Ageing Management Programs for Spent Fuel Dry Storage Systems

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INTRODUCTION

There are generally four types of ageing management programs (AMPs) that manage ageing effects on structure, systems, and components (SSCs) in nuclear power plants and spent fuel dry storage systems for license renewal applications [1–3]. These four types of AMPs are (1) prevention programs that preclude ageing effects from occurring, (2) mitigation programs that slow the effects of ageing, (3) condition monitoring programs that inspect/examine for the presence and extent of ageing, and (4) performance monitoring programs that test the ability of a structure or component to perform its intended safety function for the requested period of the license renewal application. More than one type of AMP may be implemented for a component to ensure that ageing effects are managed effectively to reduce risks, ensure public safety and health, and protect the environment. The International Atomic Energy Agency (IAEA) Specific Safety Guide SSG-15 [4] covers spent nuclear fuel storage facilities and provides guidance and recommendations on how to comply with the safety requirements. According to the IAEA, the Safety Guides present international good practices that help users striving to achieve high levels of safety.

In this paper, we provide a brief overview of the IAEA Coordinated Research Project (CRP) on ageing management programs for spent fuel dry storage systems (2016–2021), for which Argonne National Laboratory (Argonne) participated as a member and served as chair of the working group supporting the IAEA CRP lead, with other members from Argentina, Czech Republic, France, Germany, Hungary, Japan, Pakistan, Spain, Switzerland, United Kingdom, and the United States of America. The first and the second Research Coordination Meetings (RCM) of the CRP were held at IAEA and Argonne, respectively, in October 2017 and April 2019. Because of the pandemic, the third RCM was held online, as were three other Consultancy Meetings in 2020 and 2021. Numerous Webex meetings were also held with designated section writing teams during the pandemic to discuss progress toward completion of the final report [5], which will be published by IAEA as a TECDOC in 2022.

SCOPE AND OBJECTIVE

The specific objectives of the CRP were to (1) investigate how ageing effects leading to degradation of materials used in the spent fuel dry storage systems could be managed by AMPs and (2) using existing AMPs as a basis, establish guidance on how to develop, generate, and maintain AMPs for dry storage systems of spent nuclear fuel (SNF) that can be accomplished in various ways. Many different technologies are available, and some might also be used to store other spent fuel types. Each country generally selects the storage system that best serves its needs with respect to the anticipated disposal policy and associated timeline. One can assume that different technologies based on different materials and storage environments will require separate and specific AMPs. For this reason, the CRP report has focused on approaches in developing AMPs for all current dry storage technologies.

The CRP report contains the following sections:

1. Introduction
2. National regulatory approaches to ageing management of dry storage systems
3. Methodology for generating an ageing management program
4. Identification and classification of structures, systems, and components (scoping evaluation)
5. Technical underpinning (specific ageing mechanisms)
6. Operating experiences (lessons learned)
7. Monitoring, mitigation, and repair technologies for ageing-management programs
8. Update of AMPs
9. Conclusions
10. Annexes
11. References

Participating member states volunteered to write sections and subsections, and small groups were assigned to write the material. Drafts underwent iterations, including interfacing with writing teams of other sections, until all comments were addressed in the final review by all CRP member participants.

All members agreed that the CRP report should be concise, and that relevant IAEA publication documents and references should be used when they are available. Emphases in the sections, therefore, should focus on general principles, which are illustrated by selective examples showing sufficient levels of details and elaborations in the ensuing subsections. In the national approaches to ageing management of dry storage systems in Section 2, for example, extended abstracts on national approaches to ageing management guidance were provided by the member participants in 2018. These abstracts and additional survey questions and comments were discussed during the second RCM meeting in 2019, with the following observation that the national approaches to ageing management guidance vary depending on the country's waste management policy (reprocessing and recycling or direct disposal); technology (wet or dry storage); and subsequent transportation via road, rail, or waterways. Choices of dry storage locations (at-reactor or away-from-reactor) and storage environment (indoor or outdoor) also vary, as reflected in each country's approach to ageing management guidance. The need to store spent fuel in dry storage systems (DSSs) longer than initially intended is recognized; therefore, effective AMPs are required to reduce risk, ensure public safety and health, and protect the environment. The final abstracts on national approaches to ageing management guidance can be found in Annex I, Section 10 of the CRP report.

