Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Study of Concrete Structures and CCTVs for the Aging Regulation of Target Set Protection Measures in Nuclear Power Plants

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Keywords : aging evaluation, physical protection, target set protection facility

1. Introduction

In the early years of nuclear power plant (NPP) operation, routine inspection and maintenance were considered sufficient to ensure reactor safety. However, with increasing operational years and progressive aging, emerging safety issues, evolving safety standards, and advances in analytical techniques have raised doubts about the adequacy of conventional safety measures. To address these concerns, the Periodic Safety Review (PSR) system was introduced in 1994 to conduct systematic and comprehensive safety reassessments of operating reactors at regular intervals.

Aging evaluation, one of the 14 safety factors in PSR, examines the actual condition of major structures, systems, and components (SSCs), the effects of aging, and the adequacy of aging management plans. Without proper management, degradation mechanisms—such as corrosion, wear, irradiation embrittlement, and thermal aging—can compromise the functionality of key SSCs. While the United States Nuclear Regulatory Commission (NRC) mandates maintenance programs for physical protection–related target set protection facilities, no equivalent regulatory requirements currently exist in Korea.

This paper aims to contribute to the establishment of aging evaluation regulations for target set protection facilities through the presentation of publicly available information on the maintenance and replacement cycles of concrete structures and closed-circuit television (CCTV) systems. The findings are expected to support researchers, plant operators, and regulatory bodies in developing integrated management programs for target set protection facilities.

2. Aging of safety related systems in Korea

In the Republic of Korea, PSR is conducted in accordance with Article 23 of the Nuclear Safety Act and Article 20 of its Enforcement Decree. The review encompasses 14 safety factors, including the assessment of aging effects. To evaluate aging, the following elements are included:
(a) classification and selection of SSCs subject to assessment; (b) analysis of aging phenomena for each selected SSC; (c) evaluation of the functional capability and safety margins of SSCs in light of aging effects; (d) prediction of the end-of-life and future condition of safety-significant SSCs; and (e) current condition of safety-significant SSCs, along with ongoing or planned mitigation measures and management programs for aging. The evaluation of aging is conducted as presented in Table 1.

Table 1. Evaluation Process of Aging [1]

Category	Description
Verification of actual physical condition of the plant	The evaluation is performed by referencing all relevant documents, including general information, equipment configuration and functions, design and operational characteristics, testing/ inspection/ maintenance history, management programs, and data management systems, with particular emphasis on the FSAR(1), PUMAS(2), and P&ID(3).
Assessment of service life and aging management	Based on the FSAR and PUMAS, the target systems, structures, and components are selected. Their service life is assessed through the review of operational and maintenance history and diagnosis of aging, and management strategies are established for key aging mechanisms.
Evaluation of implementation and record management of the aging management program	Implementation procedures for the aging management program are established, and an aging management database is developed. Aging-related data for the components are compiled and utilized for the next PSR cycle.

(1) FSAR: Final Safety Analysis Report
(2) PUMAS: Power Unit Maintenance System
(3) P&ID: Piping and Instrumentation Diagram

Aging evaluations for safety-related structures are being properly implemented in accordance with relevant regulations and legislation.

Table 2. Aging Evaluation Targets in the 20-Year PSR Report for Hanbit Units 1 and 2[2]

Reactor Pressure Vessel	Reactor Internals	Control Rod Drive Mechanism	Steam Generator
Pressurizer	Primary System Piping	Reactor Coolant Pump	Supports / Pipe Rupture Restraints
Valves / Valve Actuators	Instrumentation and Control System	Electrical Power System	Heat Exchanger Group
HVAC System	Emergency Diesel Generator	Fire Protection System	Secondary System Piping
Turbine System			

However, as shown in Table 2, aging evaluations have not been implemented in Korea for target set protection facilities and components associated with physical protection. Moreover, no regulatory framework or standardized procedures currently exist to ensure the long-term integrity of these protective elements.

3. Aging of physical protection systems in U.S.

In the United States, under 10 CFR 73.46, aging evaluations are required not only for safety-related structures and components but also for target set protection facilities associated with physical protection.

Table 3. Summary of 10 CFR 73.46 [3]

Category	Description	Frequency / Condition
Testing and inspection during installation	Verification that physical protection subsystems and components meet design criteria and performance specifications	During installation and construction
Pre-operational testing and inspection	Demonstration of effectiveness and availability of systems	Before the start of operation
Operational testing and inspection	Ensuring operability and effectiveness of protection systems	Performed regularly during operation
Intrusion alarm testing	Functional check of intrusion detection systems	At the beginning and end of each period of use; if used continuously for more than 7 days, then at least once every 7 days
Communications equipment testing	Performance check of communication systems	Onsite communications: at the beginning of each security shift Offsite communications: at least once per day
Preventive maintenance program	Maintenance planning to ensure continued operability of protection systems	Continuously implemented
Corrective actions and compensatory measures	In the event of failure or scheduled maintenance: – Maintenance performed by two qualified individuals – Security organization notified before and after maintenance – Post-maintenance performance verification required	As needed during failure or routine maintenance

As shown in Table 3, U.S. regulations require nuclear power plants to establish in-house maintenance programs for target set protection facilities. In addition, the results of periodic reviews—including recommendations and any corrective actions taken—must be documented and reported to the plant manager as well as to corporate management at least one level above those responsible for daily operations. These reports must be maintained in an auditable form for at least three years and be made available for review during inspections.

