doi.org/10.15392/2319-0612.2024.2670
2024, 12(4B) | 01-14 | e2670
Submitted: 2024-08-29
Accepted: 2025-05-06

IPR-R1 Triga Reactor aging management approach

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Abstract: A global nuclear safety regime is in place and is being continuously improved. In this context, the aging management of research reactors is one of the requirements for licensing by the regulatory body. The IPR-R1 Triga reactor, located at the for Nuclear Technology Development Center (CDTN), is a nuclear reactor used primarily to research support. It has been in operation for over 60 years and its activities are expected to continue. Thus, the aging management of components, structures and systems is one of the safety factors included in the Periodic Safety Report and encompasses several programs and activities, following the Specific Safety Guide SSG-10 (Aging Management for Research Reactors) of the International Atomic Energy Agency (IAEA). These programs are broad and transversal, serving as input for critical analysis of the Aging Management Plan (AMP), aimed at its continuous improvement. This paper aims to systematically present information related to the AMP of the CDTN IPR-R1 Triga reactor, such as visual inspection, reactor pool water quality control, maintenance, obsolescence control, investigation of operational parameters and all necessary controls to ensure that the safety margins required in the reactor design are maintained throughout its useful life.

Keywords: Aging management, Triga, Research reactor.

doi.org/10.15392/2319-0612.2024.2670
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Submitted: 2024-08-29
Accepted: 2025-05-06

Abordagem de gestão de envelhecimento do Reator Triga IPR-R1

Resumo: Um regime global de segurança nuclear está em vigor e está sendo continuamente aprimorado. Nesse contexto, o plano de envelhecimento para reatores de pesquisa é um dos requisitos para o licenciamento junto ao órgão regulador. O reator Triga IPR-R1, localizado no Centro de Desenvolvimento de Tecnologia Nuclear (CDTN), é um reator nuclear usado principalmente para dar suporte à pesquisa. Ele está em operação há mais de 60 anos e suas atividades não devem cessar. Durante esse período, algumas reformas e melhorias foram feitas em suas instalações. O gerenciamento do envelhecimento é um dos fatores de segurança incluídos no Relatório Periódico de Segurança e engloba vários programas e atividades tais como, inspeção visual, controle da qualidade da água da piscina do reator, manutenção e atividades relacionadas ao controle de obsolescência e investigação de parâmetros operacionais, seguindo o Guia de Segurança Específico da Agência Internacional de Energia Atômica (AIEA). Esses programas são amplos e transversais, servindo de insumo para análise crítica do Plano de Gerenciamento do Envelhecimento (PGE), visando sua melhoria contínua. Este artigo tem como objetivo apresentar sistematicamente as informações relacionadas com PGE do Reator Triga IPR-R1 do CDTN, incluindo os controles necessários para garantir que as margens de segurança exigidas no projeto do reator sejam mantidas durante toda sua vida útil.

Palavras-chave: Gestão de envelhecimento, Triga, Reatores de pesquisa.

1. INTRODUCTION

IPR-R1 Triga research reactor, Mark I model from General Atomics (GA), was acquired in 1960 and is located at CDTN (Nuclear Technology Development Center*)*. Initially, the reactor operated in a permanent thermal power regime at 30 kW and at 100 kW in an intermittent regime. Since 1973, it has operated at 100 kW continuously, which is its current and maximum operating power level. By the end of year 2000, several actions and experiments were carried out to increase its power to 250 kW. IPR-R1 Triga reactor has been in operation for more than 60 years and is not expected to close its activities. During this period, some renovations and improvements took place in its facilities [1,2].

Brazilian Nuclear Energy Commission (Cnen) has granted a Permanent Operation Authorization for the CDTN IPR-R1 Triga research reactor. One of the requirements for Permanent Operation for CDTN Triga reactor is related to the implementation of an effective aging management system, which can demonstrate that the effects of aging are managed so that the intended functions of the structures, systems, and components (SSCs) can be maintained consistently based on the current reactor license.

Aging management is one of the safety factors contained in the Periodic Safety Report (licensing requirement for IPR-R1 Triga Reactor) and covers several mechanisms (programs and procedures). Aging management is defined as an engineering, operation, and maintenance strategy that includes actions to control within acceptable limits the aging degradation of SSCs [3]. In the case of research reactors, there are two types of time-dependent changes: the degradation of the SSCs' physical characteristics and the obsolescence.

