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Preparatory Framework for Acquiring Long-Term Degradation Data of Concrete in Nuclear Power Plant Decommissioning

Su Hee Lee *
Growth Research Laboratory, Central Research Institute, Korea Hydro& Nuclear Power Co.,LTD, Daejeon, 34101
**Corresponding author: suhee.lee@khnp.co.kr*

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1. Introduction

The concrete structures in nuclear reactors have been exposed to long-term operational stresses and radiation, leading to various degradation mechanisms that may differ significantly from those observed in conventional concrete structures. Studying these degradation characteristics is essential for assessing the long-term safety, maintenance, and potential recycling of materials from nuclear facilities.

This paper focuses on the preparatory work required to establish a robust data acquisition and management system for investing the long-term degradation characteristics of concrete used in nuclear power plants. By developing standardized protocols and evaluation methodologies prior to the actual dismantling, we aim to ensure that once dismantling commences, the data can be rapidly and efficiently collected, analyzed, and applied to future safety and recycling strategies.

2. Research Methods and Plans

2.1 Preparatory Phase

The preparatory phase focuses on laying the groundwork necessary for effective data acquisition and management once the dismantling process commences. First, a thorough literature review will be conducted, examining international and domestic decommissioning projects, concrete degradation mechanisms, and relevant data acquisition techniques. This review will help identify best practices, establish standardized protocols, and highlight potential challenges specific to nuclear facility concrete.

Next, a sample collection plan will be designed to guide the selection of representative concrete specimens from various structural locations within decommissioned nuclear power plants. Because the reactor's operational history and radiation exposure can vary significantly from one area to another, careful mapping of these conditions is essential. The plan will also include guidelines for documenting key parameters such as temperature, humidity, and neutron flux history, ensuring that each sample is accompanied by comprehensive metadata.

2.2 Evaluation Techniques and Data Analysis Framework

To capture the full spectrum of concrete degradation phenomena, the study will employ both mechanical testing and non-destructive testing (NDT). Mechanical tests, such as compressive strength, tensile strength, and modulus of elasticity measurements, will provide baseline information on the structural integrity of the concrete. Meanwhile, NDT methods, like ultrasonic pulse velocity and rebound hammer tests, will help identify internal flaws, microcracking, and other indicators of progressive deterioration without damaging the samples.

In parallel, chemical and microstructural analyses will be conducted using X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive spectroscopy (EDS). These techniques are crucial for understanding changes in mineral composition, detecting secondary reaction products (e.g., alkali-silica reaction gels), and mapping the distribution of microcracks. The combined results from mechanical, NDT, and microstructural analyses will yield a multi-faceted perspective on the concrete's degradation state.

A key component of this paper is the development of a data standardization and management system. Prior to dismantling, the utility owner will establish consistent measurement units, testing conditions, and metadata requirements. A relational database or big data platform will be set up to store raw test results, images, and contextual information (e.g., sample location, operating history). This centralized platform will facilitate data sharing among project collaborators and support advanced analytics such as machine learning for pattern recognition or predictive modeling once sufficient data has been collected.

2.3 Future Research Plans

Once dismantling plans are approved, the methodologies and frameworks established during the preparatory phase will be put into practice. Post-approval data acquisition will involve on-site sampling, laboratory testing, and iterative refinement of protocols as real-world conditions are encountered. The validation will continuously conduct the effectiveness of each procedure, adjusting ensure the accuracy and reliability of results.

Once a robust dataset has been accumulated, predictive models for long-term degradation will be developed. These models may incorporate statistical approaches, finite element simulations, or machine learning algorithms to forecast the future performance of concrete under varying operational and environmental conditions. By comparing predictive outcomes with actual inspection data over time, the models can be iteratively improved to better capture the nuances of nuclear facility concrete degradation.

Furthermore, the findings from this study will inform life-cycle assessments and recycling strategies for dismantled concrete. Insights into residual strength, contamination levels, and chemical stability will guide decisions on whether the concrete can be repurposed for secondary construction applications or requires specific disposal methods. Ultimately, the integration of systematic data collection, rigorous analysis, and predictive modeling will contribute to safer and more sustainable nuclear decommissioning practices, offering a roadmap for future projects both domestically and abroad.

3. Conclusions

This paper outlines a preliminary review and conceptual framework for acquiring and managing long-term degradation data from dismantled concrete in nuclear power plants. In preparation for future dismantling activities, the study focuses on the concrete structures that have been exposed to prolonged operational conditions and radiation. By establishing standardized protocols and evaluation methodologies prior to dismantling, the framework aims to support future safety assessments and recycling strategies.

The proposed approach encompasses mechanical and non-destructive testing methods, chemical and microstructural analyses, and a comprehensive data management system designed to integrate and standardize results from various tests. Although actual data acquisition will only be feasible after dismantling is officially underway, the groundwork laid out in this study will streamline subsequent research efforts and facilitate the development of predictive models for long-term concrete degradation.

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