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DESIGN OF A SYSTEM FOR FUEL ELEMENTS CLADDING INSPECTION OF A NUCLEAR RESEARCH REACTOR

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ABSTRACT

The CDTN has in its facilities a TRIGA-type nuclear reactor. The reactor´s cooling water must be treated and managed with the goal of keeping its low conductivity to minimize corrosion of the reactor components, mainly of fuel elements (FE), and reduce the level of radioactivity. The aim of this paper is to present a proposal for the development of a system for verification of some possible leaks in FE nuclear research reactors, based on the sipping test. This type of testing is a way to check for leaks of fission products from fuel element of nuclear research reactor. In the future, when the test will done, it will have a correlation between the components found in the reactor cooling water pool and integrity of nuclear fuel elements. The device development and its application will be presented here, covering results that were not previously investigated yet, giving originality to this project.

Keywords: sipping test, TRIGA, nuclear research reactor, corrosion, nuclear fuel element.

INTRODUCTION

The *Centro de Desenvolvimento da Tecnologia Nuclear* - CDTN) (Nuclear Technology Development Center - *CDTN*) is a nuclear research institute administered by the *Comissão Nacional de Energia Nuclear – CNEN* (Brazilian Nuclear Energy Commission - CNEN), an agency of the Ministério de Ciência, Tecnologia e Inovação (Ministry of Science, Technology and Innovation of Brazil). CDTN has in its facilities a nuclear reactor type TRIGA (Figure 1), Training Reactor, Isotope, General Atomics, Model Mark I (General Atomics, 2012). His name is IPR-R1 (Research Institute Radioactive - Reactor No 1).

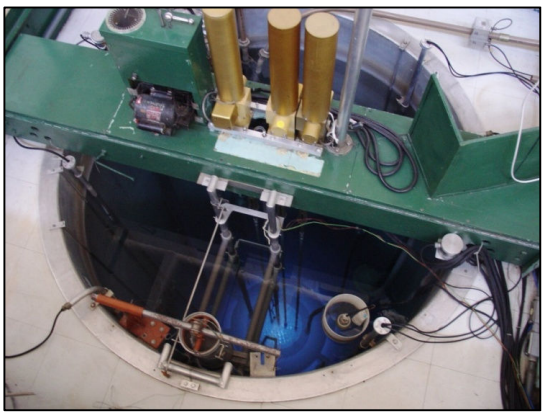

Figure 1 - IPR-R1 TRIGA research nuclear reactor. View from the top of the reactor pool, showing reactor core emitting Cherenkov radiation in the violet-blue background, triggers the control rods and other accessories in gold on the beam central green.

This reactor is in the pool type, ie is immersed in a cylindrical tank (Figure 2) whose walls are coated with aluminum having a diameter of 1.92 m and 6.62 m deep. This volume contains the reactor core and its associated structures and is stocked with approximately 18,000 liters deionized water, which serves as coolant and as secondary neutron moderator and biological shielding also (CDTN / CNEN, 2008).

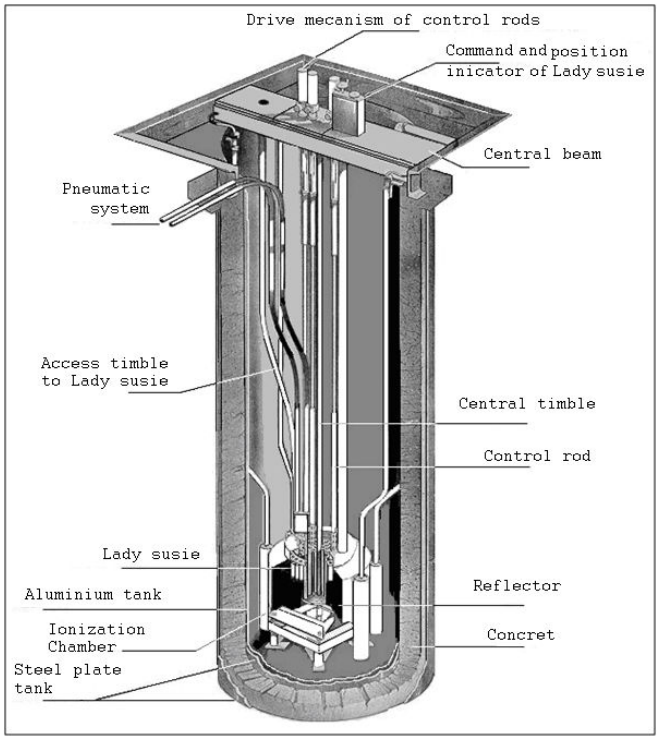

Figure 2 - Above a schematic drawing showing the IPR-R1TRIGA reactor pool and its main components (Mesquita, 2005).

