

Specific Induced Activity Profile at the Rotary Specimen Rack of IPR-R1 TRIGA Reactor

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The IPR-R1 TRIGA nuclear reactor at Nuclear Technology Development Center, CDTN/CNEN, Belo Horizonte, Brazil, has a rotary specimen rack, RSR, outside the reactor core, and it is composed for forty irradiation channels in a cylindrical geometry. The aim of this work is to evaluate the neutron fluence rate distribution at the RSR and its variation under different irradiation conditions by means of specific induced activity measurements. Al-0.1 % Au reference materials were irradiated simultaneously at 100 kW in these irradiation channels and gamma spectrometry was applied with HPGe detector to determine the specific induced activity. This procedure was repeated six times. The results show an asymmetrical neutron fluence rate distribution at the RSR. The variation between the minimum and the maximum specific induced activity values in the RSR channels is about 14%.

Keywords: TRIGA nuclear reactor, neutron fluence rate, neutron activation

I. INTRODUCTION

The IPR-R1 TRIGA MARK 1 nuclear reactor of CDTN/CNEN in the city of Belo Horizonte, Brazil, has been operating since 1960. TRIGA utilizes solid fuel elements in which the zirconium-hydride moderator is homogeneously combined with 20%-enriched uranium. It uses graphite as reflector and deionized light water as moderator and cooling. IPR-R1 is used in neutron physics research, production of radioisotopes for industrial, medical and environmental applications, besides sample irradiation for instrumental neutron activation analysis INAA. It has three facilities for sample irradiation: the central thimble CT, the rotary specimen rack RSR and the pneumatic tube transfer system PT. The power level of the reactor is controlled with three control rods: Regulating, Shim, and Safety. The actual reactor core configuration has 63 fuel elements, as shown in Figure 1. The CT is placed at the center of core reactor and permits sample irradiation with maximum neutron fluence rate, besides neutron beam extraction. This facility is made of anodized aluminum tube with an external diameter of 3.81cm, an internal diameter of 3.38cm and 6.1m height. CT is removable and when it is not in use the reactor pool water occupies its volume. The PT facility is mainly used for analysis by the delayed fission neutron method. The RSR is placed outside the reactor core and has 40 irradiation channels, each one with 31.75mm diameter and 27.4 cm high for sample accommodation. RSR is the most used irradiation facility at IPR-R1, which has the INAA as one of the main applications [1 - 8]. Actually sample irradiations for INAA at RSR are made with this facility unmoving due to the aging of the rotary mechanism. Previous measurements [4, 6] indicate significant variation of the neutron fluence rate distribution between the RSR irradiation

channels.

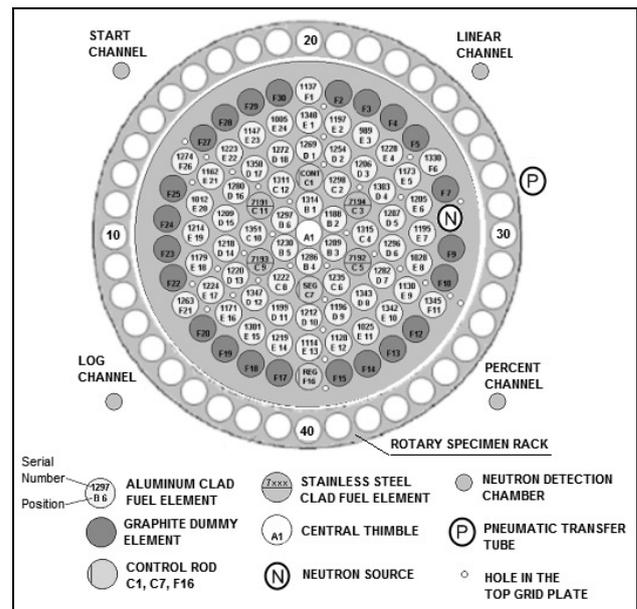


FIG. 1: Actual horizontal cross-section of IPR-R1 TRIGA Mark I reactor core [9]

The aim of this work is to evaluate the neutron fluence rate distribution at 100 kW in the RSR and its variation under different irradiation conditions by means of specific induced activity measurements.

II. MATERIALS AND METHODS

II.1. Experiment

Al-0.1 % Au reference material [10] was used as neutron fluence rate detector. The reference material was cut in disks about 1cm diameter and weighted in a precision balance. A

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set of 39 disks was irradiated simultaneously in 39 irradiation channels of the rotary specimen rack. The channel 4 (showed in Figure 1) of the RSR is not in use at this moment. During the irradiation, the rotary specimen rack remained unmoving. The irradiations were performed in six different dates between 4 Mach, 2008 and 29 April, 2008. For each date, it was applied the same irradiation time, 1 hour, and the same reactor power, 100kW. In these six irradiations, the operational conditions were chosen to simulate the typical conditions of reactor operation. On this purpose, sometimes bared or Cd covered samples were introduced into the CT. Besides, sometimes CT was removed from the reactor core. Table 1 resumes the operational conditions of the six experiments. The column Reactor Status indicates the previous utilization of the IPR-R1: "cold" means at least five days of reactor inactivity, and "hot" means at least eight hours of reactor operation at the day before the experiment.