This paper describes the Aging Management Plan (AMP/CDTN) for IPR-R1 Triga reactor that was initiated in 2002 [4] and last updated in 2023 [5]. It presents all controls (programs/procedures) used to ensure that the safety margins required in the reactor design are maintained throughout time, including the identification of SSCs, the methodology to detect and evaluate degradation of the aging, and actions to prevent and mitigate it.

2. MATERIALS AND METHODS

The regulatory requirement for CDTN Triga's Permanent Operation license defines the IAEA Specific Safety Standards Guide N. 10 (Rev.0) [3] as a base document. So, the Aging Management Plan - AMP/CDTN implementation methodology consists of covering all items, services, and processes important for safety, involving stakeholders and people in the organization in the context of the reference document. This approach was based on the definition of responsibilities and the implementation of programs/procedures, using continuous evaluation meetings of the AMP/CDTN team. The AMP/CDTN comprises the following elements:

- Screening of structures, systems, and components;
- Identification, understanding, detection, and mitigation of ageing degradation, acceptance criteria and corrective actions;
- Constant updating of reactor control and automation systems,
- Continuous improvement of the ageing management program;
- Record keeping.

3. RESULTS AND DISCUSSIONS

PGE/CDTN comprises the following elements: screening of structures, systems, and components; identification, understanding, detection, and mitigation of ageing degradation, acceptance criteria and corrective actions; constant updating of reactor control and automation systems, continuous improvement of the ageing management program, and record keeping.

3.1. Screening of structures, systems, and components

A screening of all SSCs was performed by Cruz *et al.* [4] based on the following criteria: the relationship with safety and the degree of ease of replacement. Table I presents the criteria used to classify SSCs, including obsolescence. Fifty-four items were identified and organized into eight groups covering the following SSCs:

- Reactor core (bottom plate, top plate, aluminum cladding fuel element, stainless steel cladding fuel element, control rod, graphite element, reflector, core radiation detector support, and reactor core support);
- Primary cooling system (tank, aluminum reactor tank liner, pump, heat exchanger, piping, valves, sensor box, and rotameter);
- Secondary cooling system (pump, cooling tower, piping, valves, rotameter, sensor box, and water supply piping);
- Irradiation device and control (rotating specimen rack, control rods mechanisms, devices for introducing/removing samples on the rotating rack, pneumatic transfer system, central tube, and central beam);
- Instrumentation and control (nuclear power monitoring channels, cooling water temperature monitoring system, cooling water electrical conductivity monitoring and level measurement system, radiation monitors of cooling water and reactor areas, and reactor control desk);
- Water treatment systems (pump, piping, valves, rotameter, sensor box, filter, and resin systems);
- Building installations (structure, building foundations, air conditioning, ventilation, electrical installation, hydraulic installation irradiated fuel storage system, fuel safe, and access);
- Other factors - non-SSCs (organization, training, documentation, and safeguards).

Table 1: Criteria for classification of SSCs

IMPORTANT TO SAFETY?	REPLACEMENT COMPLEXITY	OBSOLESCENCE (IT NEEDS TO BE UPDATED?)	AGEING MECHANISMS
S- Yes N - No T – Maybe, depending on specific reactor design and features.	A – Very difficult B – Difficult technically or costly C – Normal D - Readily	S- Yes N - No T – Maybe, depending on specific reactor design and features.	**1-** Damage due to irradiation **2-** Damage due to temperature **3-** Damage due to humidity and pressure **4-** Fatigue **5-** Wear due to operation and corrosion, including changes in the dimensions of individual components or the relative position between individual components **6-** Erosion **7-** Wear or inadequate construction, incorrect installation, or maintenance **8-** Chemical attack: presence of chemically active liquids or gases (before or during operation) **9-** Lack of replacement parts or suppliers **10-** Non-conformity with new security criteria **11-** Human factors **12-** Incomplete or outdated documentation

3.2. Identification, understanding, detection, and mitigation of ageing degradation, acceptance criteria and corrective actions

Aging mechanisms are processes that gradually introduce damage, modifying the characteristics over time or use of a given component, for example: fatigue, creep, irradiation or thermal embrittlement, corrosion, intergranular attack, and wear. The main ageing degradation mechanism identified by Cruz *et al.* [2] is related to wear due to corrosion and operation, including changes in the dimensions of individual components or in the relative position between individual components, as well as due to wear or inadequate construction, incorrect installation, or maintenance. In this analysis, information from visual inspections carried out, operational experience acquired, as well as reference documents were considered.