Reactor core consists of fuel elements (FE) of uranium-zirconium hydride with 8% in the alloy of uranium which presents enrichment in uranium of atomic mass 235 (U-235) approximately lowest, 20%. His initial charge in 1960 consisted of 56 FC encapsulated in aluminum AL1100 type the power of 30 kW (Zangirolami, 2009). In the 2000s were added 4 new FC, but caddied in stainless steel AISI-304 (Mesquita et al., 2012). Figure 3 shows a fuel element IPR-R1TRIGA reactor. Currently (2012) the reactor core contains 63 fuel elements in all.

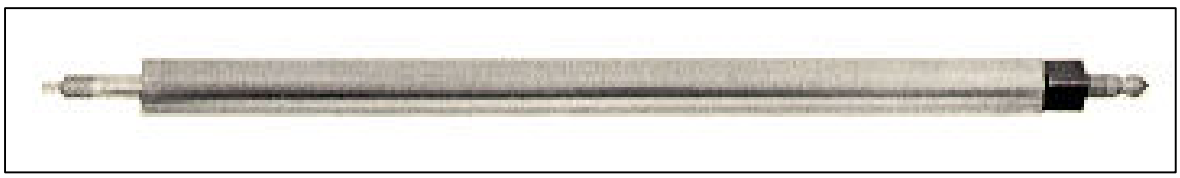

Figure 3 - Fuel Element of the IPR-R1 TRIGA reactor.

The reactor core is formed by FE and the supporting structures. This is immersed in pool water reactor. The water in pool of reactor consists of demineralized water, and is subjected to a treatment in order to maintain conductivity between 1.25 and 1.45 μ S/cm.

Although the diffusion of electrolytes in the water in pool is minimum, as well reactor is opened, always occurs impregnation of dust from the air in water pool, causing impurities. In pools research nuclear reactors, which are almost all open to the air, there is the possibility of inclusion of unknowns materials varied. Oxidizing gases such as oxygen dissolved in pool water, for example, can increase the concentration of dissolved ions in the coolant of the reactor core (Auler, 2012).

There is one study by Sabino (1995), which states that most of the supernatant in pool reactor water consists of micro-organisms (including the Trichoderma sp, see Figure 4a) and of residues from the purification resin itself at the time of the study.

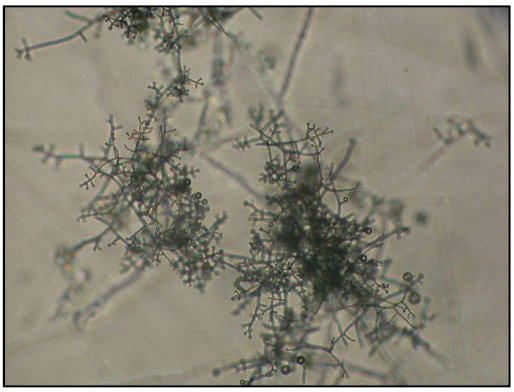

Figure 4a - Trichoderma SP (Deuteromycetes / Ascomycetes) Incubated in the midst of Agar-agar, microscope analysis from forest soil; Tanabe city, Wakayama Prefecture, Japan. Author: Keisotyo; September,