However, while regulatory texts provide descriptions of maintenance programs for physical protection systems and components, they do not specify which protection structures or equipment are subject to these programs or how they are to be maintained in detail. Therefore, this study aims to support the development of maintenance programs by summarizing deterioration characteristics and repair methods for concrete structures—commonly used materials in target set protection facilities—as well as requirements related to the replacement cycles of CCTV systems.

4. Evaluation of concrete aging and maintenance

Cracking and spalling are among the most common aging phenomena observed in concrete structures. Therefore, this chapter presents repair options for addressing these two types of deterioration.

4.1 Cracking

The allowable crack widths for external environments, as specified by the American Concrete Institute (ACI), are presented in Table 4.

Table 4. Guidance for crack width acceptability[4]

Condition	crack widths
Severe exposure to deicing chemicals or watertightness, widths	< 0.1 mm
Normal exterior exposures or interior exposures subjected to high humidity	< 0.3 mm
Internal protected structures	< 0.2 mm
Structures containing chemicals or fluids that must remain leaktight	< 0.05 mm

In the repair of concrete cracks, identifying the root cause is of paramount importance. Cracks in concrete structures can arise from a variety of causes, including impact loads, chemical reactions, and volumetric changes. Since each cause may require a different repair approach, it is essential to select a method appropriate to the specific mechanism of cracking. For instance, in the case of fine cracking, applicable techniques include (1) coatings, (2) penetrating sealers, and (3) autogenous healing for newly cast concrete. For large, isolated cracks, effective methods include (1) epoxy injection, (2) route and seal, and (3) stitching.

4.2 Spalling

Spalling can occur due to issues such as impact, corrosion of embedded metal, alkali-aggregate reaction, freeze-thaw cycles, and fire exposure. The concrete matrix should be sound, and exposed surfaces should be free from moisture and particles such as oil. Cracking can sometimes lead to spalling. Spalling can be repaired by classifying it into shallow spalling and deep spalling, as shown in Tables 5 and 6, respectively.

Table 5. Guide to repair options for shallow spalling[5]

Repair options	Perceived durability rating (1–5)	Comments
Portland cement grouts	3	Not good for acid attack
Polymer modified grout	2	Different thermal coefficient
Coatings	4	Limited to shallow areas
Membranes	3	Acids: epoxy, methacrylate, butyl, neoprene
Polymer grouts	2	Acids use polyester grout

Table 6. Guide to repair options for deep spalling[5]

Repair options	Perceived durability rating (1–5)	Comments
Portland cement concrete	2	Inexpensive
Expansive cements	3	Unreliable expansion
Gypsum based concrete	5	Do not use in moist environments
High alumina (modified)	3	Bonds best to dry concrete
Magnesium phosphate	2	Base concrete must be dry
Polymer modified	2	Thermal stress can be high
Polymer patching materials	3	Less than 40 mm thickness
Polymer overlays	2	25–50 mm thickness
Latex modified concrete overlays	2	Greater than 30 mm thickness
Portland cement concrete overlays	3	Use low water to cement ratio and high range water reducer
Silica fume overlays	3	High strength
Preplaced aggregate	2	Low shrinkage
Shotcrete	3	Good for large areas

5. CCTV Maintenance & Replacement Cycles

5.1 CCTV Maintenance Practices in the U.S.

In the United States, regular maintenance is applied as the method for maintaining CCTV systems[6]. Regular maintenance refers to maintenance activities conducted according to a predetermined schedule, involving inspections or repairs at fixed intervals to prevent equipment failure. Information corresponding to the replacement intervals of CCTV systems could not be confirmed.

5.2 CCTV Maintenance Practices in the U.K.

In the United Kingdom, prevention maintenance[7] is applied as the method for maintaining CCTV systems. Periodic maintenance refers to the regular inspection and upkeep of equipment such as machinery, facilities, systems, and IT infrastructure. The British Security Industry Association (BSIA)[8] states that CCTV systems should be replaced according to the replacement intervals specified by each manufacturer.

5.3 CCTV Maintenance Practices in Korea

In South Korea, correction maintenance and preventative maintenance are applied as methods for maintaining CCTV systems. Correction maintenance refers to maintenance activities that identify, isolate, and correct errors to restore malfunctioning equipment, machinery, or systems to operating conditions within specified tolerances or limits during service. The Korean Industrial Standards Committee, similar to the British Security Industry Association (BSIA), states that CCTV systems should be replaced according to the replacement intervals specified by the manufacturer. However, it has been confirmed that Korea Hydro & Nuclear Power (KHNP) replaces CCTV systems every seven years in accordance with the Public Procurement Service notice. Therefore, KHNP should align its maintenance practices and CCTV replacement intervals with the methods recommended by the Korean Industrial Standards Council.

6. Conclusions

This paper highlights the necessity of implementing aging evaluations for target set protection facilities related to physical protection. While the United States mandates maintenance programs for these critical elements, Korea currently lacks corresponding regulatory requirements. In the absence of such measures, deterioration over time may compromise the functionality of these protection facilities in the event of sabotage. To illustrate potential components of such maintenance programs, this study presents examples including replacement cycles for CCTV systems and aging assessments for concrete protection structures. Therefore, it is recommended that Korea establish regulatory mechanisms that require maintenance programs for target set protection elements at each nuclear power plant to ensure long-term protective integrity.

Acknowledgement

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety(KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission(NSSC) of the Republic of Korea. (No. RS-2022-KN067010 and RS-2021-KN050610)

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