The detection of the effects of aging occurs before there is loss of any structure and intended function of the component, and is carried out using the following mechanisms (programs/procedures):

- Visual inspection by video;
- Water quality program;
- Maintenance program;
- Obsolescence control, and
- Investigation of operational parameters.

a) Visual inspection by video

In the visual inspection by video scratches, wear, cracks, oxide layers, corrosion pits or surface erosion are checked, as well as geometric variations or damage to the surface of the fuel elements, graphite element, reflector, the neutron source, and the structure of the core. Two visual inspections were carried out at IPR-R1 Triga reactor, one conducted by the Ipen (Instituto de Pesquisas Energéticas e Nucleares) team of researchers and the other by the CDTN team [6,7]. Most of the noticeable indications, found in two inspections performed, are basically related to oxidation processes present in the cladding of some fuels. Other indications concern to handling operations, resulting in few cases of deformation (bending or kneading) mainly at the lower termination tips. Based on these inspections, the integrity of the whole installation was considered good. The next video visual inspection is scheduled for this year and will be carried out by the CDTN team.

b) Water quality program

The water quality program monitors the chemical-physical characteristics of water coolant within recommended standards [8]. Control limits and frequency were established for the following physical-chemical parameters followed: electrical conductivity; pHpotential of hydrogen; total alpha and total beta radiation; concentration of sulfate, nitrite, nitrate, chloride and ammonium ions, metals by ICP-MS (As, Zn, Sr, Ba, Pb, Cr, Co, Ag, Cu, Ca, Mg, Cs, La, U, Na and Fe). This program has already been revised three times since its implementation in 2012 to the present date [8,9]. In general, the results of parameters evaluated are within the limits recommended by the IAEA or they were within the values considered acceptable by CDTN technical team due to the operational history of the facility.

c) Maintenance program

The maintenance program consists of a set of specific procedures in accordance with the manufacturer's manual. Some actions related to ageing are covered in the maintenance program and for IPR-R1 Triga reactor some components run until failure. Internal procedures include frequency and prevention and mitigation actions, as well as acceptance criteria, when applicable. If results are outside the criteria, corrective actions are initiated such as adjustment, repair, or replacement. Based on recent data collected, between 2001 to current data (2024), a total of 532 actions were carried out, including corrective actions (164), preventive actions (360) and mitigation actions (8). Of the total corrective actions, 114 are related to the replacement of components (e.g.: relays, lamps, panels) mainly due to natural wear and tear and the remainder refer to repairs or adjustment (e.g.: welding of some component). A new maintenance program is being prepared, considering the specificities of the IPR-R1 Triga reactor.

d) Obsolescence control

Obsolescence control includes stock control and classification of SSCs according to the need for updating and difficulty in replacing them, minimizing the impact on reliability and availability. The IPR-R1 Triga reactor has spare parts on stock. A new model is being developed to measure the degree of obsolescence considering the aspects of safety, difficulty in replacement, market chain, availability of spare parts and technical assistance. Additionally, IAEA SSG-10 [3] has been revised and the AMP/CDTN will be updated.

e) Investigation of operational parameters

Investigation of operational parameters is based on the observation of parameter changes during operation, operational checks, and tests, as well as daily and monthly measurements. The basic guidelines, responsibilities, methodology, records, and frequency are described in the internal operational procedures, for example: daily checklist; reactor control and protection instrumentation tests; checking the linearity of the power channels, determining the drop time of the control bars, determining the shutdown margin, determining the temperature/reactivity coefficient, and determining the loss of reactivity with an increase in power.

All these mechanisms were established following the recommendations of the manufacturers of measuring equipment/instruments, as well as internal and external operational experience and historical results, providing the basis for assessing the SSCs' ability to fulfill their intended functions and facilitating periodic improvements. All these mechanisms are periodically reviewed after analyzing accumulated data, in addition to evaluating operational conditions resulting from improved maintenance practices and decision-making regarding replacement. All information collected is verified and trends arising from the results are monitored through meetings, in order to predict the onset of aging in a timely manner. There are three important principles associated with AMP/CDTN these are:

- maintaining of the functionating conditions of the structures, systems, and components (SSCs) with no reduction in performance or safety margins;
- preventing failures of critical SSCs;
- understanding and managing the age-related degradation mechanisms.