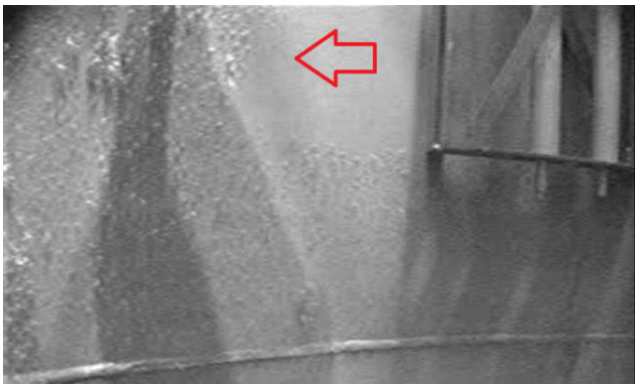

Figure 4b - Precipitates deposited on the inner wall of the tank, detected on visual inspection conducted in 2006, Is it fungus presence? (Mesquita, 2012).

Mitigation measures have been taken to avoid the presence of particulate exchange resin in the well (Sabino et al. 1995). However, the presence of micro-organisms remains, and despite the conclusion Sabino (1995) that the presence of organic material does not affect the corrosion condition of the environment, the possibility of acidifying the water for microbiological activity exists due to the consequent production and release of organic acids, for example, by Trichoderma sp quoted in Sabino (1995).

This tendency to enhance the acidity by releasing organic acids in the middle where it proliferates the Trichoderma SP was verified by Calazans (2012) and Pasetto (2011). Organic acids that although in general a high coefficient of acid dissociation in water (pKa), can lead to attacks, especially pieces of aluminum and stainless steel, even though these metals form spontaneous protections on its surface. Once the passivated surface has flaws, this may cause intense anodic attack at the point of weakness of these metal shields.

Passivated metal structures are found spontaneously in the reactor such as aluminum and the CS supporting structures also EC coated stainless steel. "All metals are subject to corrosive attack, if the medium is sufficiently aggressive" (Gentil, 2003). Figure 4b shows the presence of fungi deposited on the inner wall of the IPR-R1 TRIGA reactor tank, seen in visual inspection performed in 2006 (Alencar et al. 2006), (Mesquita, 2012).

The presence of organic acids dispersed in water and micro-flaws in the passivated surfaces of aluminum components are conditions which may lead to formation of electric batteries, which then can lead to corrosion attack anodic electrochemical type, for example, the structures of the reactor including the cladding of some FE in core (Kind, 2003).

The first and primary containment barrier of fission products from nuclear fuel is its cladding. In the case of TRIGA reactors, the alloy of zirconium hydride, which is dispersed uranium fuel, is designed to retain more than 99% of the fission products, even if the coating has been removed from FE (General Atomics, 2012) (Tigliole et al. 1991), (Simnad, 1981).

The sipping test is a way to check for leaks of fission products within the sealed fuel element recommended by Alencar et al. (2006b) after visual inspection of the state of the EC IPR-R1 TRIGA reactor in 2006.

The cladding of the FC, a priori, may leak by corrosion, or accidental mechanical handling. In reactor IPR-R1 TRIGA, the 58 elements cladding in aluminum has a wall thickness of 0.76 mm (Zangirolami, 2009). The five elements stainless steel has a wall thickness of 0.50 mm (CDTN / CNEN, 2008). These walls are designed to be the thinner possible to improve heat conduction and flux of neutrons, but on the other hand, makes it delicate manipulation of the fuel elements.

In handling of FE it is use an appropriate tool which is telescopic and is part of normal reactor tool kit. The tool is manually operated and carries the risk of causing friction in cladding of FE in metal structures of the reactor core.

The manipulation may lead to damage in cladding as scratches, holes, or even tears if there is some flaw in handling due the delicate thickness of the aluminum cladding (Alencar et al., 2006b). Steel cladding of FE is mechanically more resistant than aluminum cladding, due to different mechanical properties of these materials. (ASME II, 2004).

In general, the carefully operation over the years by operators of the nuclear reactor facility led to one of the most well preserved nuclear reactor type TRIGA Mark I and that maintains its original characteristics.

We made a few modifications to increase power operation in the 70´s, from the original 30 kW to 100 kW, with the inclusion of a new heat exchanger and a new cooling tower, after this modification and exchange of original control desk with a new domestically manufactured.

