Development of Regulatory Framework for the Implementation of Ageing Management Program for Research Reactors in Malaysia

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1. Introduction

Ageing management program (AMP) is essential for maintaining the structural integrity and operational reliability of nuclear reactors. As reactors age, their components are subject to various degradation mechanisms, including corrosion, irradiation effects, mechanical wear and etc. An effective AMP ensures these ageing phenomena are managed proactively, leading to enhanced safety, operational reliability, and cost savings by preventing significant safety risks, operational inefficiencies, and costly repairs or replacements.

Ageing degradation has been observed in TRIGA research reactors for a long time, necessitating the implementation of AMP in such reactors. For instance, the Dalat Nuclear Research Reactor (DNRR), Vietnam had reported numerous signs of ageing degradation in their modified 500kW TRIGA Mark II reactor [2]. Subsequently, DNRR has implemented a comprehensive ageing management program to address these issues. Similarly, the Bangladesh Atomic Energy Commission (BAEC) experienced corrosion-induced leakage in their 3MW TRIGA Mark-II research reactor [3]. A detailed investigation highlighted the lack of periodic inspections and maintenance as a contributing factor. This incident underscores that effective AMPs involve regular inspections and maintenance can prevent issues like corrosion and ensure the safety and integrity of reactor components.

These cases highlight the critical role of an effective AMP in ensuring the safety, reliability, and prolonged operation of research reactors. In Malaysia, a 1MW TRIGA Mark II is the only research reactor that has been in operation since 1982 and it is known as the TRIGA PUSPATI Reactor (RTP). The implementation of AMP for the RTP is imperative to avoid similar ageing-related issues. However, despite the evident need for robust ageing management, Malaysia currently lacks a comprehensive regulatory framework to oversight and guide the effective implementation of AMPs by operating organizations.

A comprehensive regulatory framework for AMP will ensure that ageing-related issues are adequately addressed by both the operating organization and the regulatory body, significantly reducing safety risks and operational inefficiencies. Furthermore, the presence of specific regulatory requirements and guidelines enhances the ability of operating organizations to fully understand and adhere to the necessary protocols for managing reactor ageing.

2. Methodology for developing AMP regulatory framework and regulatory requirements in Malaysia

A regulatory framework for AMP shall be established by a broad structure, outlining the fundamental from fundamental principles, to goals, regulations and guides hierarchically. While the framework is a crucial foundation, detailed regulatory requirements are essential to ensure the effective implementation of ageing management practices. Adapting to the International Atomic Energy Agency (IAEA) publications as in Fig. 1 are particularly important in this context [1,4,5,6,].

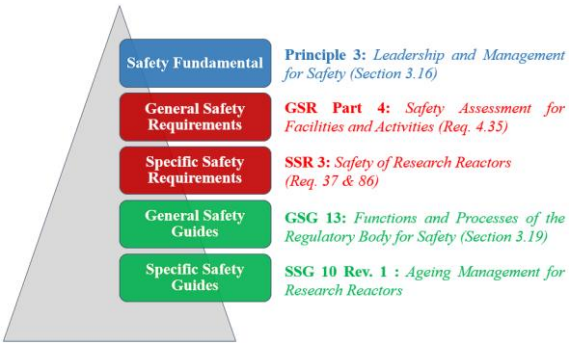

Fig. 1. IAEA publication related to AMP framework

2.1. Developing regulatory framework through Deming cycle

The overall structure of AMP can be modeled by utilizing the concept of the Deming Cycle. The Deming cycle promotes a culture of continuous improvement, essential for managing the ageing of safety-significant components and allows the structure to be flexible and adaptable to changes in technological advancements and regulatory requirements. The similar approach also can be applied to create the milestones for the

development of the AMP regulatory framework. Each phase of the PDCA cycle corresponds to specific milestones that collectively ensure the complete establishment of the framework.

