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Methodology for Management and Physicochemical Monitoring and Quality Control of the Cooling Water of IPR-R1 Triga Nuclear Research Reactor

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ABSTRACT

The IPR-R1 Triga research reactor, located at CDTN (Nuclear Technology Development Center) in Brazil, is one of the oldest reactors in operation worldwide. The Brazilian Nuclear Energy Commission (Cnen) has granted a Permit for Permanent Operation license for CDTN Triga reactor. This authorization includes some conditions to be settled until the end of 2019, which has not yet been carried out and it is currently being prepared by CDTN. For this purpose, Project 0006.23 – Maintenance of Licensing of IPR-R1 Triga Reactor was created in CDTN's Multiannual Program. In this project is included the Subproject: 6.23.3 – Preparation of the system to manage the aging of IPR-R1 Triga reactor. Inserted in this context, the main objective of this paper is the proposal of good practices to be adopted in the future by CDTN, related to the Projects of Licensing and Aging of Triga reactor, for the management and physicochemical quality control of its cooling water, considering its electrical conductivity and pH, following IAEA recommendations. So, the present work is relevant, as it addresses a proposal for monitoring pH and electrical conductivity of Triga's cooling water. As a result of this proposal, the useful life of Triga reactor may be extended and there will be greater reliability and safety in its operation.

Keywords: **IPR-R1 Triga research reactor, cooling water, physicochemical control.**

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1. INTRODUCTION

Triga IPR-R1 research reactor, located at CDTN (Nuclear Technology Development Center) in Brazil, is one of the oldest nuclear reactors in operation worldwide. At the beginning of its operations in 1960, its maximum output thermal power was 30 kW. In 1970, fuel elements were added to Triga's core, increasing the power to 100 kW, which is its current and maximum operating power level. Modifications were carried out in the core in 2022, and new fuel elements were added to it, allowing Triga reactor to reach power levels of 250 kW, according to experiments carried out by Mesquita *et al.* (2002) [1].

Brazilian Nuclear Energy Commission (Cnen) has granted a Permit for Permanent Operation license for CDTN research reactor. This authorization includes some conditions that should be settled until the end of 2019. Such terms have not yet been carried out, but they are currently being prepared by CDTN. For this purpose, Project 0006.23 – Maintenance of the Licensing of IPR-R1 Triga Reactor was created in CDTN's Multiannual Program. As part of this project, there is the Subproject: 6.23.3 - Preparation of the System to Manage the Aging of IPR-R1 Triga Reactor, which the present paper is part of.

In the aforementioned subproject, a mandatory experiment was included in such research reactor, that is, the performance of tests to verify possible fission product leaks in its fuel elements [2]. Due to Covid pandemic and homework activities, this experiment has not yet been performed, but it is intended to be realized as soon as Triga reactor returns to regular operation. All conditioning actions required by the regulatory agency are based on recommendations and standards, like the ones provided by International Atomic Energy Agency (IAEA) [3-5].

Studying the aging of nuclear reactors, in addition to paying attention to economic factors directly involved with the extension of their operational life, also provides important data on safety issues. The most recent case involving the process of extending the life of a PWR reactor was at Angra 1 nuclear power plant in the last 20 years. For the IPR-R1 reactor, it would be very important to know if it is necessary to carry out any corrective measures for the extension of its life, after the recent granting of the Permit for Permanent Operation.

In the specific case of Triga reactor, most of its fuel elements are in the core where corrosion can occur, what can compromise its fuel coating integrity. Its cooling water must be treated and controlled to maintain low levels of electrical conductivity and pH close to neutrality, in order to minimize potential corrosion processes, particularly in fuel elements [2]. At some point in the future, like other reactors, IPR-R1 will be permanently shut down.

So, the main goals of this paper, related to the Licensing and Aging Projects of Triga research reactor, are:

- Proposal of good practices to be adopted by CDTN for water quality management (electrical conductivity and pH based on on-line monitoring) related to the cooling water of Triga reactor, following IAEA suggestions [3,4]. It is done because CDTN research reactor does not have an on-line system to monitor both variables.
- Perform gamma spectrometry experiments for IPR-R1 well water to check possible fission products leakage in the fuel elements of Triga reactor (sipping test) [2].

2. MATERIALS AND METHODS

Nuclear reactors have some process variables whose operational limits cannot be exceeded. The parameters defined as Operational Limits and Conditions (OLC) must be monitored, and their values recorded and archived for later consultation. They also must cause automatic shutdown of the reactor if one OLC variable is exceeded [5-7]. These limits are necessary to maintain the integrity of the main physical barrier that protects against the uncontrolled release of radioactive material during the facility operation. Continuously recording and monitoring of the evolution of OLC variables is important to immediate or subsequent security analyses, showing both short-term and long-term trends. The organization that operates the facility must have file records to allow verification by regulatory agencies of predefined operational safe limits.