There was also another change in the 2000s, increasing the reactivity of the reactor core with the inclusion of 4 FE in stainless steel anticipating a further increase in power from the current 100 kW to 250 kW. The reactor core, the forced cooling of pool water and shut-off devices are configured to 250 kW, with only the approval of the licensing of CNEN to operate in new power level.

TASK

The main objective of this project is to develop a methodology to investigate possible leaks in FE of research nuclear reactors to meet the most stringent safety requirements that have occurred in recent times in CDTN. A correlation between the components found in cooling water from the pool and integrity of the fuel will be drawn. As a secondary objective, the inspection will be conducted in all fuel elements, reactor IPR-R1 TRIGA, checking for FE in the core of the IPR-R1 TRIGA showing noncompliance containment of fission products.

METHODOLOGY

The method of determination of FE that showing leakage of fission products will be build and have an arrangement in reactor pool which receives a small number of FE (two or three FE per test).

This arrangement has a certain amount of demineralised water separated from the remaining water from the pool. After a few hours the water to be sampled by withdrawing aliquots, or by sampling continues, depending on how the device is designed. The water samples to be analyzed by a system of detecting and analyzing radiation, for example, a HPGe ("multi channel analyzer spectrometer in **H**igh **P**urity of **Ge**rmanium crystal detector") in a laboratory nearby, or to the coupling device, which makes the detection and identification of fission products that may be released in the water sample.

If it is noticed the presence of the isotopes: I-131 and Cs-137, this indicates that some of sampled FE show leaks, ie with the cladding are compromised, since these elements are known indicators of leaks in FE of uranium reactors (Alencar et al. 2006a). The system will be adapted and will be available to analyze and identify the presence of chemicals in cooling water of reactor core in periodic tests.

Currently, there are two alternatives for the shape of the device. However, during the development of new proposals may arise or increase manufacturing items for the two proposals currently under consideration until the sponsors take decision which device will be the end result.

The first proposal is to build and fix a small auxiliary tank on the edge of the reactor pool, and the FE to check would be placed on it and then it would be expected for a while that the retained water in this tank can become saturated with fission products fetched. Figure 5 shows a schematic assembly suggested.

In this option, after a time, aliquots were subtracted from water retained in the auxiliary tank. Samples were taken for monitoring on a system HPGe spectrometer range, to be made spectral analysis of gamma emitting elements present in the samples.

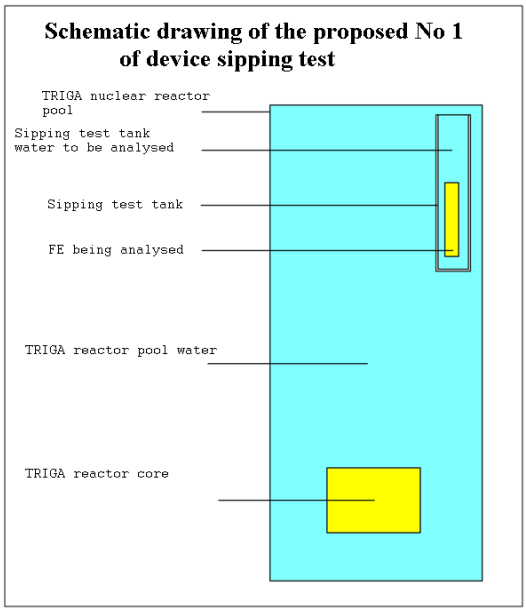

Figure 5 - Schematic diagram showing the IPR-R1 TRIGA reactor pool, the position of the core of the nuclear reactor and position the tank attachment with one or more FE under analysis on the proposition of developing device 1 for sipping test. Without cap and stuck on the edge of the pool.

The second alternative is to build a sipping tank to be sunk just off the nuclear reactor core, fixed, facilitating handling operations of the FE to be investigated. In this case, the sipping tank will trigger a lid remote to isolate the load from the FE remaining water from the well during the waiting process in saturation.

The outlet sample in this case can occur for inputs and outputs shown in Figure 6 as "A" and "B" respectively, for pumping process and subsequent passage in front of a sampler continuous or intermittent, as adapted around a crystal HPGe previously, which would be placed near the reactor pool, with all its components in order to be able to perform spectral analysis on the spot.

