although this approach allows common safety requirements to be applied to research reactors, it may result in a regulatory framework in which requirements for nuclear power reactors are applied first and certain provisions are subsequently excluded, rather than proactive graded approach in which the regulatory level is determined in advance according to the diverse risk characteristics of individual research reactors.

A particular discontinuity exists in the regulatory framework with respect to the timing of Probabilistic Safety Assessment (PSA). Under the current system, PSA is not explicitly required for research reactors at the construction permit or operating license application stages, nor is there an established framework requiring a standalone PSA report to be submitted and reviewed. In contrast, PSA is addressed as one of the safety assessment elements during PSR because the PSR provisions applicable to nuclear power reactors are applied *mutatis mutandis* to research reactors.

In its 2024 Integrated Regulatory Review Service (IRRS) mission, the International Atomic Energy Agency (IAEA) identified the need to more clearly incorporate the graded approach into the Korean regulatory framework for research reactors and to consider the use of probabilistic analysis during the

construction and operating licensing processes [1]. IAEA SSR-3 also specifies that deterministic safety analysis should serve as the primary basis for the safety assessment of research reactors, supplemented, where appropriate, by probabilistic methods [2]. This does not imply that the same scope of PSA applied to nuclear power reactors should be imposed on research reactors. Rather, it indicates the need for a regulatory framework in which the extent and level of PSA requirements are reasonably adjusted according to the risk and characteristics of individual facilities.

This study therefore focuses on identifying at which level of the current Korean nuclear safety regulatory hierarchy, and in what manner, a graded PSA framework should be linked to licensing and PSR. Based on this analysis, specific regulatory amendment alternatives and a graded PSA application framework are proposed.

2. Regulatory Gap in the Current Framework

2.1. Current Regulatory Structure for Research Reactors

Under the current Nuclear Safety Act, the construction permit for a research or educational reactor facility is governed by Article 30, while the operating license is governed by Article 30-2. However, Article 34 provides that a number of provisions applicable to nuclear power reactors shall apply *mutatis mutandis* to the obligations of research reactor operators and related matters [4]. This structure is further reflected in the Enforcement Decree and Enforcement Rule, while detailed regulatory reviews are conducted in accordance with Nuclear Safety and Security Commission (NSSC) notices and Korea Institute of Nuclear Safety (KINS) safety review guidelines.

At the construction permit stage, the design safety of a research reactor is primarily reviewed through the Preliminary Safety Analysis Report (PSAR). At the operating license stage, the Final Safety Analysis Report (FSAR), Technical Specifications (TS), Emergency Operating Procedures (EOPs), and other relevant documents are reviewed. PSA, however, is not explicitly specified as an independent licensing submittal at either stage.

The situation differs at the PSR stage. Through Article 34 of the Nuclear Safety Act and the associated provisions applied *mutatis mutandis*, research reactors are subject to the PSR framework established for nuclear

power reactors, in which PSA is included as one of the PSR assessment elements. Consequently, as illustrated conceptually in Fig. 1, the current regulatory structure results in a difference in the degree of PSA utilization between the construction and operating licensing stages and the subsequent PSR stage.

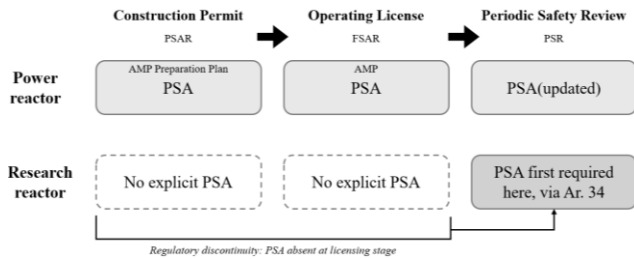


Fig. 1. Current regulatory structure and discontinuity in PSA requirements for research reactors.

2.2. Regulatory Implications of the Discontinuity

PSA is not merely a retrospective tool for quantifying the risk of an operating facility. At the construction permit stage, PSA can be used to identify major initiating events and evaluate the adequacy of safety functions. At the operating license stage, accident sequences and the roles of safety systems can be evaluated by incorporating the final design and actual operating procedures. Following the commencement of operation, the PSA model can also be continuously updated to reflect plant modifications, operating experience, and operational events.

If the first PSA is not performed until the PSR stage, risk information that could have been identified and utilized during the design and initial licensing stages may not be adequately incorporated into regulatory decision-making. Conversely, requiring every research reactor to perform a PSA of the same scope and level of detail as that required for a nuclear power reactor from the construction permit stage could impose an excessive regulatory burden on low-power and low-risk facilities.