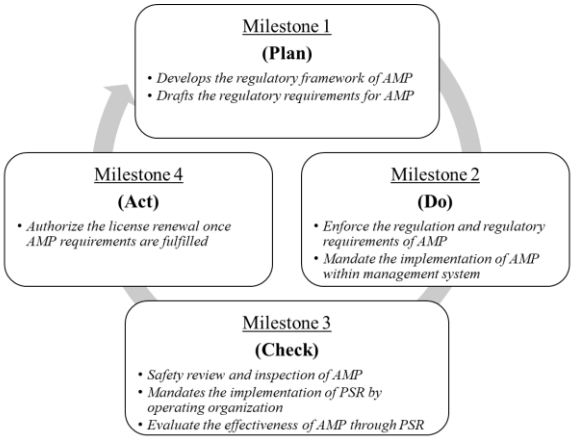

Fig. 2. PDCA approaches for milestone in developing AMP regulatory framework

The first phase, *Plan*, involves the foundational development of the AMP regulatory framework. This stage focuses on establishing the necessary legal framework and strategy that will govern the ageing management practices within nuclear facilities. During this phase, the regulatory body is responsible for preparing comprehensive regulatory requirements for AMP, ensuring they align with international standards and best practices.

The second phase, *Do*, is where the regulatory framework is put into action. This stage involves the enforcement of the developed regulations and the corresponding regulatory requirements for AMP. It is at this point that the regulatory body mandates the integration of AMP into the operating organization's management system, considering their circumstances and applicability.

The *Check* phase is critical for assessing the effectiveness of the implemented AMP. In this stage, the regulatory body mandates the operating organization to conduct a Periodic Safety Review (PSR), a key process in evaluating the adequacy and effectiveness of the AMP. Through the PSR, the operating organization must demonstrate that their AMP is functioning as intended, addressing any ageing-related issues. The regulatory body then conducts inspections and evaluates the findings using established guidelines to ensure that the AMP contributes to the overall safety and longevity of the nuclear facility

Finally, the *Act* phase involves taking corrective actions based on the inspections and evaluations from the *Check* phase. If the AMP requirements have been satisfactorily met, and the PSR indicates effective ageing management, the regulatory body can authorize the renewal of the facility's license. This phase ensures that only facilities with an effective AMP in place can continue operations, thereby reinforcing the importance of ageing management in maintaining nuclear safety

2.2. Regulatory framework for AMP

Based on the milestones in Fig. 2, the existing nuclear safety framework in Fig. 3 needs to be enhanced to incorporate a comprehensive AMP regulatory framework, as shown in Fig. 4. To effectively communicate the AMP regulations to the operating organization, regulatory requirements for AMP should be issued as guidance on how to fulfill these requirements. Furthermore, the review and inspection guideline shall be developed for the reviewers and inspectors of the regulatory body.

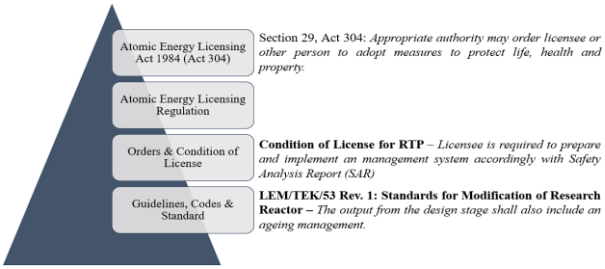

Fig. 3. Existing nuclear safety regulatory framework incorporating AMP elements

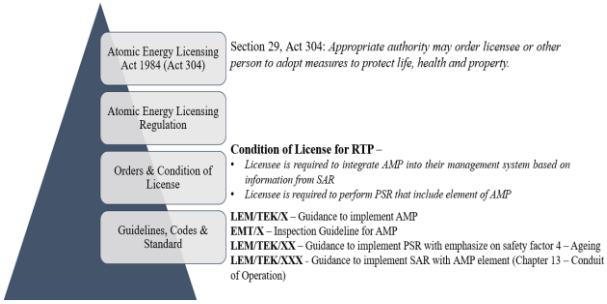

Fig. 4. Proposed integration of AMP into the existing nuclear safety regulatory framework