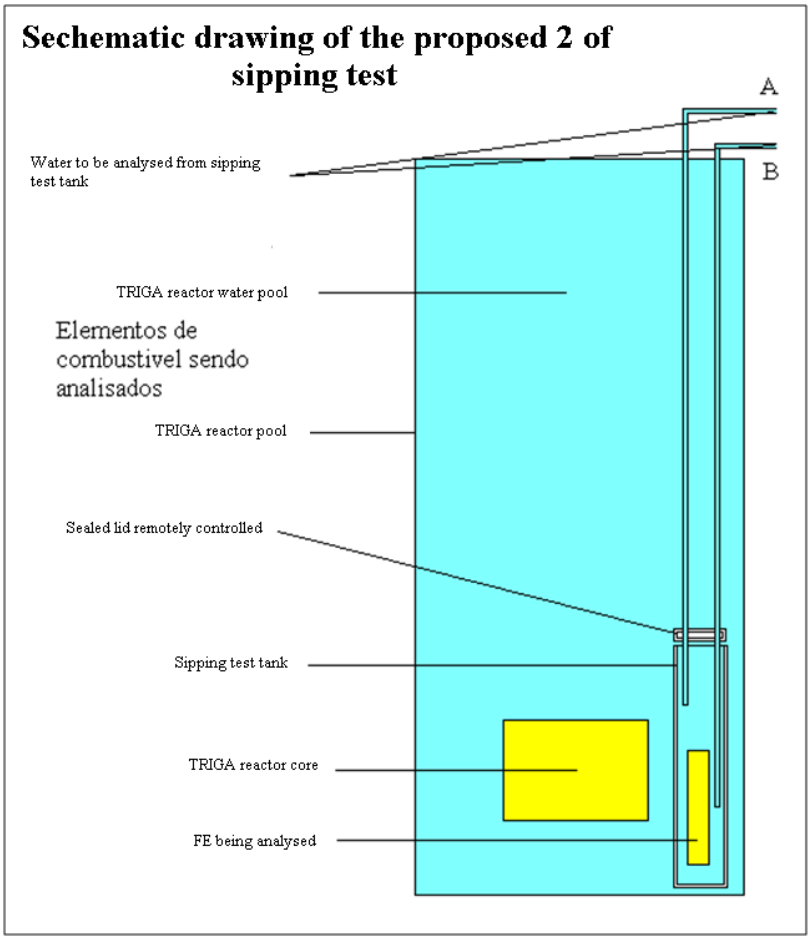

Figure 6 - Schematic diagram showing the IPR-R1 TRIGA reactor pool, the position of the core of the nuclear reactor and position the tank attachment with one or more FE under analysis concerning the motion of the second developing device to sipping test. Points "A" and "B" are return and suction aliquots of water, respectively

Following the line of exit and entry of water, the system will be positioned gamma spectrometry analysis, placed near the nuclear reactor pool with capacity to take samples intermittent or continuous, at scheduled times.

The system for spectrum analysis for the motion of the device shown in Figure 6, remains a HPGe, similar to that shown in Figure 7. Samples can be collected manually or automatically being brought to spectrometry systems installed in count laboratories associated with the IPR-

R1 TRIGA reactor in AC-1 (Controlled Area No. 1 CDTN), or read directly on spot by HPGe system installed in room of the nuclear reactor pool, respectively.

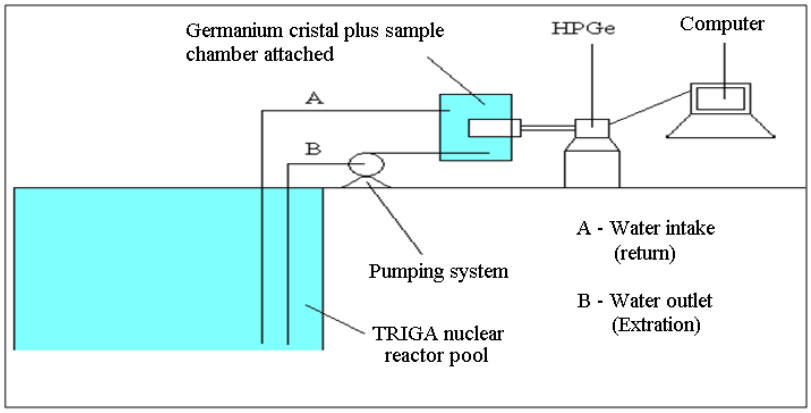

Figure 7 - schematic details of the system acquisition samples (**continuous or** intermittent**) and analysis** by gamma spectrometry HPGe adjusted to analyze the presence of 137Cs and 131I. "A" and "B**"** **return** and suction, respectively.

