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Sample to moderator volume ratio effects in neutron yield from a PGNAA setup

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Abstract

Performance of a prompt gamma ray neutron activation analysis (PGNAA) setup depends upon thermal neutron yield at the PGNAA sample location. For a moderator, which encloses a sample, thermal neutron intensity depends upon the effective moderator volume excluding the void volume due to sample volume. A rectangular moderator assembly has been designed for the King Fahd University of Petroleum and Minerals (KFUPM) PGNAA setup. The thermal and fast neutron yield has been measured inside the sample cavity as a function of its front moderator thickness using alpha particle tracks density and recoil proton track density inside the CR-39 nuclear track detectors (NTDs). The thermal/fast neutron yield ratio, obtained from the alpha particle tracks density to proton tracks density ratio in the NTDs, shows an inverse correlation with sample to moderator volume ratio. Comparison of the present results with the previously published results of smaller moderators of the KFUPM PGNAA setup confirms the observation.

Keywords: PGNAA; Fast and thermal neutron yield measurement; 2.8 MeV neutrons; NTDs; Monte Carlo simulations

1. Introduction

The performance of a Prompt Gamma ray Neutron Activation Analysis (PGNAA) setup depends upon thermal neutron flux available at the sample (Sowerby and Watt, 1994; Naqvi et al., 2003, 2004a, b, 2006; Olivera et al., 1993, 1997; Saleh and Livingston, 2000; Al-Jarallah et al., 2002; Collico Savio et al., 1995; Khelifi et al., 1999; Tickner, 2000; Lim et al., 2001). The thermal neutron flux of a PGNAA setup, which is produced by an external moderator, depends upon moderator volume available to slow down the fast neutrons to thermal energies. Therefore thermal/fast neutron intensity ratio in a PGNAA setup with adequate moderation volume, increases with moderator size. A rectangular moderator assembly has been designed for the PGNAA setup of King Fahd University of Petroleum and Minerals (KFUPM) to analyze bulk samples of cement and concrete for concrete corrosion study (Naqvi et al., 2004a, 2006). The design calculations of the rectangular moderator have been verified experimentally through thermal neutron yield measurements as a function of its front moderator thickness using CR-39 nuclear track detectors (NTDs) (Naqvi et al., 2004a). The thermal neutron yield was measured inside the sample volume of the rectangular moderator by two NTDs fixed at back and front end of the sample cavity. Previously thermal neutron flux was measured using NTDs inside two different cylindrical moderators with 25.4 cm outer diameter and 14 cm length (Al-Jarallah et al., 2002; Naqvi et al., 2003). One moderator called 'SSM' was used with a sample having 7 cm radius while the other moderator called 'LSM' was used with a sample having a 8.5 cm radius (Al-Jarallah et al., 2002). It was observed that maximum yield of thermal neutron from the LSM was $22 \pm 6\%$ smaller than that from the SSM (Naqvi et al., 2003). This was expected because the volume of the LSM was about 17% smaller than that of the SSM. Now a large size rectangular moderator has been designed for the KFUPM PGNAA setup (Naqvi et al., 2004a, b). In this study, the thermal and fast neutron yield has been measured inside the moderator in the sample volume using NTDs. Results of this study are compared to those of the SSM and LSM data to study moderator volume dependence of the neutron yield.

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2. The KFUPM PGNAA setup with the rectangular moderator

The rectangular moderator assembly of the KFUPM PGNAA setup has been described in detail elsewhere (Naqvi et al., 2004a, b) but for completion sake it will be described here briefly. The setup consists of a cylindrical sample placed inside a rectangular moderator. The moderator is made of paraffin wax and has a central cylindrical cavity, which can accommodate a sample with a maximum diameter of 25.4 cm. The rectangular moderator was designed for a 2.8 MeV neutron based PGNAA setup for the analysis of cement and concrete samples. The rectangular moderator is 19 cm thick and has a cross section of 49 cm × 49 cm (width x height). For a sample with an optimum diameter less than the maximum value, a high density polyethylene plug is used, which fills the gap between the sample and the walls of the cavity. Fast neutrons are thermalized in two regions of the moderator, being first a region located between the neutron source and the sample front end (called front moderator) and secondly in the moderator reflector collar surrounding the sample along its length. The fast neutrons that escape from the front moderator region, are reflected by the collar into the sample region. Fig. 1 shows the PGNAA setup with the rectangular moderator and the high density polyethylene plug with a sample with diameter less than the maximum diameter. The optimum value of the sample radius, front moderator thickness and the sample length were assumed to be the one which produced maximum yield of the prompt gamma rays at the detector. The optimum dimension of the sample to be used with the rectangular moderator is given in Table 1. For sake of comparison the similar data for the cylindrical moderator (Naqvi et al., 2003) is also listed in Table 1.