Therefore, the appropriate approach is not to uniformly mandate PSA for all research reactors, but rather to establish a graded framework in which the scope and level of analysis are determined according to facility characteristics from the early licensing stage and are progressively refined throughout operation and PSR.

3. Regulatory Alternatives for Graded PSA

Approaches for incorporating research reactor PSA into the existing regulatory framework can be categorized according to the level of the regulatory hierarchy at which PSA requirements are established. This study considers three alternatives involving amendments primarily to the Nuclear Safety Act, the Enforcement Decree, and the Enforcement Rule, respectively.

Table I: Comparison of the three regulatory amendment alternatives.

	level amended	Distinctive feature	Advantages	Disadvantages
Alt. 1	Act (Decree + Rule + Notice)	PSA duty written in the Act	Strongest legal basis	Slow, complex process
Alt. 2	Decree (Rule + Notice)	Class & PSA set in the Decree	Covers licensing + PSR	Details via Rule / Notice
Alt. 3	Rule (Notice)	PSA added to submittals	Fits current framework	No Act / Decree basis

3.1. Alternative 1: Amendment of the Nuclear Safety Act

The first alternative is to establish a statutory basis for the performance and graded application of PSA for research reactors directly in the Nuclear Safety Act.

For example, PSA reports corresponding to the construction permit and operating license stages could be added to the licensing documents specified in Articles 30 and 30-2, respectively. Alternatively, a new Article 30-3 could be established to prescribe the obligation to perform PSA for research reactors and the principle of graded application.

Under such a framework, a preliminary PSA could be performed at the construction permit stage using the design information available at that time. At the operating license stage, the assessment could then be updated to reflect the final design, Technical Specifications, Emergency Operating Procedures, and other finalized operational information. In addition, the PSA could be linked to the PSR provisions applied through Article 34, requiring it to be updated to reflect operating experience, facility modifications, and state-of-the-art assessment methods.

Because the requirement would be established directly in the Act, this alternative provides the clearest legal basis for both the PSA obligation and the graded approach. It would also allow the construction permit, operating license, and PSR stages to be explicitly linked at the statutory level, providing a high degree of regulatory consistency and stability. However, it would require a legislative process through the National Assembly and consequential amendments to the Enforcement Decree, Enforcement Rule, NSSC notices, and other subordinate regulations.

3.2. Alternative 2: Amendment of the Enforcement Decree

The second alternative is to retain the current Nuclear Safety Act while introducing provisions in the

Enforcement Decree concerning the risk classification of research reactors and the application of PSA.

For example, a new Article 43-2 could classify research and educational reactor facilities according to their potential risk and facility characteristics. A graded preliminary PSA could then be required at the construction permit stage, with the PSA updated at the operating license stage according to the assigned facility class.

For PSR, the provisions of Article 47 that apply requirements *mutatis mutandis* could be supplemented so that PSA is updated during PSR in accordance with the facility class established at the licensing stage.

This alternative offers a relatively favorable balance between legal enforceability and regulatory flexibility, because the facility classification system and the basis for PSA implementation could be specified at the Presidential Decree level without directly amending the Act. Detailed assessment scopes and methods could subsequently be delegated to the Enforcement Rule or NSSC notices, thereby allowing the regulatory framework to accommodate technological developments and differences among individual facilities.

However, the legal consistency of delegating PSA obligations and facility classification requirements to the Enforcement Decree would need to be reviewed in advance, particularly with respect to the scope of delegation provided under the current Act.

3.3. Alternative 3: Amendment of the Enforcement Rule

The third alternative is to maintain the existing Nuclear Safety Act and Enforcement Decree while amending Article 25 of the Enforcement Rule to add PSA-related documents to the list of licensing submittals, or alternatively, to establish a new Article 25-2.

Under this approach, a PSA report for the construction permit stage and a PSA report for the operating license stage could be included among the additional documents required under Article 25. The detailed PSR provisions could also specify that PSA be performed on a graded basis according to the risk and characteristics of each research reactor facility.

As a more independent approach, a separate article governing the submission of PSA for research reactors could be established, integrating the requirements applicable to construction permits, operating licenses, and license amendments within a single provision. The detailed assessment scope and methodology could then be prescribed by the Commission through a notice, thereby maintaining regulatory flexibility.

Among the three alternatives, amendment of the Enforcement Rule would involve the simplest implementation process and could be directly integrated into the existing licensing application framework. In particular, PSA reports could readily be incorporated into the current system of licensing attachments.

However, imposing a new substantive obligation to perform PSA solely through a Prime Ministerial Ordinance may raise questions regarding the adequacy of

delegation from superior legislation and may therefore provide comparatively weaker legal stability.

These three alternatives should not necessarily be regarded as mutually exclusive regulatory options, but rather as alternative levels of regulatory strength and institutionalization.