FEASIBILITY AND ADHERENCE

The nuclear reactor IPR-R1 TRIGA is a reactor over 50 years of operation. Bought by Instituto de Pesquisas Radioativas IPR (*Institute of Radioactive Research – IPR*), in these times belonging to the *Universidade Federal de Minas Gerais* – UFMG (Federal University of Minas Gerais, UFMG), passed later to be one of the main devices of research CDTN then, now owned by CNEN.

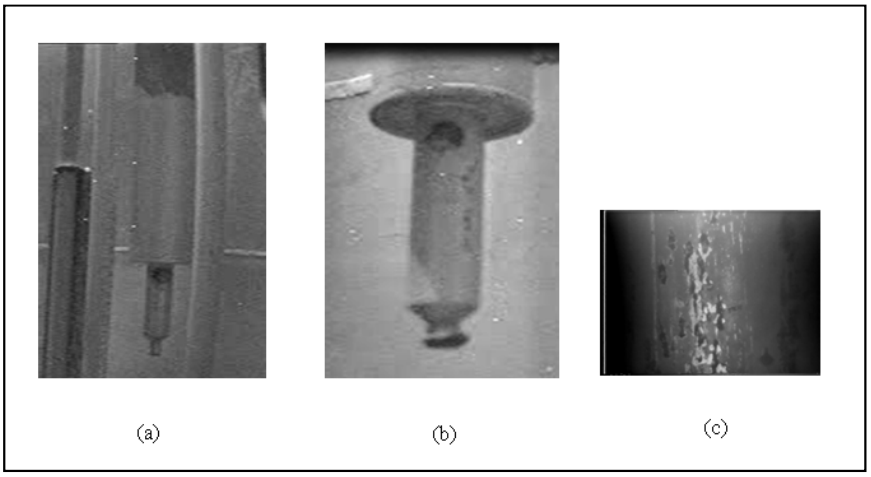

Figure 8 - Detail of inspection performed in 2006 FE in the IPR-R1 TRIGA Reactor (Alencar, 2006b). (a) Change in coloring in the body of FE and "pitting" tip, (b) Detail "pitting" corrosion at the tip of EC (c) Details of change of color in the body of FE showing an advanced state of loss of substance by corrosion in the encapsulation (aluminum FE).

In its service record, there was no operating nuclear accident and no structural failure of major consequence, unless the perception of small spots, located in some FE by visual inspection by underwater camera. Assays performed by Alencar et. al. (2006) showed that some elements showed little damage to the tip of the FE and others showing some corrosion points by "pitting" as shown in Figure 8 (Alencar, 2006b).

Due these modifications in IPR-R1 TRIGA reactor, particularly the inclusion of FE-cladding in stainless steel in reactor core, there is an increased likelihood of corrosion by forming electric cell by inclusion of different materials in the same body of electrolyte dispersion (Kind, 2003). However, essentially the concept of nuclear reactor has not changed and its general condition appears very well preserved, lacking then research about the state of containment of fission products, with the aim of registering your state (Alencar, 2006a).

A scientific research that is planned and should be conducted in parallel to this work by another group of researchers is analyzing the encapsulation of FE IPR-R1 TRIGA by the method of "eddy current testing". This is a research method of solution of continuity of the metal surfaces, comparative in nature, aimed at detecting changes in the surfaces that can be classified as corrosive processes results. The loss of substance in regions of the metal surface, such as holes, scratches, stains for loss of slag oxides and other accidents, electrical signals induce distinct patterns that identifies occurrences compared to the metal surface (Alencar, 2008).