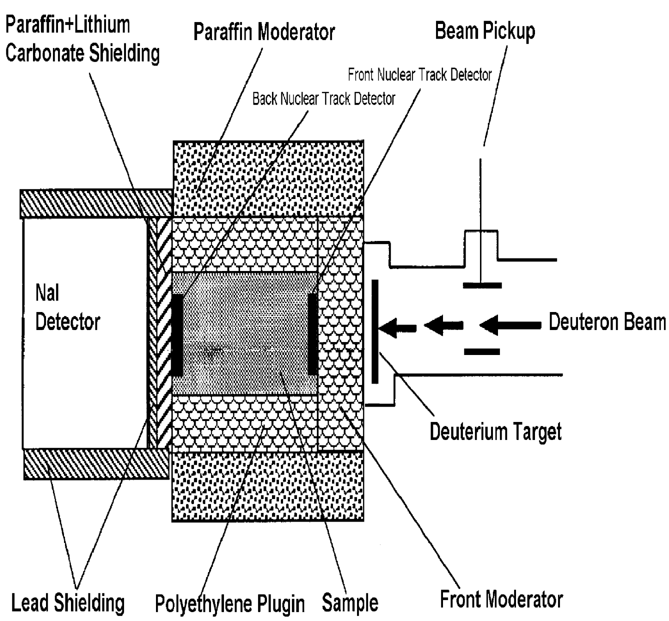

Fig. 1. Schematic representation of the PGNAA setup used to measure fast and thermal neutrons (Naqvi et al., 2004a). In thermal neutron measurements, the sample is replaced by a nuclear track detectors (NTDs) called middle detector placed in the middle of the front and back nuclear track detectors shown in the figure.

3. Fast and thermal neutron yield measurements

The thermal and fast neutron yield was measured inside the PGNAA moderator at the middle point of sample as a function of the thickness of the front moderator using NTDs. The cavity full volume was used without plugin to study the maximum effect of loss of moderation volume. One NTD was mounted in the middle of the cavity (mid detector) with reference to the incident neutron beam. The mid detector was placed at a distance of 7 cm from the front moderator and it was in the middle of the front and back detectors shown in Fig. 1 (Naqvi et al., 2004a). The mid detector was masked with boron converter to measure thermal neutron intensity via (n, α) reaction while a second NTD without boron converter, was placed next to the mid detector to measure fast neutron intensity at that location. The NTDs consist of 0.5 mm thick CR-39 NTD (Poly Allyle Diglycole Carbonate(PADC)–$C_{12}H_{18}O_7$) with an area of 1.5 cm × 1.5 cm. The mid detector represents the average intensity of the thermal neutrons at the sample location. For sake of comparison with experimental data, thermal neutron yield of the middle detector was calculated using Monte Carlo code MCNP4B2 (Briesmeister, 1997) following the procedure described elsewhere (Naqvi et al., 2004a).

The measurements were carried out using the PGNAA setup, built at the 45° beam line of the KFUPM 350 keV accelerator laboratory (Naqvi et al., 2004a, b, 2006). A 200 keV deuteron beam with 4.8 ns pulse width and a pulse repetition rate

Table 1
Dimensions of the rectangular and the cylindrical moderator assemblies of the KFUPM PGNAA setup

Moderator parameter	Rectangular moderator	Cylindrical large sample moderator (LSM) (Naqvi et al., 2003)	Cylindrical small sample moderator (SSM) (Naqvi et al., 2003)
Moderator size (diameter)	49 cm × 49 cm (width × height)	25 cm diameter	25 cm diameter
Sample radius (cm)	12–14	8.47	7
Front moderator thickness (cm)	5–6	3–4	3–4
Sample length (cm)	14	14	14
Sample volume (Li)	6.87	2.704	2.155
Moderator volume (Li)	45.62	9.33	9.33
Sample/moderator volume ratio (%)	15.0	28.9	23.1
Slope of therm/fast neutron yield	1.39 ± 0.1	0.63 ± 0.1	0.68 ± 0.1