The control of nuclear reactors must have appropriate instrumentation to measure, monitor, record and exercise control over the parameters involved in their operation. IAEA (2008) [5] recommends several parameters that can be used as operational limits for the initial licensing, which depend on the characteristics of each research reactor. IAEA (2008) [5] also suggests periodic assessment of such parameters over installation lifetime in addition to the monitoring of technological progress. Establishing which parameters will be used to establish operational limits is the most important item in the Safety Analysis Reports of nuclear reactors.

In this line of thinking, monitoring physical and chemical coolant quality in light water nuclear reactors, both in power and research ones, is one of the most important tasks in their safe operation. Those responsible for nuclear installations, in order to minimize people exposure to radiation, need to continuously monitor fuel performance, which is responsible for releasing radioactivity, through gaseous and liquid effluents from its cooling system.

In the case of CDTN Triga reactor, practical procedures will be elaborated to be adopted by the institution in the future for the management and physicochemical monitoring of the cooling water (electrical conductivity, pH and temperature) of its OLC nuclear reactor, according to IAEA (2011) [4] recommendations. In the experimental part, the analytical instruments shown in Figure 1 [8] will be installed in the primary cooling circuit of IPR-R1 reactor. They are:

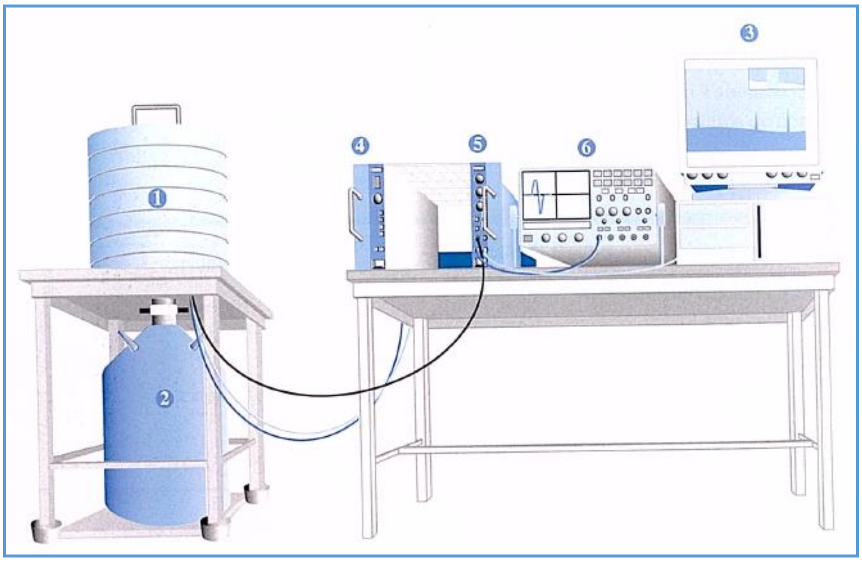
- Two digital meters with probes to monitor electrical conductivity and water temperature (George Fischer-Signet, model 8850-2 GF conductivity indicator/transmitter) [9]. Each equipment has two cables (conductivity and temperature), which connect the probes to the conductivity meters (indicator and analog output).
- A pH meter (with sensor), Dosatronic brand PH 1000 TOP [10]. It is a high-precision, fast-response microprocessor instrument for automatic pH analysis over its entire range (0 to 14). Despite being also a controller, the device will be used only for pH monitoring. It will not automatically shut down the reactor when a critical pH value is reached. Still, CDTN Triga reactor has a distilled water reservoir to replenish water that evaporates from its well. It also has an ionic exchange resin system, like a filter, that adjusts the values of pH and conductivity till the desired ones.

The output signals (pH, electrical conductivity and temperature) from the sensors will be connected to the Data Acquisition System (DAS) developed in a previous research [11]. All parameters will be displayed on a video monitor. DAS' characteristics are:

- Data Acquisition System (DAS) with USB-6211 output, manufactured by National Instruments Co. (2007) [12]. This is a multifunctional device that offers analog inputs, digital inputs, digital outputs and two 32-bit counters.
- LabVIEW® supervisory program (academic license), developed by National Instruments Co. (2007) [12]. It is an engineering software specifically created for applications that require tests, measurements and control, with fast access to both hardware and information obtained from the DAS.