The methodology for analysis of faults in fuel elements "sipping test", presented here, has never been performed in the nuclear reactor IPR-R1 TRIGA, or other similar TRIGA reactors (Delfin and Mazon, 2002) (Smith et al. 2010), (Tigliole et al. 2007). As the work proposed here approved and executed, this will add important information for management decision making regarding the future use of a device, which is not the most important center, at least that is the way its personality within the nuclear scientific community, in that the CDTN is inserted. In developing this work, experimental and analytical results, not previously investigated, will be discussed, giving it originality.

RESULTS AND CONCLUSIONS

In the development of this work, it will be presented two alternatives of devices to sipping test. Later, an alternative will be chosen and performed. There are two ideas to be developed. The first is to place a device on the edge of the reactor pool with capacity to hold up to three FE. The device would be a cylindrical tank containing demineralized water reactor pool, however isolated from the rest of the reactor pool. After a few hours of contact FE with water, water samples should be taken and analyzed in a HPGe system (Germanium High Pure System), a gamma spectrum analyzer.

The second idea is the placement of a device similar to the first, however placed on the bottom of the reactor, adjacent to the core, facilitating transfer operations FE core for the device and the device back to the reactor core. The procedures for sample collection and its corresponding analysis follow the same logic as the first device proposed.

Operational feasibility studies, economic feasibility and safety aspects will be taken into account to make the final choice of device to be built and used for sipping test IPR-R1 TRIGA. The results of analyzes in HPGe system will be investigated in order to determine the presence of Cs-137 or I-131. The presence of these elements indicates leakage of material that should be contained in FE.

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REFERENCES

Alencar, D.A.; Silva Júnior, S.F.; Mesquita, A.Z.; Câmara, L.O.I.S.; Oliveira, P.F. Ensaio de Inspeção Visual em Componentes e Estruturais e Parte dos Combustíveis do Reator IPR-R1 (Nota Téc. CDTN/CNEN). 2006a.

Alencar, D.A.; Silva Júnior, S.F.; Mesquita, A.Z.; Câmara, L.O.I.S; Oliveira, P. F. Using Visual Inspection NDT to Check Integrity of TRIGA Mark I Fuel Rods. In: 3nd WORLD TRIGA USERS CONFERENCE, Belo Horizonte., 2006b. Disponível em: http://www.cdtn.br/triga2006/internas.php?p=internas&cont_key=27.

Alencar, D.A.; Silva Júnior, S.F.; NETO, M. M.. Using Eddy Current NDT to Check Integrity of TRIGA MARK I Fuel Rods Cladding. NDT.net - The e-Journal of Nondestructive Testing (October 2008).

Auler, L. M. L. de A., Programa de Controle Físico-Químico da Água de Refrigeração do Reator TRIGA IPR-R1, Publicação CDTN – 973, maio, 2012.

ASME II, ASME Boiler & Pressure Vessel Code, part D 'Properties (Metric)', subpart 1 'Stress Tables', Table 1A 'Maximum Allowable Stress Values S for Ferrous Materials' _ stainless steel 304 (UNS S30400), pp. 82-3 and Table 1B 'Maximum Allowable Stress Values S for Nonferrous Materials' _ Aluminium alloy 1100 (UNS A91100), pp. 150-1. 2004.

Calazans, P., Produção de Aroma de Côco por Trichoderma Harzianum Utilizando Bagaço de Cana, Dissertação de mestrado em engenharia química, Universidade Federal do Sergipe, Centro de Ciências Exatas e de Tecnologia, PEQ-UFS São Carlos, 2012.

CDTN/CNEN. Relatório de Análise de Segurança do Reator TRIGA IPR-R1. Belo Horizonte, RASIN/TRIGA-IPR-R1/CDTN, 2008.

Delfin, A., Mazón, R. Visual Inspection System And Sipping Design For Spent Fuel at TRIGA Mark III Reactor of Mexico. 2002 International Meeting on Reduced Enrichment for Research and Test Reactors, Bariloche, Argentina, November 3-8, 2002.

General Atomics, TRIGA Research Reactors, http://www.ga-esi.com/triga/about/index.php, acessado em 27/novembro/2012.

