Analysis of Safety Inspection Method applying Graded Approach to Nuclear Power Plants in Korea and the U.S

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1. Introduction

In accordance with the government's energy conversion and safety enhancement policy, the Nuclear Safety and Security Commission promoted strengthening of safety standards for nuclear power plants in 2018 and strengthened on-site-oriented regulatory activities in response to the public's view, which led to actual inspection points or findings, which led to reduced utilization and increased maintenance costs, which are important factors. The current domestic inspection assumes the same importance for all facilities/systems/devices, and a large amount of time and manpower is spent. In particular, regular inspections, which are closely related to restarting nuclear power plants during inspection, have not changed much over the past 35 years, as they adopted deterministic techniques, a regulatory inspection system used in Japan in early 1980. Recently, the regulatory agency conducted related research on the use of risk information and the application of the concept of defense in order to enhance efficiency of inspection and enhance the comprehensive safety verification of nuclear power plants. Accordingly, there is a growing need to study improvements in the application of the differential approach concept in response to the regulatory agency's efforts to improve the safety inspection.

Therefore, this study focused on the feasibility of a graded approach to safety inspection from the perspective of enhancing safety of operational nuclear power plants. Based on the contribution of the concept of defence in depth and the importance of risk, the research was conducted differently by considering the weight of the structures, systems, and devices in question, and by examining the U.S. regulatory inspection system that affects safety inspection conducted by operators of major overseas nuclear power plants for the purpose of rational improvement, including safety inspection.

2. IAEA Requirements and Guidelines

The IAEA has the authority to establish or adopt safety standards and may prescribe the application of relevant standards. Standards established by the IAEA are published in a series of IAEA safety standards. These series cover nuclear safety, radiation safety, transportation safety and waste safety, and the publications in these series are divided into "Safety Fundamentals", "Safety Requirements" and "Safety Guides."

2.1 IAEA General Safety Requirements GSR Part1(Rev1)

IAEA General Safety Requirements GSR Part 1 (Rev. 1) [1] establishes requirements related to government, legal and regulatory regimes for nuclear safety. This requirement has been issued to establish a framework for safety for all nuclear facilities and activities, from the use of a limited number of radiation sources to nuclear power generation. This document contains requirements relating to inspections of facilities and activities.

Requirements 29 of GSR Part 1 [1], Item 4.50, and Item 4.52, specify the IAEA requirements for facility and activity inspections as follows:

"Requirement 29: Graded approach to inspections of facilities and activities

Inspections of facilities and activities shall be commensurate with the radiation risks associated with the facility or activity, in accordance with a graded approach."

...

"4.50 ... and shall stipulate the frequency of inspections and the areas and programmes to be inspected, in accordance with a graded approach."

...

"4.52 ... The manner, extent and frequency of inspections shall be in accordance with a graded approach."

2.2 IAEA General Safety Guide(No. GSG-13)

IAEA General Safety Guide GSG-13 [5] specifies the key functions of the regulatory body and relevant procedures to implement them, providing recommendations to meet the requirements of GSR Part 1 (Rev. 1)[1] mentioned in the previous section. Paragraphs 3.210 to 3.294 of this Safety Guide relate to inspection of facilities and activities. This includes information on the purpose, type, inspection plan establishment and follow-up measures of inspection, and is the basis for conducting inspection in all nuclear power plant operating countries. GSG-13 [5] covers different types of facilities and activities, but does not describe the type of facility or activity, construction or operation of the inspection areas, as specific areas of inspection depend on the risks associated with the characteristics of the facility or activity.