3. Developing the regulatory requirements for AMP in Malaysia

3.1. Regulatory requirements for AMP

The proposed regulatory requirements for the AMP are drafted across nine chapters, following the guidelines provided in the IAEA Safety Standards Series No. SSG-10 Rev. 1, 'Ageing Management for Research Reactors,' along with other relevant publications as follow:

(1) Scope of the AMP
(2) Management responsibility
(3) Interface with management system

(4) Screening of structure, system and component (SSC)
(5) Identification of ageing mechanisms
(6) Detection, monitoring, and identification of trends in ageing effects
(7) Corrective action for ageing effects
(8) Interface with maintenance and surveillance program
(9) AMP effectiveness evaluation

These regulatory requirements will undergo the V&V process using the Goal-Claim Network approach to systematically evaluates whether the requirements meet their intended safety objectives (goals) and can be practically implemented by the operating organizations (claims).

3.2. Drafting the regulatory requirement through V&V Goal-Claim network

The V&V (Verification and Validation) Goal-Claim Network is a structured approach that can be used to systematically demonstrates that a system meets its requirements and functions as intended. The V&V approach enhances the completeness and correctness of regulatory requirements for AMP by grounding them in evidence-based practices. Each claim made within the regulatory framework must be supported by verifiable evidence, ensuring that the requirements are not only theoretically sound but also practically achievable and effective.

The structured nature of the V&V Goal-Claim Network fosters a better understanding of AMP and facilitates compliance for operating organizations, as illustrated in Fig. 5. By linking specific goals and claims to concrete evidence, the V&V approach provides a clear pathway for organizations to meet regulatory requirements, as shown in Table 1. Additionally, the V&V Goal-Claim Network significantly enhances the drafting of inspection and evaluation guidelines, as presented in Table 2. The comprehensive nature of the V&V framework ensures that all relevant aspects of ageing management are thoroughly inspected and evaluated. The goal-claim-evidence structure mandates that each claim is supported by evidence, ensuring that no critical element is overlooked during the evaluation process.

3.3. The proposed regulatory requirements for AMP

3.3.1. Scope of the AMP

This chapter should define the comprehensive scope of the AMP, outlining its objectives, boundaries, and applicability. The AMP must be integrated into every phase of the reactor's lifecycle, from design through to decommissioning. The regulatory body requires the operating organization to demonstrate the implementation of AMP activities at each stage, effectively managing ageing effects and maintaining the reactor's safety.

The AMP must follow a systematic approach. The regulatory body mandates that the operating organization develops a structured methodology, which includes identifying critical SSC, assessing ageing mechanisms, establishing monitoring programs, and implementing preventive or corrective actions as needed. Furthermore, the AMP must encompass all SSC significant to safety. The regulatory body requires the operating organization to ensure comprehensive coverage of these SSC, with detailed consideration of their potential degradation mechanisms, ageing effects, and appropriate management strategies to mitigate associated risks.

3.3.2 Management responsibility

This chapter will delineate the roles and responsibilities of management in both the regulatory body and the operating organization concerning the implementation of the AMP. The regulatory body must underscore the importance of senior management’s commitment within the operating organization, ensuring they provide the necessary resources, training, and support to guarantee the success of the AMP. The chapter should outline the required organizational structure within the operating organization, including specific roles for AMP coordination, oversight, and continuous improvement, with the regulatory body overseeing these implementations to ensure adherence to the regulatory framework.

3.3.3. Interface with management system

This chapter will describe how the AMP should be integrated into the existing management processes, including safety, quality, and environmental management systems within the operating organization. The regulatory body should provide guidance on harmonizing the AMP with other management systems to prevent duplication of efforts and ensure a cohesive approach to managing ageing. The operating organization is responsible for ensuring this integration is effectively carried out, with oversight from the regulatory body to verify compliance.

3.3.4. Screening of SSCs

This chapter will establish the criteria for screening SSCs based on their safety significance and susceptibility to ageing. The regulatory body should outline the methodology for the operating organization to identify critical SSCs requiring detailed ageing management, ensuring that all relevant SSCs are adequately considered in the AMP. The operating organization must implement this screening process in accordance with the regulatory body’s requirements.

