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A hybrid setup for neutron imaging and prompt-gamma activation analysis at research reactor IEA-R1

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1. Introduction

Prompt-Gamma Activation Analysis (PGAA) is a powerful technique for detecting elements that are impossible to identify using conventional activation analysis methods [1,4]. However, Brazil currently lacks a PGAA facility, primarily due to the stringent requirements for its installation. These requirements include the need for a relatively high thermal neutron flux, typically ranging between 10^6 to 10^8 $n.cm^{-2}.s^{-1}$ [4], as well as various factors related to detector shielding and the installation location.

These prerequisites make PGAA installations rather expensive. One innovative approach to reduce the costs associated with PGAA is to adapt an existing neutron tomography (NT) setup into a hybrid system, referred to as PGAI-NT [2]. The neutron tomography facility employed in this study is installed at the radial channel 14 of the 4.5 MW, pool type, nuclear research reactor IEA-R1, of the IPEN/USP, and due to the configuration system, boasts a feasible cold neutron flux for PGAA applications [3]. The primary objective of this research is to enhance the existing neutron imaging system to accommodate PGAA functionality. The simulation of this project employs the MCNP6 code to model these adaptations and their potential effects.

Through the simulations were possible to obtain the best design of detector's shield for neutrons and gammas. The choice of the setup was made using different materials and geometries. The results in the present work give the first step to PGAA in Brazil, thereby contributing to the scientific community's understanding of elemental composition and analysis.

2. Methodology

The NT facility located in the reactor IEA-R1 was constructed using MCNP6.1 code for gamma and neutron transport. Fig. 1 presents the NT scheme splitted in three parts, (a) the virtual nucleon source and the pool of the reactor IEA-R1, (b) the beam collimation and the bismuth filter and (c) the diaphragm , responsible by the divergence of the beam ,and the sample holder of NT facility.

Three collimator plug models Thor, Freya and Loki have been made to ensure the best shielding and prompt-gamma collimation for the hybrid system PGAA-NT. The geometry of the models can be seen in Fig. 2 and consulted in Table 1 the respectives parameters. The materials used in the models were lead to gamma shield and borated polyethylene to neutron shield.

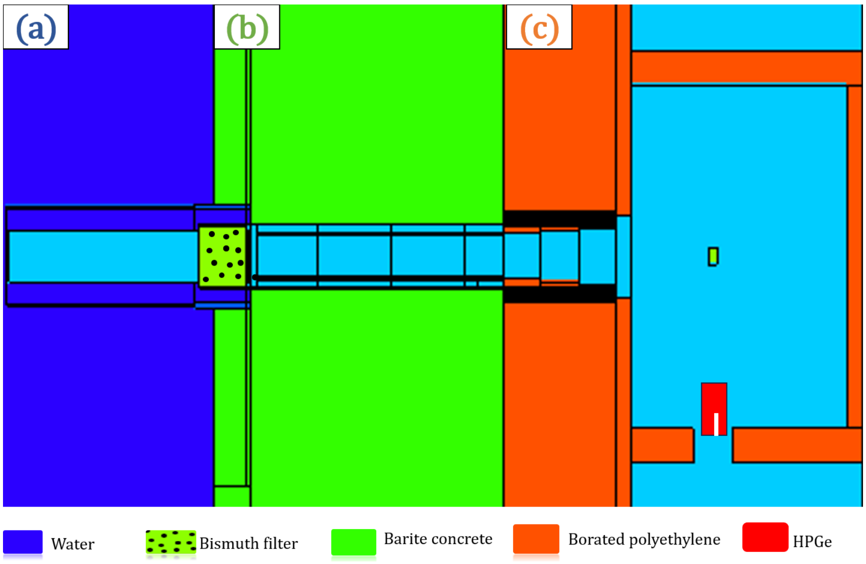

Figure 1: Scheme of the horizontal view of the NT facility at IEA-R1 reactor (a) source, (b) beam guide and (c) sample holder.

Table I: Simulation parameters of the PGAA plugs and HPGe detector

Componets	Parameters
Thor	$d_1 = 3.00$ cm, $d_2 = 3.00$ cm $d_3 = 6.00$ cm,$d_4 = 20.00$ cm Lead thickness = 4.50 cm, Polyethilene thickness = 2.00 cm
Freya	$d_1 = 3.00$ cm, $d_2 = 11.00$ cm $d_3 = 6.00$ cm, $d_4 = 20.00$ cm Lead thickness = 4.50 cm, Polyethilene thickness = 2.00 cm
Loki	$d_1 = 3.00$ cm, $d_2 = 11.00$ cm $d_3 = 20.00$ cm, $d_4 = 20.00$ cm Lead thickness = 4.50 cm, Polyethilene thickness = 2.00 cm
HPGe	$d = 6.30$ cm, $h = 8.97$ cm $d_{coldfinger} = 1.60$ cm, $h_{coldfinger} = 3.47$ cm Window = Aluminium