Regulators should establish an overall plan for the inspection programs they wish to carry out for the facility or activity. For each technical area subject to inspection, the inspection interval and the level of effort applied to the inspection are determined by the following factors: ① Type of facility or activity, **② Safety importance in the area of technology to be inspected,** ③ Test methods and approaches used (e.g., the use of resident inspectors may affect the spacing, scope and depth of the inspection), ④ Records of performance of authorized personnel and facilities (e.g. non-compliance with regulatory requirements, violation of licensing conditions, defects, number of incidents and response checks), **⑤ Regulatory review and evaluation results,** ⑥ Personnel and other resources available to regulators, **⑦ Previous Test Results.**

GSG-13 [5] covers different types of facilities and activities, but does not describe the type of facility or activity, construction or operation of the inspection areas, as specific areas of inspection depend on the risks associated with the characteristics of the facility or activity. To summarize the IAEA's requirements and guidelines for safety inspections above, regulators should develop and implement inspection programs, including various types of inspections. Each inspection program shall utilize a graded approach that takes into account risks and safety criticality, and shall take into account the performance of previous inspection results, etc. After completion of the inspection, appropriate follow-up measures shall be taken according to the results of the inspection.

2.3 IAEA INSAG Report

The International Nuclear Safety Advisory Group (INSAG) of the IAEA consists of experts with high levels of expertise in safety and provides advice and guidance on approaches, policies and principles to nuclear safety. In particular, INSAG provides advice and feedback to the IAEA, the nuclear industry and the public on current or emerging safety issues through its INSAG report. INSAG-12 [6] provides in-depth defense as one of the principles for achieving the plant's basic safety goals and describes the evidence for impotance, exceptions and scope of application for its importance.

3. Status of domestic inspection system

The safety inspection of operational nuclear power plants is carried out in accordance with the KINS's regulatory inspection, and the inspection closely related to the reactivation of nuclear power plants during the KINS' regulatory inspection, as described in the introduction, is a regular inspection. The following describes the legal framework, inspection methods, etc. for regular inspections.

3.1 Legal System

The purpose of regular inspections of domestic operational nuclear power plants is to verify that they are operating in compliance with the operational license criteria pursuant to Article 21 (Approval Criteria) of the Nuclear Safety Act, and that the performance of each equipment and facility is satisfied with the rules on the technical standards in accordance with Article 35 (regular inspection) of the Enforcement Decree of the Nuclear Safety Act, and the purpose of verifying the compliance with the conditions of the inspection at the use. According to Article 19 paragraph 6[2] of the Enforcement Rules of the Nuclear Safety Act, it is stipulated that the containment of nuclear reactors for the power increase of nuclear reactors can be allowed if the inspection results meet the requirements of Article 21 paragraph 1 of the Nuclear Safety Act. In other words, "The performance of power reactors and related facilities shall comply with the technical standards set by the Commission's rules, so as not to interfere with the prevention of human, physical, or public disasters according to radioactive materials (article 21 no. 1 no. 2 of the Act), and "Follow the Presidential Decree to prevent the health and environmental hazards of the people from operating power reactors and related facilities" (21). Therefore, the acceptance criteria of paragraphs 2 and 3 of Article 21 paragraph 1 of the Nuclear Safety Act indicate that the entire system of the nuclear power plant must maintain the capability to operate normally. However, the focus is ultimately on disaster prevention due to the operation of nuclear reactors. Article 19 of the Enforcement Regulations of the Nuclear Safety Act (regular inspection) stipulates that the inspection period is from the day the reactor is shut down to the date when the entire power operation is resumed for the purpose of replacing the nuclear fuel, and that the reactor is allowed to be leased if the inspection results meet the approval criteria of Article 21 of the Nuclear Safety Act.

3.2 Inspection Item

As shown in Table 1, Article 19 of the Enforcement Rules of the Nuclear Safety Act (regular inspection) states that detailed inspection methods and inspection targets for each facility are specified in the notice, and, accordingly, for light water reactors, 11 facilities, including the main body, are subject to regular inspection, as shown in Table 1.

Table 1: Regular inspection items for domestic operational nuclear power plants

Law	Contents
Notice of the Nuclear Safety Commission, No.2017-28.	Designation of facilities subject to regular inspection by type of road - Facilities subject to light water reactor inspection: 11 Selection of inspection items - Selection considering the impact on safety and performance among test subjects

In addition to a total of 10 facilities ranging from the main body of the reactor to the power conversion system under Article 19 (regular inspection) of the Enforcement Rules of the Atomic Energy Act, the total number of facilities subject to regular inspection is 11 including those related to safety of other reactors as stipulated in Article 2017-18 of the Atomic Energy Accreditation Notice and 2017-28. Eight other facilities related to the safety of nuclear reactors are designated for structures, water systems, air conditioning and ventilation systems, power systems, auxiliary systems, power conversion systems, moderator system facilities (as pressurized heavy water reactor type), and severe accident prevention and mitigation facilities.