3.3.5. Identification of ageing mechanisms

This chapter will focus on the identification and understanding of ageing mechanisms that could affect the SSCs included in the AMP. The regulatory body should provide guidance on conducting assessments to determine the impact of various ageing mechanisms, such as corrosion, fatigue, or thermal ageing, on SSCs over time. The operating organization is responsible for ensuring a thorough understanding of these mechanisms, which is crucial for informing effective ageing management strategies. The regulatory body will assess the adequacy of these assessments during inspections and reviews.

3.3.6. Detection, monitoring, and identification of trends in ageing effects

This chapter will specify the methods and techniques for detecting and monitoring ageing effects on SSCs. The regulatory body should suggest appropriate techniques, such as inspections, testing, and condition monitoring, that the operating organization must employ. Additionally, the chapter should outline the requirements for identifying trends in ageing effects and assessing their impact on the safety and performance of SSCs. The regulatory body should emphasize the importance of data collection, analysis, and trending to predict future ageing effects, with the operating organization being responsible for implementing these activities and reporting the findings to the regulatory body.

3.3.7. Corrective action for ageing effects

This chapter will outline the steps for evaluating and responding to detected ageing effects. The regulatory body should specify the process for the operating organization to follow, including the evaluation of the significance of ageing effects and the determination of appropriate corrective actions to mitigate or eliminate these effects. The chapter should also address the prioritization of corrective actions based on safety significance and potential impact on reactor operations. The regulatory body will oversee the implementation of corrective actions by the operating organization, ensuring they meet the required safety standards.

3.3.8. Interface with maintenance and surveillance program

This chapter should describe how the AMP should interface with the facility's existing maintenance and surveillance programs. The regulatory body should provide guidelines on coordinating ageing management activities with routine maintenance and surveillance to ensure that ageing issues are promptly identified and addressed. The operating organization must integrate AMP requirements into maintenance and surveillance schedules, optimizing the overall management of SSCs. The regulatory body will monitor this integration to ensure it is performed effectively and according to the established regulatory framework.

3.3.9. AMP effectiveness evaluation

This chapter should outline the process for evaluating the effectiveness of the AMP. The regulatory body should specify the criteria and performance indicators that will be used to assess whether the AMP is achieving its objectives. The operating organization is responsible for conducting these evaluations and reporting the results to the regulatory body. The chapter should also provide guidance on conducting periodic reviews of the AMP to identify areas for improvement and ensure continuous enhancement of the ageing management strategies. The regulatory body should stress the importance of feedback loops, where lessons learned from the evaluation process are used to inform future AMP activities, ensuring a dynamic and responsive approach to managing ageing.

3.4 The proposed formatting for regulatory requirements and evaluation guidelines for AMP

To provide a thorough understanding of the proposed format for regulatory requirements and evaluation guidelines for the AMP, it is essential to introduce Tables 1 and 2 with a clear explanation of their development, purpose, and how they contribute to the overall structure of AMP management. These tables specifically relate to the first chapter of the regulatory framework, which defines the scope of the AMP. Tables 1 and 2 were constructed based on the results of the V&V Goal-Claim network, a systematic approach used to establish and validate the regulatory requirements and evaluation guidelines for the AMP as illustrated in Fig. 5.

Table 1 outlines the regulatory requirements for the AMP as they pertain to the first chapter, "Scope of AMP." It details the specific requirements that must be met, the basis for these requirements, and references to relevant documents and standards. This structured approach ensures that the AMP is integrated into every phase of reactor operation, from design and commissioning to decommissioning, providing a holistic view of aging management within the defined scope.

Table 2, closely related to Table 1, provides the evaluation guidelines for the first chapter of the AMP. It describes the specific evaluations that need to be conducted to verify that the AMP is being implemented effectively within the defined scope. The table includes detailed criteria that reviewers should use to assess the adequacy of the AMP, ensuring that all aspects, such as the systematic approach to implementation and consideration of safety-critical systems, are thoroughly

evaluated within the comprehensive scope defined in the first chapter.

