Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

Application of PSA to Research Reactors Using a Graded Approach

Seolsonghwa Song [a], Jaehyun Cho [a*]
[a]*Chung-Ang University, 84, Heukseok-ro, Dongjak-gu, Seoul, Korea 06974*
[*]*Corresponding author: jcho@cau.ac.kr*

***Keywords :** research reactor, graded approach, probability safety assessment

1. Introduction

Research and development on research reactors (RRs) are actively progressing worldwide. Research reactors serve a wide range of purposes, including the production of radioactive isotopes, materials testing, neutron scattering experiments, and nuclear technology development, making significant contributions to both scientific and industrial fields. The Korea Atomic Energy Research Institute (KAERI) invented HANARO, Korea's first multipurpose research reactor. Furthermore, KAERI successfully exported the Jordan Research and Training Reactor (JRTR) and is currently engaged in the Kijang Research Reactor (KJRR) project.

In the design and operation of research reactors, the necessity of a flexible regulatory framework tailored to their specific characteristics and objectives has been increasingly recognized. Unlike power reactors, research reactors are designed for diverse experimental and research applications, necessitating regulatory frameworks that ensure both safety and operational efficiency. Given these distinct requirements, the establishment of an appropriate and adaptive regulatory system has become a critical research topic.

In this context, the graded approach to research reactor regulation has emerged as a key issue. This approach involves the application of differentiated regulatory requirements based on factors such as reactor risk level, scale, and intended use. By implementing a graded approach, regulatory frameworks can be adapted to reflect the unique characteristics of research reactors, thereby enhancing both regulatory and operational flexibility. This study aims to analyze the necessity of a graded regulatory approach for research reactors and propose a structured framework for its effective implementation.

2. IAEA Requirements and Guidelines

A graded approach is a structured method determining the characteristics of a facility or activity and operational procedures according to the safety significance and complexity. [1]

2.1 IAEA General Safety Requirements Part1 (Rev.1)

In 2016, as revision of Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety, IAEA General Safety Requirements(GSR) Part 1 (Rev.1) was published. [2] Its objective is to establish requirements in respect of the governmental, legal and regulatory framework for safety. This document contains requirements relating to entire range of facilities and activities from the use of a limited number of radiation source to a nuclear power program. In requirement 29, the publication stipulates graded approach to inspections of facilities and activities. The inspections of facilities and activities shall be commensurate with the radiation risks associated with the facility or activity, in accordance with a graded approach.

2.2 IAEA Specific Safety Requirements No. SSR-3 (Rev.1)

This document which is named Safety of Research Reactors was published in September 2016 as revision of NS-R-4 published in June 2005. [3] Its main objective is to provide a basis for safety and safety assessment for all stages in the lifetime of a research reactor by establishing requirements on aspects relating to regulatory supervision, management for safety from evaluation to decommissioning. Technical and administrative requirements for the safety of research reactors are established in accordance with this objective. This safety requirement publication establishes requirements for all the important areas of the safety of research reactors, with particular emphasis on requirements for design and operation.

The publication mentions graded approach for research reactor as following. "*2.15.Research reactors are used for special and varied purposes, such as research, training, education, radioisotope production, neutron radiography and materials testing. These purposes call for different design features and different operational regimes. Design and operating characteristics of research reactors may vary significantly, since the use of experimental devices may affect the performance of reactors. In addition, the need for flexibility in their use requires a different approach to achieving and managing safety".* Also it includes the factors to be considered in deciding whether the application of certain requirements established may be graded include: *(a) The reactor power, ..., (i) The utilization of the reactor (experimental devices, tests and reactor physics experiments) ...* In item of requirement 5 Safety assessment, the requirement is that verification of the adequacy of the design of the research reactor in accordance with the management system by means of comprehensive deterministic safety analysis and complementary probabilistic analysis as appropriate.

2.3 IAEA Specific Safety Guide No. SSG-22 (Rev.1)

The safety guide provides recommendations on the use of a graded approach in the application of the safety requirements established in SSR-3 for research reactors. In February 2023, the revision of this document which was released in November 2012 has been published. [4] The safety guide is primarily intended for use newly designed and constructed reactors, it may also be applied to existing reactors to extent practicable. It has a similar structure to the SSR-3 in a few sections but more provides description basic elements and its application.

The complementary probabilistic safety assessment which might be carried out to supplement deterministic safety analysis is another element of the safety analysis report(SAR) requirement. The appendix to SSG-20 (Rev.1) provides recommendations on safety assessment and the safety analysis report for research reactors, including of a graded approach.

2.4 IAEA Specific Safety Guide No. SSG-20 (Rev.1)

The appendix describes methods for conducting safety analysis of research reactors, focusing primarily on deterministic methods. However, probabilistic methods are also mentioned as a complementary approach to deterministic method. Probabilistic safety assessment can be used to evaluate accident scenarios with higher likelihood, analyze relative risk factors, and identify potential design weaknesses. It acknowledges its applicability and the contents are the following.

I–3. Postulated initiating events are possible occurrences that might lead to research reactor fault sequences or to accident scenarios. They might originate from component failures, system malfunctions, human errors, or external events or particular internal events.