Items for each facility subject to regular inspection were selected in consideration of the effects on safety and performance in accordance with the original safety notice No. 2017-28. The total number of items was confirmed to be 100 based on KINS's Periodic Inspection Guide (Rev. 3, 2015.10).

The KINS's regular inspection guidelines were developed for KINS to conduct regular inspections of power generation reactors and related facilities in a more systematic and efficient manner. This guideline has been developed since 1991 and has been revised according to changes in the regulatory environment, including the integrated inspection of the first and second systems of nuclear power plants and the regular inspection of standard nuclear power plants using risk information in 2006, and has been revised to reflect changes in domestic and overseas environment, such as the SBO and Fukushima accident, as well as the re-evaluation of the changed regulatory standards.

This handbook provides guidelines for inspection items, including inspection items/targets, inspection contents and methods, and judgment criteria for four types of nuclear power plants currently in operation in Korea: Westinghouse-type, Candu-type, Pramatom-type and Korean Standardized Nuclear Power Plants. Figure 71 illustrates the inspection check table for measuring the leakage rate of the reactor coolant system, which is an inspection item for the reactor coolant system facilities.

3.3 Inspection Vulnerability

Although regular inspections are the most important regulatory inspection activities for ensuring the safety of operational nuclear power plants, they show insufficient reflection on the requirements and guidance of IAEA in Chapter 2. The Nuclear Safety Act, the Enforcement Decree of the same Act, the Enforcement Decree of the Act and the Enforcement Rules of the Act and the original draft stipulate that 12 facilities, 100 items, and 322 areas have equal importance without any difference depending on risk and safety importance, and the concept of defense systems at each stage from normal operation to emergency measures in depth is not clearly shown. Since the inspection of radioactive defense, which is the fifth step of in-depth defense, is carried out separately according to the Radiation Prevention and Countermeasures Act, regular inspection should actually check steps 1 to 4 of the in-depth defense, but the inspection system of the current regular inspection makes it difficult to tell which inspection items are related to which stage of the in-depth defense.

In addition, the current regular inspection is conducted in the form that inspectors check each of the designated test targets without any differences in importance across the plant's entire system and facilities, requiring a relatively large number of personnel and resources. In addition, since the inspection details are described in Article 19 of the Enforcement Rules, the focus is mainly on verifying the normal operation and performance of each equipment at the nuclear power plant, the verification of the safety function perspective performed by one or more systems and devices in an organisational manner to cope with the accident and accident situation is insufficient.

4. U.S inspection system

Safety checks by U.S. operators are carried out in accordance with the safety inspections by the U.S. Nuclear Regulatory Commission (NRC) conducted under the Reactor Overweight Process (ROP).

4.1 ROP System

The NRC's ROPs are carried out by establishing a reactor supervisory system, as shown in Figure 1.

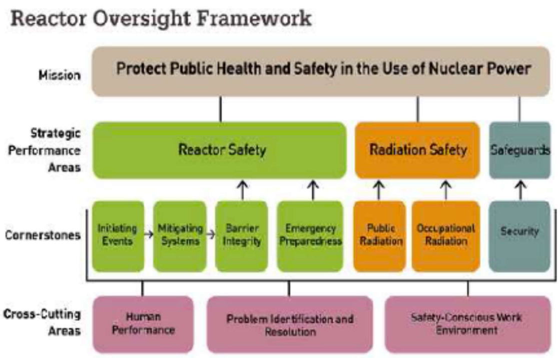

Fig. 1. ROP System in U.S[3]

The core objectives of the reactor supervisory system are to protect and ensure safety of the public during the use of nuclear energy, and the selection of reactor safety, radiation safety and safety measures are key strategic performance areas to achieve this.