Gentil, V., Corrosão, 4º edição, Rio de Janeiro: Livros Técnicos e Científicos Editora S. A., 2003.

IAEA - International Atomic Energy Agency. Safety Analysis for Research Reactors, Safety Reports Series No. 55, Vienna, 2008.

IAEA – International Atomic Energy Agency. Strategic Planning for Research Reactors, Guidance for Reactor Managers. IAEA-TECDOC-1212, Vienna, 2001.

Maretti, F.; Alvarenga F. L., Levantamento de Doses na Área Controlada e no Laboratório do Reator TRIGA IPR-I. In 2005 International Nuclear Atlantic Conference - INAC 2005 Santos, SP, Brazil, Associação Brasileira de Energia Nuclear – ABEN, August 28 to September 2, 2005.

Mesquita, A. Z. Visual inspection personal files. Octuber 2012.

Mesquita, A. Z., Investigação Experimental da Distribuição de Temperaturas no Reator Nuclear de Pesquisa TRIGA IPR-R1, Tese de Doutorado, Universidade Estadual de Campinas, São Paulo. 2005.

Mesquita, A. Z.; Costa, A.C.L.; Souza, R.M.G.P.; Palma, D.A.P. Medidas Experimentais de Parâmetros Termohidráulicos no Núcleo de Reator Nuclear de Pesquisa. Revista Iberoamericana de Ingeniería Mecánica, v. 16, p. 10-23; Disponível em: http://www.uned.es/ribim/volumenes/Vol16N1Abril2012/V16N1A09%20Mesquita%20101-113.pdf ; Série: 1; ISSN/ISBN: 11372729, 2012.

Mesquita, A.Z.; Souza, R.M.G.P. On-line Monitoring of the IPR-R1 TRIGA Reactor Neutronic Parameters. Progress in Nuclear Energy, v. 52, p. 292-297, 2010. doi:10.1016/j.pnucene.2009.07.013

Private conversation with the team of operators IPR-R1 TRIGA reactor, November 2012

Pasetto, S. Lima, M.L.P. Aspectos Gerais e Morfológicos Trichoderma sp, http://fitopatologia1.blogspot.com.br/2010/12/descricao-micologicaaspectos-gerais-e.html, acessado em 25/out/2012.

Reis, P.A.L.; Costa, A.L.; Pereira, C.; Veloso, M.A.F.; Mesquita, A.Z. Analysis of Hypothetical Core Blockage Cases in a Research Reactor Using the Thermal-Hydraulic Code Relap5. In: XVII Meeting on Nuclear Reactor Physics and Thermal Hydraulics (XVII ENFIR), Belo Horizonte. International Nuclear Atlantic Conference (INAC 2011). Rio: Brazilian Association of Nuclear Energy (ABEN), 2011.

Sabino, C.V.S., Oliveira. P.F., Amorim, V.A., Estudos sobre a àgua do poço do Reator Triga IPR-R1, Nota Interna CDTN, NI-AT4/95, 1995.

Simnad, M.T. The U-ZrH x Alloy: Its Properties and Use in TRIGA Fuel, General Atomic Company, San Diego, CA, USA Nuclear Engineering and Design 64 (1981) 403-422, North-Holland Publishing Company.

Smith. M.L.; Bignell, L.J.; Alexiev. D. And Li Mo. L.; Sipping Test: Checking for Failure of Fuel Elements at the OPAL Reactor. Nuclear Engineering and Technology, Vol.42 No.1 February 2010.

Tigliole, B.A, Cagnazzo. M; Lana, F.; Losi, A.G. Magrotti, S. Manera, F. Marchetti, P. Pappalrdo. A. Salvini, G.Vinciguerra., Identification of a Leaking TRIGA Fuel Element at the Nuclear Reactor Facility of the University of Pavia, Laboratorio Energia Nucleare Applicata – LENA - University of Pavia Via Aselli 41, 27100, Pavia -. Italy, 2007.

Zangirolami, D. M., Fluxo Neutrônico a 100kW nos Terminais de Irradiação do Reator TRIGA IPR-R1, Dissertação de mestrado, UFMG, Belo Horizonte, 2009.