4. Graded PSA Framework

4.1. Basic Concept of Grading

A graded approach to PSA for research reactors is not simply a process for determining whether PSA should or should not be performed. The fundamental purpose of grading is to adjust the scope of analysis, level of model detail, treatment of external events, and degree of utilization of PSA results in proportion to the potential risk of the facility.

In this study, rated thermal power is considered as an initial screening parameter, while additional factors such as the source term, characteristics of experimental facilities, operating modes, accident mitigation features, level of defense-in-depth, and site conditions are treated as supplementary considerations.

4.2. Three-Step Classification Process Based on Thermal Power

Rated thermal power provides a relatively simple and objective indicator that indirectly reflects the scale of a facility and its radioactive material inventory, making it useful for initial classification. Examples of IAEA hazard categorization for research reactors also use thermal power as one of the principal classification parameters [3]. Thermal power also has the advantages of being readily understandable to non-specialists and enabling rapid administrative application based on a clear and transparent criterion.

However, even among research reactors with the same thermal power, risk characteristics may differ substantially depending on the types of experimental facilities and irradiated materials. Therefore, determining the final facility class based solely on reactor power would not adequately reflect differences in design, experimental activities, and site characteristics.

Accordingly, the class boundaries considered in this study are not intended to represent finalized regulatory criteria. Rather, they are candidate values for initial screening, after which the final PSA application level would be determined through additional adjustment assessments reflecting facility-specific characteristics.

A conceptual example of graded PSA application is as follows:

Table II: Graded PSA application framework by facility class.

Class	Representative category	PSA application level
Class 1 (High)	High-power / high-hazard reactors	Full Level 1 PSA + limited Level 2 PSA (external events as needed)
Class 2 (Medium)	Medium-power / multipurpose reactors	Simplified Level 1 PSA (internal events) + external event screening
Class 3 (Low)	Low-power education / Small experimental reactors	Deterministic analysis PSA omitted or qualitative

The key principle of this process is that facilities near classification boundaries should not be classified mechanically on the basis of thermal power alone. Instead, the final class should be determined through a supplementary assessment and expert judgment so that the classification appropriately reflects facility-specific characteristics.

5. Discussion and Conclusions

This study analyzed limitations in the current Korean regulatory framework for applying a graded approach to PSA for research reactors and proposed both a risk-based facility classification framework and regulatory amendment alternatives at different levels of the regulatory hierarchy.

One of the most important issues in the current research reactor regulatory framework is not the necessity of PSA itself, but rather the absence of consistent criteria and continuity in the application of PSA throughout the licensing and safety assessment process. Although the construction permit and operating license stages are critical phases in which the design and operational safety of a research reactor are established, explicit mechanisms for reviewing PSA are limited at these stages. In contrast, PSA is included as an assessment element during PSR.

The first principle for addressing this issue is that the institutionalization of PSA and the graded approach should be designed together, rather than imposing an identical PSA requirement on all research reactors.

The second principle is that the fundamental legal basis for graded application should be established at the level of the Act or Enforcement Decree, while detailed technical requirements should be addressed separately through NSSC notices and regulatory review guidelines. Such a structure could provide both regulatory predictability and technical flexibility.

The third principle is that PSA should not be treated as a separate document that is independently repeated at each licensing stage. Instead, it should be managed as continuous safety assessment information extending from the construction permit through the operating license to PSR. Under such an approach, the preliminary assessment developed at the construction permit stage would be refined during the operating license stage, updated to reflect modifications during operation, and further updated during PSR. This would help resolve the current inconsistency in PSA requirements between licensing and PSR.

At the present stage, rather than selecting a specific regulatory amendment as the final option, it is appropriate to consider an institutional framework in which higher-level legislation provides the legal basis for graded risk assessment, while subordinate NSSC notices and review guidelines specify the actual facility classification criteria and the corresponding scope of PSA.

The facility classes and PSA application levels proposed in this study are not finalized regulatory criteria, but rather an initial framework that should be validated and further developed through expert consultation and pilot applications to actual research reactor facilities. In particular, additional quantitative bases are required for the class boundary values based on rated thermal power, methods for incorporating source term and accident consequences, criteria for adjusting classifications according to experimental facility characteristics, and conditions under which PSA may be simplified or omitted for low-risk facilities.

Future work will therefore evaluate the appropriateness of the classification factors and class-specific PSA application levels through an expert panel and apply the proposed framework on a pilot basis to research reactors to comprehensively assess the resulting facility classifications. Based on these validation results, the PSA scope for each facility class should be further specified, and screening criteria and regulatory review items that can be directly applied in actual regulatory reviews should be developed.

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