3.3 Reactor Supervision Procedure and Inspection Program

The reactor supervisory procedure and the inspection program ROP are programs for NRC to inspect, determine and evaluate the safety and performance of operational nuclear power plants and to respond to degradation of the capability as shown in Figure 2.

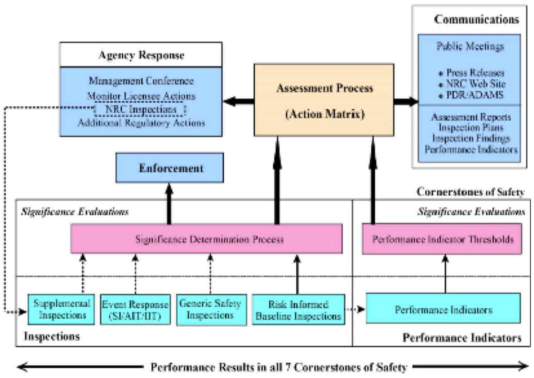

Fig. 2. ROP Overview[4]

The ROP largely collects information about a licensee's safety performance through two methods: inspection (Inspection) and performance indicators (PI). The significance of the collected information is assessed using the Significance Evaluation Process (SDP) and PI Boundary (Threshold) respectively, and the action matrix appropriately responds to the information at a level suitable for its importance.
The inspection, one of the ROP's data collection methods, is carried out to verify the accuracy of the operator's report on inspection 2 PI for areas not reflected by 1 PI3 and to review the effectiveness of the operator's detection and resolution of problems, and the types of in-ROP inspection programs are as follows: Risk-Informed Baseline Inspection Program (Baseline) Inspections, Plant Specific Supplemental Inspections, Generic Safety Issue, Special, and Infrequent Inspections.

3.4 Evaluation of Inspection Points

If an issue is found through baseline inspection, etc., the importance is assessed through the following steps.

The issue is referred to as 'findings' after two procedures (Performance Definition, Issu Screening) are classified as performance deficiencies above minor importance, and appropriate SDPs are selected for evaluation of these points through the initial characterization procedure of those comments. The inspector shall document and review all supporting information related to the comments in a concise format through the Finding Consolidated Information Sheet form, and identify which cornerstone the points belong to through the Cornerstone Affected by Degraded Condition or Programmatic Weakness form. The SDP Appendix Router form then selects the appropriate SDP for subsequent materiality assessments. In the subsequent steps, this report is of interest : Significance Detection of Reactor Inspections for At-Power Situations only.

4. Conclusions

So far, the safety requirements of IAEA GSR Part 1 and the safety guidelines of IAEA GSG-13 and the inspection systems in the U.S. were investigated and analyzed based on the report of INSAG to identify the reasons for the differences, and the following improvements were derived from the results.

1. Utilization of risk information
IAEA Safety Requirements GSR Part 1 4.50 and 52 and Safety Guide GSG-13 3.226 items need to be applied to establish a system that can be performed differently using risk information for inspection. Differential approaches for using risk information can be used to establish the frequency of inspection, and can also be used in selecting subjects for inspection, calculating input resources, and determining the number of test samples.

2. Utilizing plant performance
Performance evaluation results need to be utilized for inspection by reflecting IAEA Safety Guide GSG-13 3.254 e and g items. As with the risk information, the plant's performance is utilized to select the frequency of the inspection so that the inspection can be performed in a differential manner.

3. Utilization of Deep Defense Concepts
The concept of defence in depth should be utilized for inspection by reflecting IAEA INSAG-12 that states that defence in depth is based on securing safety of the plant and that inspection can be used as a means of establishing an independent defence step, as well as inspection of defence in depth. This requires the selection of function-oriented inspection items rather than facility-oriented ones by linking the safety functions of each system and device with the concept of in-depth defense.

REFERENCES

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[3] NRC Home Page, "ROP Framework," https://www.nrc.gov/reactors/operating/oversight/rop-description.html
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[5] IAEA, "Functions and Processes of the Regulatory body for Safety", IAEA Safety Standards Series No. GSG-13, (2018)
[6] International Nuclear Safety Advisory Group, "Basic Safety Principles for Nuclear Power Plants, 75-INSAG-3 Rev. 1", INSAG-12, (1999)