An important aspect of the AMP/CDTN is the distinction between passive and active systems, structures, and components. Passive SSCs are those for which age-related degradation can only be monitored through inspections, tests, and measurements. Active SSCs are included in the reactor maintenance program. The Table II describes the inspection type or testing, program or procedure adopted and planned actions supposed for each SSCs of IPR-R1 Triga reactor.

Table 2: Criteria to classify the inspection type/testing, program or procedure and action

INSPECTION TYPE/TESTING	PROGRAM OR PROCEDURE	PLANNED ACTIONS
Functional (operability)	Operational internal procedures Maintenance program	Measuring, Operability checks and Survey
Visual with camera video	Visual inspection by video program	Monitoring, Operability checks
Chemical analysis	Water quality management program	Measuring
Visual examination/corrective	Maintenance program/Safety inspection	Survey/ Operability checks
Instrumental	Operational internal procedures Maintenance program	Measuring, Operability checks

The main mitigation actions implemented include the appropriate selection of materials in the design phase, actions established in the maintenance program and the pH control through water purification in a treatment system. Other actions were carried out to prevent and mitigate the effects of aging, such as the study to verify the occurrence of microorganisms in water and the study of corrosion of aluminum alloys

3.3. Acceptance criteria and corrective actions

Acceptance criteria refer to a set of basic requirements defined in the technical specifications of the SSC's design or according to the manufacturer's manual. Whenever an acceptance criterion is not met, the abnormal condition is evaluated and corrected before it causes a significant safety consequence, and corrective actions are taken. In the case of qualitative acceptance criteria, decision-making by the responsible party is based on verifying whether there are sufficient signs of damage or degradation to justify continued monitoring, evaluation, or repair.

3.4. Constant updating of reactor control and automation systems

IPR-R1 Triga reactor control desk was manufactured by the Instituto de Engenharia Nuclear (IEN) and since its implementation some modifications and updates have been made to the instrumentation and control system [9]. The main changes and improvements have been updated or are currently under development since the start of IPR-R1 Triga Reactor operations [10]. All actions performed are recorded in the reactor's Maintenance Book.

3.5. Continuos improvement of the ageing management program

All mechanisms (programs/procedures) used in the PGE/CDTN will continue to be improved, based on operational experience and monitoring results. In addition to the annual critical analysis, periodic meetings are held with everyone involved for the confirmation process. This continuos improvement comprises the following elements:

- analysis of trends identified in the programs/procedures, with accompanying graphs, whenever applicable;
- corrective and preventive actions to analyze effectiveness, and to identify the root cause.

It also involves identifying techniques to prevent or reduce further degradation of selected systems, structures and components and techniques to repair or replace them.

3.6. Record keeping

Records control involves identification, storage, archiving, retrieval, retention time, and disposition of records. All records generated from the AMP/CDTN are analyzed and maintained according to the CDTN's internal procedure.

4. CONCLUSIONS

The Aging Management Plan for the IPR-R1 Triga reactor included the selection of 54 SSCs, identification of mechanisms for detecting the effects of aging, mitigation actions, and control of obsolescence. The main degradation mechanism identified is related to wear due to corrosion. The reference for this plan was document from IAEA SSG -10 Rev 0 guideline "Aging Management for Research Reactors". Considering the age of the IPR-R1 Triga reactor, special attention was paid to the management of aging mechanisms, whether related to the physical aging of the SSCs or to non-physical aging, related to technological obsolescence. For the IPR-R1 Triga reactor, the maintenance and aging plan were combined. So, AMP/CDTN was established, with some adaptations applicable to the case of research reactors. All these adaptations were based on initiatives and updates carried out in other research reactors. However, adjustments are still necessary and are being prepared in accordance with the new revision IAEA SSG -10, including time limited aging analyses.

ACKNOWLEDGMENT

The authors would like to thank the financial support of the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (Fapemig).

CONFLICT OF INTEREST

We have no conflicts of interest to disclose.

All authors declare that they have no conflicts of interest.

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