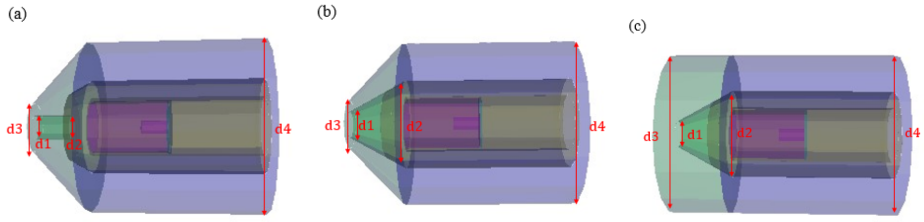

Figure 2: 3D scheme of the three models of plug for PGAA called (a) Thor, (b) Freya and (c) Loki.

To evaluate the shielding efficiency of the collimators model, a standard gamma fission source was utilized for the gamma simulation and for the neutron simulation a neutron source was made based on the neutron spectrum of the IEA-R1 reactor nucleon.

3. Results and Discussion

The three plugs were simulated with an objective to obtain the gamma shield efficiency. The gamma fission source was located in the nucleon face and the HPGe detector was located in the sample position. Fig. 3 show the shielding performance of the plug models using a Tally of flux in the detector volume, the discrepancy between the flux in the detector without the plug and with plug show the necessity of the plug to shield the gamma provided of the nucleon fission. Among the three plugs the best performance in relation to the shielding was Loki.

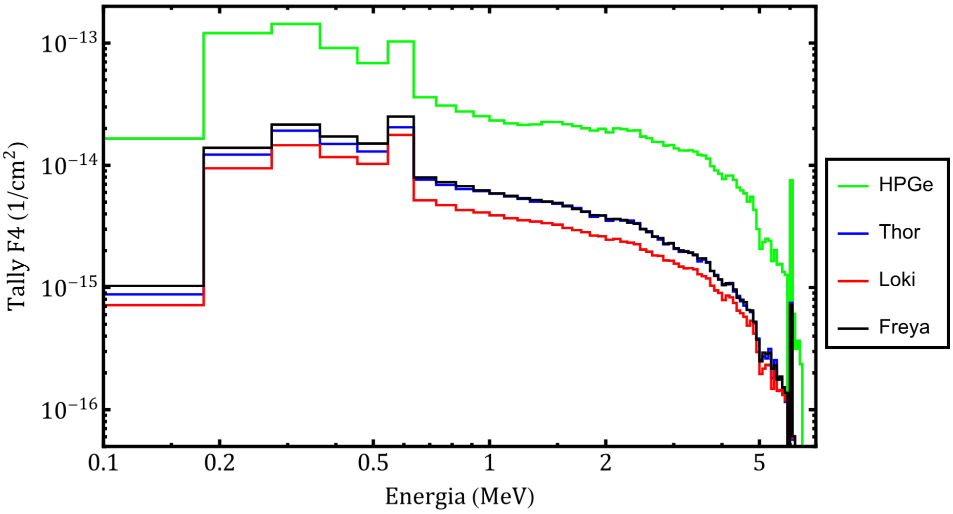

Figure 3: Scheme of the horizontal view of the NT facility at IEA-R1 reactor (a) source, (b) beam guide and (c) sample holder.

Although the three plugs have been obtained near results, the dose presented in Table 2 favors a solid analysis in relation to the shield performance. Loki's design presented a better shielding performance in relation to Thor and Freya. This finding ensures Loki as the best choice design collimation for the construction of the hybrid system in the IEA-R1 reactor.

Table II: Values of the MCNP gamma dose induced by gamma of the thermal fission in the detector volume with the relative error of the simulation.

Plug	Tally F6 Dose (MeV/g)	Error (%)
Thor	$6.77x10^{-15}$	3.11
Freya	$6.96x10^{-15}$	3.06
Loki	$4.72x10^{-15}$	3.29
HPGe	$4.30x10^{-14}$	2.67

4. Conclusions

In summary, the MCNP6.1 simulation provides valuable insights for determining the optimal configuration for installing the first PGAA system in Brazil, specifically in the NT channel of the IEA-R1 nuclear reactor. In terms of shielding analysis, Loki outperforms Thor and Freya in providing superior gamma radiation shielding. These findings position Loki as the most suitable choice for the PGAA plug in adapting the NT facility into a hybrid system of PGAA and neutron radiography (NT).

This study not only contributes to the development of a new design that can serve as a basis for various installations but also provides essential information for the installation of the first PGAA system at the IEA-R1 reactor. These findings also have implications for future installations at the Brazilian Multipurpose Reactor, enhancing the overall capabilities of the facility.

Acknowledgments

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