After the irradiation, the samples were removed from the RSR and two days later they were submitted to gamma spectrometry. The gamma spectrometer system is equipped with an HPGe detector model CANBERRA[®] 5019 (counting efficiency: 50%; resolution: FWHM 1,85keV for 1332keV gamma energy from ⁶⁰Co), and the software Gennie 2000 v2.0, CANBERRA[®]. The counting time was adjusted to provide a net peak area about 60,000 counting for the 411.8keV peak from ¹⁹⁸Au radioisotope.

II.2. Theoretical basis:

The characteristic nuclear reactions in the experiment are:



The ¹⁹⁸Au radioisotope has a half-life of 2.694 days, and the ²⁸Al radioisotope has a half-life of 2.24 minutes. Therefore, after half an hour, almost all ²⁸Al have been decayed, not disturbing the ¹⁹⁸Au counting, which was performed two days after the irradiation.

The reaction rate per nucleus, R , of the formed radioisotope is given by [11]:

$$R = \int_0^{\infty} \sigma(E) \phi(E) dE \quad (3)$$

where E is the neutron energy in eV; $\sigma(E)$ is (n, γ) cross-section of target nuclei in cm^2 ; $\phi(E)$ is the neutron fluence rate per unit of energy interval in $\text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{eV}^{-1}$.

Adopting the Høgdahl convention [11]:

$$R = (\phi_{th}\sigma_{th} + \phi_{epi}I\gamma) \quad (4)$$

where σ_{th} is the thermal neutron radioactive capture cross-section of the target nuclei; ϕ_{th} and ϕ_{epi} are the thermal and epithermal neutron fluence rates, respectively, in sample channel; and $I\gamma$ is the radioactive capture resonance integral of the target nuclei.

The sample induced activity A_0 at the end of the irradiation time t_{irr} , is given by [11]:

$$A_0 = N(\phi_{th}\sigma_{th} + \phi_{epi}I\gamma) (1 - e^{-\lambda t_{irr}}) \quad (5)$$

where N is the number of target nuclei in the sample; λ is the radioisotope decay constant ($\lambda = \ln 2 / T_{1/2}$; $T_{1/2}$ is the radioisotope half-life).

After gamma spectrometry analysis, the specific induced activity may be obtained by [11]:

$$A_0 = \frac{N_p e^{\lambda t_d}}{\varepsilon \gamma \theta w t_m} \quad (6)$$

where t_d is the time interval between the irradiation ending and start counting; t_m is the counting interval time; ε is photo peak counting efficiency; θ is isotopic abundance of the target nuclide; γ is the gamma emission probability; w is the target nuclide mass in the sample; N_p is the counts number of the photo peak, in interval t_m .

The uncertainty analysis based on Equation 6 leads to:

$$\frac{\sigma_{A_0}}{A_0} = \sqrt{\frac{\sigma_{N_p}^2}{N_p^2} + \frac{\sigma_w^2}{w^2} + \frac{\sigma_\varepsilon^2}{\varepsilon^2} + \frac{\sigma_\gamma^2}{\gamma^2} + \frac{\sigma_\theta^2}{\theta^2} + \frac{\sigma_{t_m}^2}{t_m^2} + (t_d \sigma_{t_d})^2 + (\lambda \sigma_\lambda)^2} \quad (7)$$

In the Equation 7, θ , t_m , t_d , γ , and λ uncertainties are very small and therefore the last five terms are negligible. Then,

$$\frac{\sigma_{A_0}}{A_0} \cong \sqrt{\frac{\sigma_{N_p}^2}{N_p^2} + \frac{\sigma_w^2}{w^2} + \frac{\sigma_\varepsilon^2}{\varepsilon^2}} \quad (8)$$

III. RESULTS AND DISCUSSIONS

Figure 2 presents the specific induced activity results obtained for all the RSR channels. The channel 4 results are the mean values of data from channel 3 and channel 5. In Figure 2A, the results for all the six experiments are presented. In these experiments, typical uncertainty values (equation 8) are: $\sigma_{N_p}/N_p = 0.007$; $\sigma_w/w = 0.004$; $\sigma_\varepsilon/\varepsilon = 0.02$; which leads to $\sigma_{A_0}/A_0 = 0.02$. The error bars representing uncer-

Table 1 – IPR-R1 Operational Conditions

EXPERIMENT	SAMPLE IN RSR	SAMPLE IN CT	REACTOR STATUS
1	B	CT absent	hot
2	B	CT absent	hot
3	B	CT absent	hot
4	B	CT absent	cold
5	B	B	hot
6	B	Cd	cold

B=Bared Cd=Cadmium covered

tainty values were omitted in Figure 2A. Figure 2B shows the mean value and standard deviation (bar error) of specific induced activity in each RSR channel.