TRANSPORTATION AFTER STORAGE

The need for transport of SNF after extended storage is also recognized, and the storage method needs to comply with the transport safety regulations in effect at the time of license renewal during storage or shipment, which may occur decades in the future. The 2018 version of SSR-6 [6] introduced the following requirements that will be applied to "shipment after storage."

Para 106: "Transport comprises all operations and conditions associated with, and involved in, the movement of *radioactive material*; these include the *design*, manufacture, maintenance and repair of *packaging*, and the preparation, consigning, loading, carriage including in-transit storage, *shipment* after storage, unloading and receipt at the final destination of loads of *radioactive material* and *packages*."

Para 503 (e): "For *packages* intended to be used for *shipment* after storage, it shall be ensured that all *packaging* components and *radioactive contents* have been maintained during storage in a manner such that all the requirements specified in the relevant provisions of these Regulations and in the applicable certificates of *approval* have been fulfilled."

Para 613A: "The design of the package shall take into account ageing mechanisms."

Para 809 (f): "If the *package* is to be used for *shipment* after storage, a justification of considerations to ageing mechanisms in the safety analysis and within the proposed operating and maintenance instructions."

Para 809 (k): "For packages which are to be used for *shipment after storage*, a gap analysis program describing a systematic procedure for a periodic evaluation of changes of regulations, changes in technical knowledge and changes of the state of the package design during storage."

Concerning Para 613A, for shipment after storage, consideration of ageing mechanisms is important because of the long period between loading and the start of shipment after storage. The consideration of the impact of ageing on the package should be supported by AMPs and time-limited ageing analyses. The AMPs should address ageing effects by including prevention, mitigation, condition monitoring, and performance monitoring for effective ageing management. Concerning Para 809 (f), justification of considerations of ageing mechanisms, and Para 809 (k), the gap analysis is a periodic assessment of whether the package design complies with the current transport regulations. This gap analysis should consider changes in the regulations, changes in technical knowledge, and changes of the state of the package due to ageing during storage, resulting in the identification of gaps and research actions to fill the gaps.

EXAMPLES OF AMPs

Example AMPs in Section 3 of the CRP report illustrate an acceptable generic approach to managing the credible ageing effects that were identified in the ageing management review (AMR). The example AMPs may be used/credited by operators, but the regulatory body should ensure that the operator demonstrates that the design features, environmental conditions, and operating experience for the subject facility or DSS are bounded by those evaluated in a specific license renewal application. Otherwise, the regulatory body should ensure that the operator augments the AMPs, as appropriate, to address the impact of unique design or operating parameters. Five AMPs are included in Section 3 as examples that illustrate the general principles of the AMP: (1) monitoring of metallic surfaces, (2) bolted-cask seal-leakage monitoring, (3) reinforced-concrete structures, (4) localized corrosion and stress corrosion cracking of welded stainless steel dry storage canisters, and (5) structural and functional integrity monitoring of canister/cask internals.

TIME-LIMITED AGEING ANALYSES

Depending on national requirements, some ageing effects may not require an AMP if the effects can be shown, by analysis, to be incapable of adversely affecting a safety function for the licensed operating period. Such analyses are usually a design-basis safety analysis with a time-dependent component. These analyses are referred to as time-limited ageing analyses (TLAAs). TLAAs are calculations or analyses used to demonstrate that SSCs within the scope of ageing management review will perform their safety function(s) throughout the operating period. TLAAs may be used to assess fatigue life (number of cycles to predicted failure) or time-limited life (operating time frame until expected loss of intended function, such as a corrosion-rate calculation). TLAAs should account for environmental effects that contribute to ageing effects. Examples of TLAAs are (1) fatigue analyses of metallic structures and components to determine the number of loading cycles to failure, (2) boron depletion analysis of neutron poison plates to evaluate the potential loss of criticality control due to neutron irradiation, and (3) corrosion-rate calculations to determine if the loss of material from metallic surfaces could degrade structural and shielding functions.

