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The Development of a Systematic Assessment Tool for the Ageing Management Program of Research Reactors: A Case Study HANARO Research Reactor

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1. Introduction

The research reactor stands as a symbol of scientific advancement and innovation, enabling discoveries that span various fields. These reactors are designed to be simple and small, operating on the principles of controlled nuclear fission to generate power at lower ranges. The benefits of research reactors extend across diverse sectors, providing insights in medicine, environmental studies, materials science, and energy exploration.

However, the effectiveness and value of research reactors also face challenges, including aging degradation. This phenomenon, a result of various aging mechanisms, presents potential risks that cannot be inevitable. Aging mechanisms encompass a wide range of physical, chemical, and mechanical processes that can arise from factors such as radiation exposure, thermal stress, corrosive environments, improper maintenance, and other operational influences. Corrosion, embrittlement, and mechanical wear are just a few of the forces that can gradually compromise the integrity and safety of reactor components, thereby threatening the primary safety objective.[1]

Recognizing the imperative to manage the aging degradation in research reactors, the International Atomic Energy Agency (IAEA) mandates the implementation of comprehensive aging management programs. These programs are designed to ensure the safe and efficient operation of reactors, offering strategies that include inspection, surveillance, maintenance, and the replacement of components before they can pose a threat to safe operations.[2][3]

The Research Reactor Aging Management Program acknowledges that the accumulation of small, undetectable changes can gradually compromise the performance of safety significant systems. Guided by international standards and regulatory frameworks, the aging management program covers a range of activities from conducting detailed assessments of aging effects and identifying vulnerable components to implementing preventive and corrective actions and engaging in periodic safety reviews (PSRs).[4]

The High Flux Advanced Neutron Application Reactor (HANARO), designed and constructed by the Korea Atomic Energy Research Institute (KAERI) for neutron beam applications, nuclear fuel and material testing, radioisotope production, and neutron activation analysis, serves as a notable example.

HANARO's periodic safety review is utilized as a case study for the practical evaluation of the Aging Management Program (AMP). This endeavor aims to develop a systematic assessment guideline or assessment tool that enables operators and regulatory bodies to comprehensively assess the adequacy and effectiveness of AMP. By translating and comparing HANARO's periodic safety review with regulatory requirements for aging management, this research seeks to ascertain the efficacy of the currently applied aging evaluation program.[5][6]

By providing a valuable tool for evaluating aging programs, this research holds the promise of averting accidents by mitigating cumulative aging effects, extending reactor lifetimes, and identifying best practices that enhance overall safety.

2. Methodology

The Aging Management Program (AMP) is a robust and systematic framework designed to ensure the ongoing safety, reliability, and performance of nuclear facilities as they age. The methodology employed within the AMP encompasses several interconnected components, each contributing to the comprehensive management of aging effects:

- Screening and Monitoring for Identification of Aging Degradation: by the application of advanced techniques such as non-destructive testing, online monitoring, and real-time data analysis.
- Minimization and Mitigation of Aging Degradation by continuously detecting the trending of aging degradation and improving the aging management program AMP.
- Comprehensive Record Keeping: Inspection results, maintenance activities, and aging assessments establish a historical record.

For identifying key components sensitive to aging degradation, a detailed listing of systems, structures, and components (SSCs) within the HANARO research reactor is undertaken, using comprehensive referencing from various sources. Subsequently, the SSCs are discerned, categorized, and stratified based on their safety significance and potential vulnerability to aging mechanisms. Then an accurate delineation of aging phenomena relevant to each component is posited.

Throughout the data collection step, relevant segments from HANARO's periodic safety review documents, encompassing both Books 1 and 2, are acquired and subsequently translated. The objective is to gain an intrinsic comprehension of the reactor's current state, the outlines of its aging management strategies, and its commitment to regulatory conformance. In this process, vital insights about aging phenomena, the execution of the aging management program, ameliorative interventions, maintenance protocols, and vigilant surveillance activities are extracted and collated.

The formulation of an adeptly structured assessment tool to facilitate aging management unfolds as an essential undertaking. This tool adopts a structured tabular framework designed by the author. This framework is meticulously fashioned to encapsulate critical particulars of the aging management program for each SSC. Encompassing a spectrum of attributes, these columns encompass safety classifications, SSCs of paramount significance, the gamut of aging phenomena, stipulated acceptance criteria, envisaged consequences, inherent risks, the efficacy of mitigation methodologies, frequencies of vigilant monitoring, attendant maintenance costs juxtaposed against accrued benefits, and a steadfast alignment with regulatory mandates.

In the sphere of data collection and compilation, the assessment tool is substantiated with empirical data extracted from the meticulously translated HANARO periodic safety review documents. Augmenting the empirical repository, additional insights are gleaned from pertinent regulatory directives, scholarly literature of technical provenance, and direct engagements through colloquy with domain experts vested in the reactor's operations. This comprehensive engagement is poised to holistically refine the tool's efficacy and expedite discernment regarding its operational effectiveness, thus contributing to a profoundly fortified assessment paradigm.

3. Results

The periodic safety review of the HANARO research reactor shows that the operator applies the IAEA requirements for the aging management program which include

1- **Inspections and Monitoring:** Regular inspections of key components and systems to identify signs of wear, degradation, or other age-related issues. This might involve non-destructive testing techniques, visual inspections, and monitoring of key parameters.

