A Study on the Graded Regulation of Zero Power Research Reactors: A Case Study of PSR Exemptions

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1. Introduction

South Korea's Nuclear Safety Act classifies reactors into two categories: power reactors and research reactors. However, this classification does not sufficiently account for differences in risk levels based on reactor thermal power and radioactive material inventory. For example, the Hanaro reactor has a thermal power of 30 MW, whereas the AGN-201K educational reactor has a thermal power of only 10 W. Despite the AGN-201K's thermal power being three million times lower than Hanaro's, both reactors are subject to the same regulatory standards, leading to regulatory inefficiencies.

Awareness of the challenges posed by unreasonable regulations has been established internationally through the concept of a “graded approach” or “graded regulation.” In the case of zero power research reactors, their physical characteristics more closely resemble those of radiation-generating devices due to their low thermal power and radiation levels. Therefore, a tailored regulatory framework that considers these characteristics is necessary.

A previous study proposed several regulatory improvements for zero power research reactors. [1] Among them, there was a proposal to exempt zero-power research reactors from Periodic Safety Reviews (PSRs) and instead supplement the regular inspection system. In this study, we conducted a comparison between the PSR requirements with the regular inspections conducted for the AGN-201K reactor. Based on this comparison, we proposed methods to exempt the AGN-201K from PSRs while strengthening the regular inspection system to compensate. Through this approach, we aim to improve regulatory efficiency by ensuring the safety of educational zero power reactors while reducing unnecessary regulatory burdens.

2. Graded Regulation Framework of Zero Power Research Reactors

2.1 Graded Regulation Proposal

A previous study proposed three graded regulations for zero power research reactors.

1. Classify existing research reactors into two categories based on their thermal power levels: “zero power research reactors” and “medium and low power research reactors”. Medium and low power research reactors will be subject to the current regulatory framework for research reactors. In contrast, zero power research reactors will be designated as a separate graded regulatory category, reflecting their low thermal power characteristics.

2. For zero power research reactors or critical assemblies with simple equipment structures, the construction permit and operating license may be integrated and operated accordingly.

3. For zero power research reactors, PSRs may be exempted and replaced with regular inspections.

3. Status of Activities at AGN-201K

3.1 Periodic Safey Reviews

In accordance with South Korea’s Nuclear Safety Act, all nuclear reactors must undergo periodic safety reviews (PSRs) every 10 years. Following the Fukushima accident, research reactors were also required to undergo PSRs. The AGN-201K, an educational zero power reactor, also underwent its first PSR in compliance with domestic regulations.

According to Article 37 of the Enforcement degree of the nuclear safety act [2], the details of the PSR must include the 14 items specified in Table I.

Table I: Details of the Periodic Safety Reviews

No.	Details
1	Matters concerning the design of reactor facilities
2	Matters concerning the actual status of structures, systems and equipment crucial for safety
3	Matters concerning deterministic safety analysis
4	Matters concerning probabilistic safety reviews
5	Matters concerning hazard analysis
6	Matters concerning equipment verification

7	Matters concerning aging degradation (referring to physical or chemical process that causes damage to the system, structure and equipment of a nuclear power plant by passage of time or use)
8	Matters concerning safety performance
9	Matters concerning the utilization of nuclear power plant operating experience and research findings
10	Matters concerning operation and maintenance procedures, etc.
11	Matters concerning the organization, management structure and safety culture
12	Matters concerning human factors (including matters concerning the situation of members, etc. necessary for the operation of a nuclear reactor)
13	Matters concerning radiation emergency plans formulated under Article 20 of the Act on Measures for the Protection of Nuclear Facilities and Prevention of Radiation Disasters
14	Matters concerning radiological environmental impacts

3.2 Status of PSR activities at AGN-201K

Currently, the first PSR has been conducted for AGN-201K. Table II provides details regarding the status of the first 1st PSR [3]. Seven items were not performed, six were partially performed, and one was fully performed. In the design and actual status of reactor facilities, the primary reason for not performing was the absence of a formal safety classification of SSCs (structures, systems and components). For the deterministic safety analysis (DSA), the application of high power reactor requirements, such as the single failure criterion (SFC), was deemed to have low practical relevance due to the reactor's very low power and limited inventory. The probabilistic safety assessment (PSA) was not performed because there are few safety-significant SSCs and insufficient data. About hazard analysis, it concluded that off-site consequences would be negligible even under a maximum hypothetical accident (MHA). Aging Management (AM) identified no SSCs requiring dedicated aging evaluation. Operations and Maintenance was partially not performed, with procedures noting the absence of emergency operating procedures (EOPs). Both radiological emergency planning (REP) and environmental impact assessment (EIA) were considered out of scope because AGN-201K sits below legal thresholds.

4. Detailed Comparison for AGN-201K: PSR Requirements VS. Regular Inspections

4.1 Regular Inspections at AGN-201K

PSR has been performed for AGN-201K since 2018, and regular inspections have been conducted every two years. Regular inspections are conducted by the Korea Institute of Nuclear Safety (KINS) and consist of performance inspections (5 items) and operational inspections (4 items).