I–4. The method used to identify postulated initiating events will ensure that the list of postulated initiating events is as complete as possible, that postulated initiating events are grouped in a logical fashion to simplify the analysis, and 115 that bounding postulated initiating events in each group are selected for further analysis. The method could include one or more of the following: (a) Lists of postulated initiating events in research reactors — a list of possible postulated initiating events in research reactors is provided in para. 3.23 of this Safety Guide. (b) Engineering evaluation — potential sources of radiation and types of radiological hazard within the research reactor are identified, and a systematic review of the research reactor design, operations and site factors is made to identify occurrences that could lead to radiological hazards. (c) Operating experience — past experience from the research reactor or from similar facilities, including experience derived from the examination of safety reports and the IAEA's Incident Reporting System for Research Reactors (IRSRR) database, can be used to develop or to supplement the list of postulated initiating events. (d) Logical analysis — an example is a top-down logical model known as a master logic diagram, which is similar to a fault tree. [5]

3. Regulatory Framework

3.1 Implementing PSA in RRs

Article 21 of the Nuclear Safety Act (Periodic Safety Review) stipulates that "The Nuclear Safety and Security Commission may require a periodic safety review of nuclear reactor facilities." Although this provision does not explicitly mention Probabilistic Safety Assessment (PSA), it implies that PSA can be utilized as part of the Periodic Safety Review (PSR) process.

Article 39 (Safety Analysis) of the Enforcement Regulation on Technical Standards for Nuclear Reactor Facilities designates both Deterministic Safety Analysis (DSA) and Probabilistic Safety Assessment (PSA) as acceptable methods of safety analysis. This regulation provides a legal basis for the application of PSA to all nuclear reactor facilities, including research reactors. However, the scope of PSA for research reactors may be adjusted according to a graded approach, taking into account the specific characteristics and risk profiles of such facilities.

Furthermore, during the IAEA Integrated Regulatory Review Service (IRRS) mission conducted in July 2011, it was noted that PSA had not been applied to research reactors in Korea, and it was recommended that PSA be incorporated as a key element of future PSR. [6] This reflects a broader trend in which domestic nuclear safety regulations are increasingly aligning with international standards, thereby supporting the application of PSA to research reactors.

These regulatory and international recommendations highlight the need for PSA in research reactors, which have motivated the development of a framework for its graded approach application.

3.2 Framework

To develop an appropriate framework for applying PSA to research reactors, regulatory documents from Canada and the United States were reviewed. The Canadian Nuclear Safety Commission (CNSC) stipulates in REGDOC-3.5.3 that, using a graded approach, it conducts an assessment of a safety case for a proposed activity to ensure that regulatory requirements and safety objectives are met. For example, the inherent risk levels between a research reactor such as SLOWPOKE-2 and a large reactor designed for electricity generation are significantly different. [7] The CNSC has emphasized that both deterministic and probabilistic safety analyses should be incorporated into an organization's management systems as tools for risk-informed decision-making. [8] At a 2017 workshop, stakeholders further proposed requiring vendors, applicants, and licensees to demonstrate the conduct of both deterministic and probabilistic analyses for all identified phenomena or hazards. [9]

In March 2022, the U.S. Nuclear Regulatory Commission (NRC) issued Regulatory Guide (RG) 1.247 for trial use, titled *Acceptability of Probabilistic Risk Assessment Results for Non-Light-Water Reactor (NLWR) Risk-Informed Activities*. This guide outlines one acceptable approach developed by the NRC for determining whether a design- or plant-specific probabilistic risk assessment (PRA) provides sufficient confidence to support regulatory decision-making for NLWRs. [10] Although this guide is not directly applicable to research reactors due to differences in design, purpose, and risk level, it offers useful insights into structured PSA application for advanced reactor types.

These international regulatory efforts reflect a growing recognition of the importance of applying PSA to research reactors using a graded approach. Drawing on these insights, a tailored framework has been proposed to implement PSA techniques for Korean research reactors, aiming to enhance their safety in alignment with both domestic regulations and international standards.

Review documents and methodologies
↓
Gap analysis between PWR and RR
↓
Conduct PSA to HANARO using GA
↓
Optimize methodology
↓
Propose regulatory guidelines

4. Conclusion

This study has confirmed that graded approach continues to be a major issue and has emphasized the necessity of broader discussions and consensus-building to meet international standards. In particular, close collaboration with the Probabilistic Safety Assessment field is crucial for enhancing the reliability of safety assessments and establishing reasonable regulatory standards. To achieve this, fostering consensus among various stakeholders and implementing effective policy coordination are essential for improving the effectiveness of graded approach.

Future research should further explore concrete implementation measures and case studies to deepen the discussion and enhance practical applicability.

ACKNOWLEDGEMENT

This work was supported by the Nuclear Safety Research Program through the Regulatory Research Management Agency for SMRS(RMAS) and the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 1500-1501-409).

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Glossary, Terminology Used in Nuclear Safety and Radiation Protection 2007 Edition, IAEA, Vienna (2007).
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1, IAEA, Vienna (2016).
[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Standards Series No. SSR-3, IAEA, Vienna (2016).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors, IAEA Safety Standards Series No. SSG-22, IAEA, Vienna (2023).
[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report, IAEA Safety Standards Series No. SSG-20, IAEA, Vienna (2022).
[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Integrated Regulatory Review Service Misson, Republic of Korea (2011).
[7] CNSC, REGDOC-3.5.3, Regulatory Fundamentals, Feb., 2022
[8] CNSC, Use of the Graded Approach in Regulation, Sep., 2014
[9] CNSC, Stakeholder Workshop Report: Application of the Graded Approach in Regulating Small Modular Reactors, Nov., 2017
[10] NRC, ACCEPTABILITY OF PROBABILISTIC RISK ASSESSMENT RESULTS FOR NON-LIGHT-WATER REACTOR RISKINFORMED ACTIVITIES, Oct., 2021