2- **Maintenance and Repair:** Timely maintenance and repair of components showing signs of aging. Replacement of components that have exceeded their expected operational life might also be a part of this.

3- **Upgrades and Modernization:** Incorporating modern technologies and upgrades to enhance the safety, efficiency, and reliability of the reactor. This could involve replacing obsolete systems with state-of-the-art equipment.

4- **Documentation and Record-Keeping:** Maintaining comprehensive records of inspections, maintenance activities, repairs, and upgrades. This helps in tracking the aging process and decisions made throughout the reactor's lifecycle.

5- **Periodic Safety Reviews:** Conduct periodic safety assessments to evaluate the reactor's safety performance and identify potential concerns related to aging. This could lead to adjustments in the aging management program.

The approach to assess the aging mechanisms for the research reactor SSCs important for design integrity, and safe performance during normal operation: using Specific Safety Requirements 29, 37, 86.[7]

Tables 1, 2, and 3 show an example of some components of the control rod drive mechanism CRDM in the proposed tool to assess the aging mechanisms for the research reactor SSCs important for design integrity, and safe performance during normal operation.

4. Conclusion

As the structures, systems, and components within the research reactors undergo gradual effects of time and service conditions, their integrity and safety could be compromised, potentially undermining the very objectives they were designed to fulfill. The aging management programs, adhering to international standards and regulations, proactively address the effects of aging through meticulous strategies like inspections, maintenance, and component replacements. Their overarching goal is to prevent the gradual accumulation of degradation that might ultimately compromise safety and performance. The case study of the High Flux Advanced Neutron Application Reactor (HANARO) exemplifies the practical application of an aging management program. By evaluating its periodic safety review in alignment with regulatory requirements, this study seeks to unveil the program's efficacy, offering insights into the reactor's functionality and safety assurance.

By forging a path through the complexities of aging management, we can extend reactor lifetimes, mitigate the impact of cumulative aging effects, and uphold the utmost standards of safety. Through meticulous assessment tools and unwavering dedication to regulatory compliance, we pave the way for continued scientific exploration and innovation, secure in the knowledge that our research reactors stand as beacons of progress in a rapidly evolving world.

Table 1: An example of applying the assessment tool on the Control Rod Drive Mechanism System of the HANARO

SSC	Sub-parts	Component operation mode	Safety Significance	Aging degradation class, and degradation rate	Aging phenomena	Acceptance criteria (boundaries of operation limits)	Consequences and risks
CRDM	Stepping motors	Standby	Critical	Moderate	Wear and electrical aging	Functionality within specified parameters	Potential loss of control rod functionality leading to reactor instability
	Counter cards	Alternating	Low	Low	Electrical aging	Functionality within specified parameters	Limited impact on reactor safety; minor disruption
	Control rod position detectors,	Continuous	Critical	Moderate	Mechanical wear and electrical aging	Accuracy within a specified tolerance	Potential misalignment of control rods leading to reactor instability
	Magnetic clutches	Continuous	Moderate	High	Mechanical wear and magnetic degradation	Proper torque transmission	Potential loss of control rod control leading to reactor instability

Table 2: An example of applying the assessment tool on the Control Rod Drive Mechanism System of the HANARO con.

Mitigation method	Mitigation effectiveness (Correction)	Monitoring method	Maintenance cost and benefits	Replacement plan / Cumulative operation time	Inspection frequency	Regulatory compliance
Regular maintenance, replacement of worn components	Effective in preserving functionality	Routine electrical testing, visual inspections	Moderate cost, ensures reactor stability	Replacement as needed based on wear / 2 years	Bi-annually	Compliant
Routine maintenance, replacement as needed	Effective in preserving functionality	Routine electrical testing	Low cost, maintains functionality	Replacement as needed / 7 years	Annually	Compliant
Regular calibration, replacement of worn components	Effective in preserving accuracy	Routine calibration, electrical testing	Moderate cost, ensures reactor stability	Calibration and replacement as needed / 10 years	Bi-annually	Compliant
Regular maintenance, replacement of worn components	Effective in preserving functionality	Routine mechanical testing, torque measurements	Moderate cost, ensures reactor stability	Replacement as needed based on wear / 20 years	Bi-annually	Compliant

Table 3: An example of applying the assessment tool on the Control Rod Drive Mechanism System of the HANARO (cont.)

Documented Procedures	Record Maintenance (creating, storage, and disposal)	Document Control	Data Logging (collecting, storage, and analysis)	Historical Records keeping	Data Accessibility	Audit (data integrity and privacy)
Yes	Yes	Yes	Yes	Yes	Restricted access	Yes
Yes	Yes	Yes	Yes	Yes	Restricted access	Yes
Yes	Yes	Yes	Yes	Yes	Restricted access	Yes
Yes	Yes	Yes	Yes	Yes	Restricted access	Yes

5. References:

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[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management for Research Reactors, IAEA Safety Standards Series No. SSG-10, IAEA, Vienna (2010)

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Periodic Safety Review for Research Reactors, Safety Reports Series No. 99, IAEA, Vienna (2020)

[5] HANARO Periodic Safety Review Book 1

[6] HANARO Periodic Safety Review Book 2

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Standards Series No. SSR-3, IAEA, Vienna (2016)