Table II: AGN-201K 1st PSR item performance status

No.	Details	Full Not Performed	Full Performed	Partially Not Performed	Reason for not performing
1	Matters concerning the design of reactor facilities			O	No SSC safety-classification scheme in place
2	Matters concerning the actual status of structures, systems and equipment crucial for safety	O			No SSC safety-classification scheme in place
3	Matters concerning deterministic safety analysis			O	Consideration of the SFC judged not applicable
4	Matters concerning probabilistic safety reviews	O			No SSCs credited with safety functions and insufficient data to support a PSA
5	Matters concerning hazard analysis	O			Bounding MHA analysis indicates no environmental hazard
6	Matters concerning equipment verification	O			No safety-function SSCs requiring EQ
7	Matters concerning aging degradation (referring to physical or chemical process that causes damage to the system, structure and equipment of a nuclear power plant by passage of time or use)	O			No SSCs within the scope of Aging Management evaluation
8	Matters concerning safety performance			O	No ESFs or SPIs; no radioactive effluents or radwaste generated
9	Matters concerning the utilization of nuclear power plant operating experience and research findings		O		
10	Matters concerning operation and maintenance procedures, etc.			O	EOPs not established
11	Matters concerning the organization, management structure and safety culture			O	Accident likelihood attributable to safety-culture deficiencies considered negligible
12	Matters concerning human factors (including matters concerning the situation of members, etc. necessary for the operation of a nuclear reactor)			O	Very low task/workload; HFE evaluation not warranted
13	Matters concerning radiation emergency plans formulated under Article 20 of the Act on Measures for the Protection of Nuclear Facilities and Prevention of Radiation Disasters	O			Outside the scope of REPP requirements
14	Matters concerning radiological environmental impacts	O			Not subject to REIA requirements

In terms of performance, inspections are performed on the reactor core, fire prevention facilities, measurement and control systems, electrical facilities, and radiation management facilities. And in terms of operation, inspections are conducted on the operating organization, qualifications and training, operational experience, and human factors management.

4.2 Comparison of PSR and Regular Inspections at AGN-201K

To exempt PSR and supplement regular inspections, we compared the differences between PSR and regular inspections.

1. (1) Design of reactor facilities – A PSR re-evaluates design documentation against current codes and standards, whereas a regular inspection verifies only the continued functional performance of SSCs.
2. (3) Deterministic Safety Analysis – A PSR reselects applicable design-basis accidents according to the latest criteria and re-runs the reactor's accident analysis. The AGN-201K also evaluated only a reactivity insertion accident as a design-basis accident. Whereas a regular inspection conducts performance tests and checks without reanalyzing the entire reactor.
3. (9) Operating experience and research findings – PSR include internal recognition of the system's appropriateness and validity, as well as statistical analysis. In contrast, regular inspections primarily confirm compliance with procedures, review actual records, and verify the implementation of measures. However, regular inspections mainly focus on document review and on-site verification, with no explicit mention of conducting survey activities.
4. (10) Operation and Maintenance Procedures – Although the establishment or revision of procedures is prompted by regular inspections, explicit evaluations of the procedural system are not conducted. Furthermore, regular inspections do not assess the clarity of these procedures.
5. (11) Organization, Management structure and Safety Culture – Although quality assessments are conducted during regular inspections, the "regular quality assurance audits involving independent assessors and detailed evaluations of the quality assurance plan itself" performed by PSR are not specified in the regular inspections. Furthermore, regular inspections do not include specific items related to safety culture.
6. (12) Human Factors – Regular inspections verify the maintenance and management of human-system interface equipment but do not employ detailed validity assessment techniques such as PSR, which involves the actual execution of procedures. Additionally, specific workload assessment methodologies are not applied.

5. Proposal for improving Regular Inspections

To apply graded regulatory approach that considers the low risk and unique characteristics of zero power research reactors, we propose a new regular inspection system that exempt PSRs and replaces them. This system comprises inspections conducted on two and ten year cycles. The 2-year cycle inspection is conducted the same as before, but at the 10-year cycle, the parts performed only by PSR are supplemented so that it can be a comprehensive regular inspections. For 10-year cycle,

1) evaluate design documentation against current codes and standards,
2) re-select the applicable design-basis accidents in accordance with the latest criteria and re-perform the reactor's accident accident analysis,
3) conduct a survey on the employee's perception of the appropriateness and validity of the operating experience and research results applicacion
4) conduct preliminary reviews of the procedure manual's structure and clarity,
5) evaluate effectiveness through control panel about MMI devices.

Furthermore, we suggest to exempt quality assurance audits and evaluations of the quality assurance itself because AGN-201K does not have safety-related structures, systems and components.

6. Conclusions

This study proposes replacing the existing PSRs with regular inspections to improve regulatory efficiency for zero power research reactors. Currently, domestic nuclear safety laws apply uniform standards to reactors with significantly different power powers, resulting in regulatory inefficiencies. Therefore, the need for graded regulation considering low-risk characteristics has been emphasized.

We conducted a detailed comparison and analysis of PSR and regular inspection details, confirming that regular inspections do not adequately address certain safety assessment components. As a complementary measure, we propose a new regular inspection system that includes two-year regular inspection conducted in the same way as before and comprehensive evaluation conducted every ten years. This new system is expected to thoroughly reconfirm safety by integrating the important parts of PSR while also reducing unnecessary regulatory burdens and enhancing regulatory efficiency.

In conclusion, the differential regulation-based regular inspection system proposed in this study offers an effective approach to ensuring safety by reflecting the unique characteristics and low risk of zero power research reactors, while simultaneously reducing the regulatory burden on operators.

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