Figure 1: *Conductivity/temperature and pH meters.*
Source: [8]

Additionally, as schematized in Figure 2 [13], it will be performed a spectrometry based on a 5019 coaxial HPGe (hyper-pure germanium) detector, with nominal efficiency of 50%, model DSA-2000, coupled to a 8.0 channels Canberra gamma spectrometer. The system will be connected to a computer with a multichannel spectra acquisition board with the Genie 2K program, provided by Nuclear Spectrometry Laboratory-LEN of Seama/CDTN. The assembly will detect and identify leaked fission products. The presence of specific isotopes (Cs-137, La-140 and I-131) indicates that some sampled fuel elements present leakage. It means they have a compromised coating, since these elements are well known indicators of leakage in nuclear reactors. Such apparatus will receive specific water samples from Triga reactor in order to perform the proposed gamma spectrometry; the system is not on-line with the nuclear reactor.



Legend:

1. High purity germanium detector with lead shield ;
2. Dewar bottle with cryostat and preamp ;
3. Computer with analog-to-digital converter and program to manage a multi-channel analyzer ;
4. Polarization source for the detector ;
5. Electrical Signal Amplifier;
6. Oscilloscope.

Figure 2: *Schematic drawing of a gamma emission spectrometer*.
Source: adapted from [13]

3. EXPECTED RESULTS AND DISCUSSIONS

Coolant quality tests commonly applied for water-cooled reactors assess temperature and pressure. However, new studies justify the analysis of other physicochemical factors, such as pH and electrical conductivity as temperature function, in order to minimize undesirable effects, like erosion and the deposition of corrosive products on heat transfer surfaces [4,5]. Among the expected results, depending on the experiments to be carried out, previously described in methodology section, are the values of electrical conductivity and pH for Triga's well water. To exemplify the expected results of the current proposal, it will be comment on the next paragraph the values of electrical conductivity and pH from previous similar studies about CDTN research reactor.

IAEA standards (2011) [4] recommends that pH related to research reactors cooling water should be between 5.5 and 6.5. In IPR-R1 reactor, values of 5.2 and 7.0 for pH, monthly measured between Jun/2016 and May/2017, have already been reached, and they are showed in Figure 3 [14]. Regarding electrical conductivity, IAEA publication (2011) [4] recommends that it should be below 1.0 µS.cm-1. Such value was never reached in Triga research reactor; the lowest value reached was 1.3 µS.cm-1, monthly measured between Jun/2016 and May/2017 as can be seen in Figure 4 [14]. All these samples for the IPR-R1 reactor were analyzed by the Analytical Chemistry Laboratory of the Analysis Service and Environment (Seama) of CDTN [14].

pH is one of the most important parameters in water quality control of water-cooled reactors. It influences three of the four objectives of water chemical control, which are: control of the radiation field, fuel integrity and integrity of reactor materials. pH is an indicator that provides the total concentration of ionic impurities. The increase in ionic impurities levels adversely influences the following aspects: corrosion of materials in the reactor cooling system, increase in the radiation field and fuel performance. Therefore, pH needs to be close to neutrality while electrical conductivity should be kept as low as possible [2]. Emphasizing that, nowadays, there is no system that monitors these parameters in real time (on-line approach) in CDTN IPR-R1 research reactor as suggested by IAEA [4].

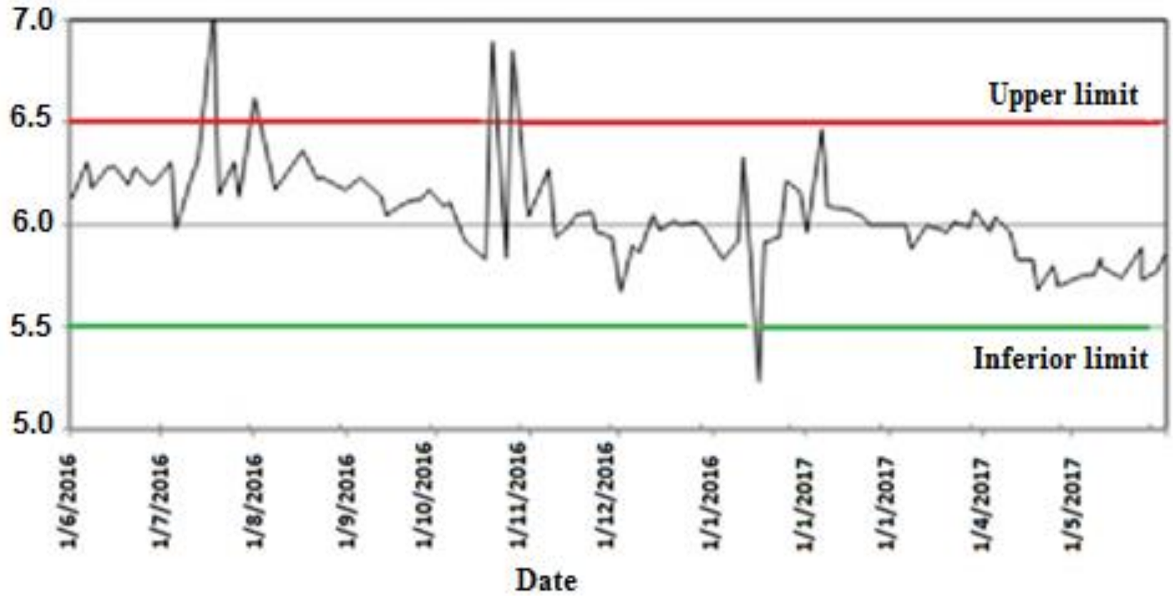


Figure 3: *Values of pH for the primary cooling water of Triga reactor from Jun/2016 to May/2017.*
Source: [14]