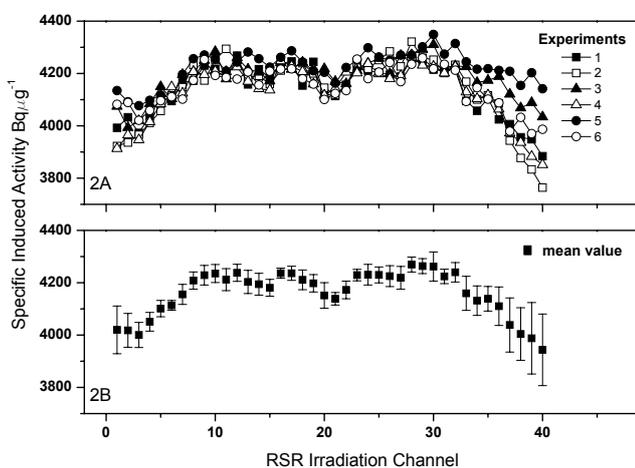


FIG. 2: Specific induced activity for the Reference Material

Figure 2B shows that from channel 1 to channel 10 the mean value of the specific induced activity in each channel tends to increase. This fact may be explained by the reactor core configuration (Figure 1). The F16 core reactor position is occupied the REGULATING control rod. The control rods, neutron absorbers, disturb the neutron fluence rate in their vicinity. From channel 1 to channel 10, the distance from the

REGULATING control rod increases. This explains the increase of the observed specific induced activity in this region. Figure 2B also shows that the mean value of the specific induced activity tends to decrease from channel 30 to 40. Due to the cylindrical core configuration, this observation also may be explained by the relative position of these channels to the REGULATING control rod.

The specific induced activity values in the RSR show a relatively flat maximum from the 10 to the 30 channels. This fact is also explained by the reactor core configuration: these channels are far from the REGULATING control rod. The small observed specific induced activity depression around channel 20 may be explained by the SHIM control rod position (C1 position in Figure 1). This control rod is placed on the axis passing through the tree control rods and the 20 channel.

Figure 2 shows that the greatest values of the specific induced activity standard deviation are from the channel 36 to 02. This fact is due to the neighborhood of the REGULATING rod position. In each experiment, the REGULATING control rod vertical position varies according to the reactor start up procedure, which is manual.

In order to illustrate the behavior of channels 36 to 02, Table 2 presents the data about REGULATING and SHIM control rods vertical positions and the specific induced activity in the channel 40. In all reactor operation the SAFETY control rod (labeled C7 in Figure 1) is withdrawn from the core.

Table 2 – Experiments Summary – IPR-R1 at 100kW

Experiment number	REGULATING rod position *	SHIM rod position*	Specific Induced Activity in channel 40 (Bq.µg ⁻¹)	RSR Mean Specific Induced Activity and Standard Deviation (Bq.µg ⁻¹)
2	560	570	3764	4132±136
4	588	595	3851	4132±111
1	642	580	3884	4134±102
3	693	580	4033	4184±77
6	694	609	3987	4146±79
5	830	605	4142	4221±65
ALL	-	-	-	4158±103

*(Range 150-900; 150: rod totally inserted; 900: rod totally extracted)

Table 2 shows a directly relation between the REGULATING rod vertical position and the specific induced activity

at channel 40: as more inserted the REGULATION rod is into the reactor core as lower is the specific induced activity at channel 40. However, the RSR mean value of specific induced activity does not varies significantly with the REGULATION rod vertical position. This fact causes an increase in the value of standard deviation for RSR mean specific induced activity.

Tables 1 and 2 show that the CT presence, with or without Cd sample, has no significant influence in the neutron fluence rate in the RSR. In the same way, the reactor status (cold or hot) did not affect the experiments. The ^{135}Xe is a fission product, which absorbs neutrons. This effect is calling “ ^{135}Xe poisoning”. Hot reactor tends to have more of this element [12]. However, in our experiments, the reactor status has no significant influence in the neutron fluence rate in the RSR.

IV. CONCLUSIONS

The results obtained indicate that the profile of the specific induced activity in the rotary specimen rack depends mainly on the control rods position during reactor criticality. For each experiment (one hour irradiation, 100kW power) the specific induced activity value depends on the relative position between the RSR irradiation channel and the SHIM and the REGULATING control rods placement. Because of this it is possible to identify regions at RSR with similar variability.

One region at channels 36 to 02 with lower nominal neutron fluence rate and greatest standard deviation values. Another region from channels 10 to 30 with the greatest nominal values and lower standard deviations, presenting a small neutron fluence rate depression around channel 20. The reactor core has a symmetrical axis through control rods, but the specific induced activity profile does not match this axis, probably due to different fuel elements burning. The presence or absence of the CT facility, with or without samples does not cause significant neutron fluence rate variation at the RSR, and neither the reactor status (cold or hot).

Channel 40 has the lower specific induced activity mean value; the maximum values are around channels 10 and 30. Channels 7 and 33 correspond to the RSR mean value. The variation between the minimum and the maximum specific induced activity values for the reference material is about 14%.

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