SCOPING EVALUATION

Section 4 of the CRP report provides guidance for the identification and classification of the SSCs to be considered in the AMR for DSSs and Dry Storage Facilities (DSFs). The main objective of the scoping evaluation is to identify SSCs that are within the scope of the AMR and considered either Important to Safety (ITS) or not ITS, but the failure of which may affect ITS of the SSCs. The in-scope SSCs may contain subcomponents and identify the ITS function or functions for each of them, such as structure support, confinement boundary, heat transfer, radiation shielding, and criticality control. There are some components of DSFs that have not been mentioned in Section 4; they can be included in the scope of the AMR if they affect the fulfillment of a safety function, such as radiation shielding.

TECHNICAL UNDERPINNING

The development of an effective AMP requires an understanding of the degradation mechanisms that may be active for the storage system materials in their service environments over time. Several resources are available to aid this understanding, including inspection findings and other operating experience from the nuclear and non-nuclear industries, reports from research programs, and technical documents that summarize and evaluate available ageing information. Based on Ref. [2], three summary tables are included in Section 5.1 of the CRP report showing various ageing mechanisms for concrete overpacks and support pads, materials for spent fuel assemblies, and materials for various components in dry storage systems. Section 5.2 on functional materials summarizes the state of knowledge of three selected ageing mechanisms relevant to DSSs, with elaborations on how functional materials in dry storage systems must be systematically evaluated to understand how they may degrade under thermal and radiation exposures, corrosive environments, and mechanical stressors. The three specific ageing mechanisms are (1) stress corrosion cracking of canister (Section 5.2.1), (2) creep of lid seals for bolted metal cask (Section 5.2.2), and (3) alkali-silica reaction of concrete (Section 5.2.3). The first two subsections contain additional sub-subsections providing further details on the physics of the specific ageing mechanisms for the functional materials and environmental interaction.

OPERATING EXPERIENCES

Section 6 of the CRP report summarizes operating experiences (Lessons Learned) associated with ageing management for different DSSs, as provided by Japan, Germany, and the United States, and for DSF, as provided by Argentina. In the United States, the Institute of Nuclear Power Operations (INPO) established a clearinghouse of ageing-related information relevant to dry-cask storage SSCs. Its development was facilitated through agreements between INPO and the 10 CFR 72 Certificate of Compliance (COC) holders. The Aging Management

Institute of Nuclear Power Operations (INPO) Database (AMID) has since been implemented through separate agreements between the CoC holders and licensees of Independent Spent Fuel Storage Installations (ISFSI), including ISFSI licensees for shut-down plants, to provide a centralized location where the ISFSI licensees and CoC holders can store, access, search, and create reports. Periodic reports are provided to the NRC upon request. Unlike other INPO operating-experience sharing tools, AMID contains positive information about inspection results that simply confirmed DSS integrity, along with lessons learned, that might require industry-wide corrective action.

MONITORING, MITIGATION, AND REPAIR

As noted earlier, condition monitoring and performance monitoring are two types of AMPs for SSCs in dry storage systems or facilities. Monitoring could be continual or continuous, whereby periodic inspection is a key element of an AMP that inspects (and evaluates) the SCCs by using nondestructive examination (NDE) methods. Periodic inspections of SSCs identify active degradation that exceeds the AMP acceptance criteria and requires corrective action in mitigation and repair. Subsequent inspections may be conducted more frequently and on a larger sample size. For potential degradation that is below the AMP acceptance criteria, future inspection is based on monitoring and trending, whereby the inspection frequencies and sample sizes may be adjusted as necessary. The goals of periodic inspection (or continual monitoring) are to verify that part or all of the inspected SSCs are free from active degradation, mitigate and repair if active degradation were found, and adjust the planned inspection frequency accordingly.