These tables are proposed as the proper format for structuring both the regulatory requirements and the evaluation guidelines for the AMP, specifically for the first chapter – Comprehensive Scope of AMP. By presenting the requirements and evaluations in a clear and organized manner, they serve as essential tools for regulatory bodies and operational organizations alike, ensuring that the AMP is effectively contributing to the safety and longevity of nuclear facilities. This structured approach not only facilitates compliance with regulatory standards but also promotes continuous improvement in aging management practices.

Fig. 5. Example of V&V Goal-Claim Network application for AMP regulatory requirements and evaluation

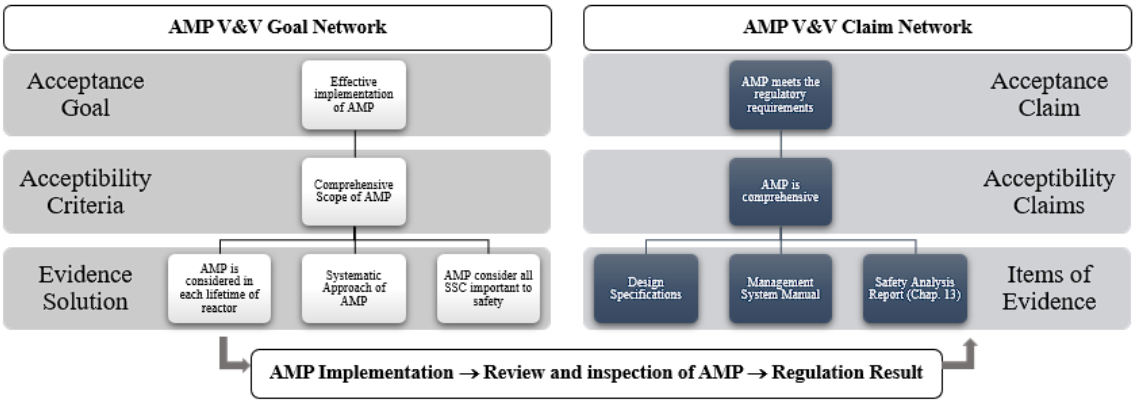

Table 1. Regulatory requirements of AMP based on V&V Goal Network

1. Comprehensive Scope of AMP	
Requirement	Basis for Requirements
1.1. Consideration of AMP across the reactor's lifetime	**Summary of the requirement to be satisfied** The AMP must be integrated into all phases of the research reactor's lifetime: (a) Design (b) Commissioning (c) Operation (d) Utilization and Modification (e) Extended Shutdown (f) Decommissioning
	Relevant documents of operating organization 1) Safety Analysis Report (SAR) 2) Reactor Design Specifications 3) Decommissioning Plan
	Relevant references IAEA SSG-10 Rev. 1, Section 4
1.2. Systematic Approach to AMP Implementation	**Summary of the requirement to be satisfied** The approach to AMP must be methodical and structured, comprising the following elements: (a) Screening of SSCs (b) Identification and understanding of degradation mechanisms; (c) Minimization of ageing effects; (d) Detection, monitoring and identification of trends in ageing effects; (e) Mitigation of ageing effects; (f) Acceptance criteria; (g) Corrective actions; (h) Review and improvement of the ageing management programme; (i) Record keeping.

	Relevant documents of operating organization 1) Management System Manual 2) Operational Procedures 3) Maintenance Records
	Relevant references IAEA SSG-10 Rev. 1, Section 5.3
1.3. Consideration of All SSC Significant to Safety	**Summary of the requirement to be satisfied** 1) The AMP specifically considers all structures, systems, and components (SSC) that are significant to the safety of the reactor, ensuring that resources are focused on the most critical elements of the reactor. 2) The AMP should identify these SSCs, assess their susceptibility to ageing, and establish a management plan that prioritizes their continued safe operation.
	Relevant documents of operating organization 1) Safety Analysis Report (SAR) 2) Final Safety Analysis Report (FSAR) 3) SSC Classification Document
	Relevant references IAEA SSG-10 Rev. 1, Section 5.4 IAEA No. SSG-30, Section 3.15