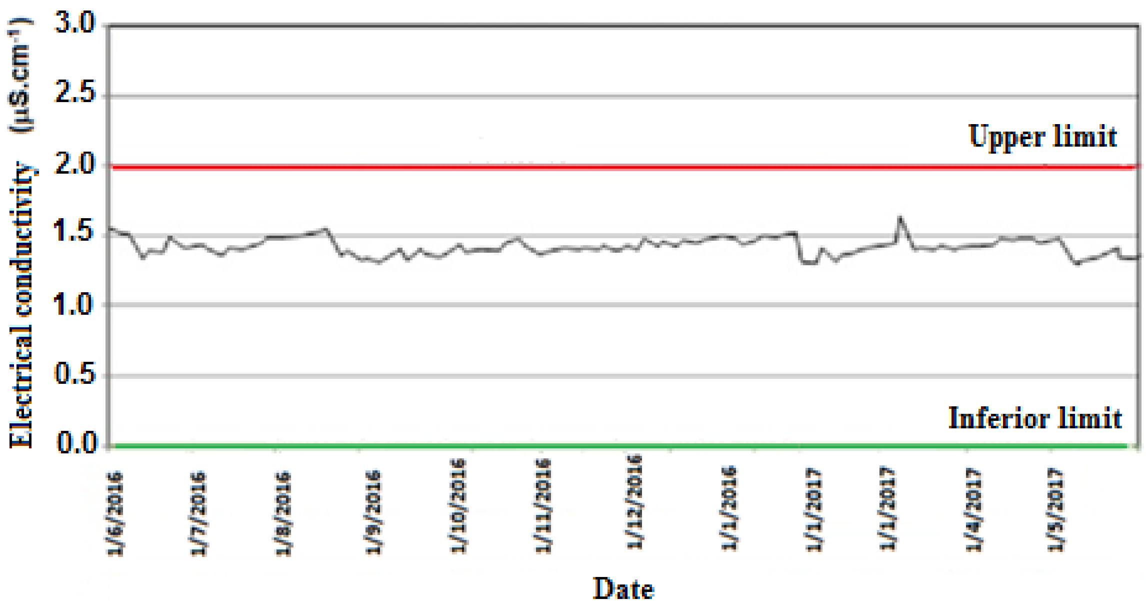


Figure 4: *Values of electrical conductivity for the primary cooling water of Triga reactor from Jun/2016 to May/2017.*
Source: [14]

IAEA (2011) [4] publication recommends periodic verification of fuel elements integrity. With the modifications introduced in IPR-R1 reactor over the years, especially the inclusion in its core of stainless steel coated fuel elements for operation at power level of 250 kW, the probability of occurring corrosion due to electric currents has been increased, by the formation of galvanic cells between different materials in contact. These galvanisms can contribute to deterioration processes in metallic structures (corrosion) [15] of Triga reactor. In this way, the present proposal related to the chemical control of IPR-R1 reactor cooling water can help to avoid such inconvenient.

4. CONCLUSIONS

The water used in IPR-R1 Triga research reactor acts as coolant, neutron moderator and biological shielding. The entire tank, as well as the core, and the main reactor components are in direct contact with water. Therefore, it is extremely important to maintain the physical and chemical characteristics of its coolant within recommended standards, enabling a safe and efficient operation of this nuclear reactor. Additionally, as the natural aging of Triga reactor progresses, such action becomes more necessary to guarantees its operation at high safety levels, in order to maintain the integrity of its components and also to minimize possible corrosion processes.

So, the present work is relevant as it addresses a proposal for monitoring pH and electrical conductivity of Triga reactor cooling water. The measurements of both variables will be saved in the Data Acquisition System (DAS), allowing future consultation and analysis by operators and authorities. Such acquisition system is under implementation and it is expected to start its operation by the end of 2022, when both pH and electrical conductivity meters will be installed in order to perform the proposed experimental analysis. As a result of such proposal, and the adoption of procedures for new management of water quality in Triga reactor, its useful life may be extended and there will be greater reliability and safety in its operation.

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