Section 7 of the CRP report provides descriptions of the state-of-art technologies in monitoring, mitigation, and repair for AMPs. Subsections 7.1 and 7.2 describe bolted-cask systems and welded-canister systems, respectively, and each subsection contains three sub-subsections on ageing-related effects, inspection challenges, and NDE operational experience. Subsection 7.3 covers concrete inspection, whereas subsection 7.4 describes monitoring systems that are, or could be, employed to help augment inspections or potentially reduce the frequency of (or eliminate) inspections. Continuous and periodic condition and/or performance monitoring would enable timely detection of ageing effects, such as pressure drop and/or leakage from the confinement boundary of bolted casks or welded canisters, thus allowing mitigation and repair to continue effective ageing management of DSSs that reduces risk, ensures public safety and health, and protects the environment. Various monitoring technologies are at different stages of development and implementation. The primary monitoring systems that are in common usage today are pressure-monitoring systems for bolted-cask systems (Subsection 7.4.1) and temperature-monitoring systems (Subsection 7.4.2) for both bolted-cask and welded-canister system. Other monitoring systems are briefly described in Subsections 7.4.3 through 7.4.6 that include acoustic emission, helium, concrete, and radiation.

UPDATE OF AMPs

During extended storage of spent fuel, the state of the storage system SSCs may change, related technical knowledge may change, and related regulations may change. With those changes, the AMPs described in Section 3 may need to be updated. To ensure continued safe storage of SNF, operating experience on age-related degradation and ageing management should be used to update AMPs. Operators should review operating experience to confirm that the AMPs remain effective at managing age-related degradation or make any necessary changes to AMPs to ensure their continued effectiveness. In this way, the AMPs are considered learning programs that evolve to respond to operating experience. This approach is often called 'Plan/Do/Check/Act' (PDCA) cycle (Figure 1), introduced first time for ageing management of nuclear power plants, which is also applicable to spent fuel dry storage systems.

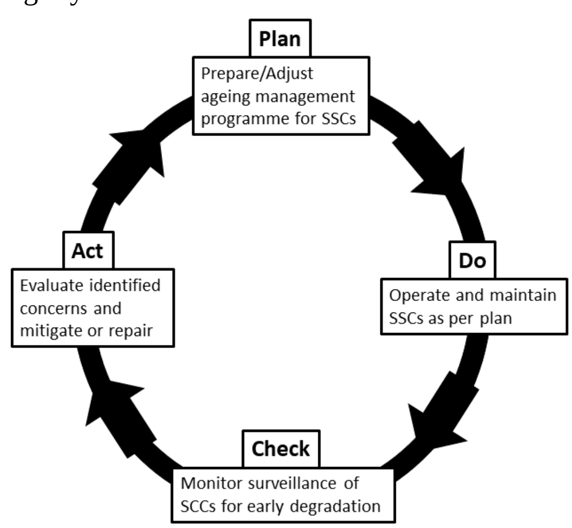

Figure 1. Plan/Do/Check/Act (PDCA) cycle for AMPs

SUMMARY AND CONCLUSIONS

A summary description has been provided for the IAEA CRP final report on ageing management programs for spent fuel dry storage systems (2016–2021). The CRP final report will be published by IAEA in 2022. A new CRP on Performance and Assessment of Storage Systems for Extended Durations (PASSED) has been launched in 2022 [7]. PASSED expands the scope of ageing management programs to cover many aspects related to storage systems, dry and wet, including performance, monitoring and inspection, mitigation, and remedial actions.

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