Table 2. Evaluation guideline of AMP based on V&V Claim Network

1. Comprehensive Scope of AMP	
Evaluation	Basis for Evaluation
1.1. Consideration of AMP across the reactor's lifetime	**Summary of the evaluation to be confirmed** The reviewer must ensure that the AMP is integrated into all phases of the research reactor's lifetime, including: (a) Design (b) Commissioning (c) Operation (d) Utilization and Modification (e) Extended Shutdown (f) Decommissioning
	Relevant documents to be assessed/examined 1) Safety Analysis Report (SAR): Provides an overview of the reactor's design and operational considerations, including those related to ageing. 2) Design Specifications: Contains details on how ageing management is considered during the reactor's design phase. 3) Decommissioning Plan: Outlines how ageing management is integrated into the decommissioning process.
	Relevant references IAEA SSG-10 Rev. 1, Section 4
1.2. Systematic Approach to AMP Implementation	**Summary of the evaluation to be confirmed** The approach to AMP should be methodical and structured, and the evaluation must confirm the inclusion of the following elements: (a) Screening of SSCs; (b) Identification and understanding of degradation mechanisms; (c) Minimization of ageing effects; (d) Detection, monitoring, and trend identification of ageing effects; (e) Mitigation of ageing effects; (f) Establishment of acceptance criteria; (g) Implementation of corrective actions; (h) Continuous review and improvement of the AMP; (i) Comprehensive record keeping.

	Relevant documents to be assessed/examined 1) Management System Manual: Outlines the overall management approach, including the systematic implementation of ageing management. 2) Operational Procedures: Provides details on the specific procedures used to monitor and manage ageing within the reactor. 3) Maintenance Records: Document the history of SSC inspections, maintenance, and any corrective actions taken due to ageing effects
	Relevant references IAEA SSG-10 Rev. 1, Section 5.3
1.3. Consideration of All SSC Significant to Safety	**Summary of the evaluation to be confirmed** 1) Reviewer must confirm that the AMP specifically considers all SSCs that are significant to the reactor's safety, ensuring that resources are focused on the most critical elements. 2) Reviewer must verify that the AMP identifies these SSCs, assesses their susceptibility to ageing, and establishes a management plan that prioritizes their continued safe operation.
	Relevant documents to be assessed/examined 1) Safety Analysis Report (SAR): Identifies SSCs relevant to reactor safety and discusses their role in overall safety. 2) Final Safety Analysis Report (FSAR): Provides detailed safety analysis, including the consideration of SSCs significant to safety. 3) SSC Classification Document: Classifies the SSCs based on their importance to safety, guiding the focus of the AMP
1.3. Consideration of All SSC Significant to Safety	**Relevant references** IAEA SSG-10 Rev. 1, Section 5.4 IAEA No. SSG-30, Section 3.15

4. Conclusion

A comprehensive regulatory framework for AMP is necessary to ensure that ageing-related issues are adequately addressed by both the operating organization and the regulatory body. Such a framework would significantly reduce safety risks while also enhancing the ability of operating organizations to fully understand and adhere to the necessary protocols for managing reactor ageing. The presence of specific regulatory requirements and guidelines will provide clear direction for the operating organizations, ensuring that their AMPs are aligned with international standards and best practices.

The methodology for developing this regulatory framework must be systematic and adaptable to changes in the nuclear industry. The Deming Cycle offers a model for continuous improvement, essential for managing the ageing of safety-significant components. By structuring the regulatory framework through the PDCA cycle, the regulatory body can establish milestones that guide the development and implementation of the AMP, ensuring that it remains flexible and responsive to evolving technological advancements and regulatory requirements.

Furthermore, the use of the V&V (Goal-Claim Network approach ensures that the regulatory requirements for AMP are both comprehensive and evidence-based. This approach facilitates compliance for operating organizations by providing a clear pathway for meeting regulatory requirements. The structured nature of the V&V framework ensures that all relevant aspects of ageing management are thoroughly evaluated, with each claim supported by verifiable evidence.

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