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Moderation and shielding optimization for a ^{252}Cf based prompt gamma neutron activation analyzer system

Kamal Hadad [a,b], *Mohammadreza Nematollahi* [a,b,*], *Hoda Sadeghpour* [a,b], *Reza Faghihi* [a,c]

[a] *Department of Nuclear Engineering, Shiraz University, Mollasadra St, 71348-51154, Shiraz, Iran*
[b] *Nuclear Safety Research Center, Shiraz University, Mollasadra St, 71348-51154, Shiraz, Iran*
[c] *Radiation Research Center, Shiraz University, Mollasadra St, 71348-51154, Shiraz, Iran*

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ABSTRACT

Prompt Gamma Neutron Activation Analysis (PGNAA) is a fast, online and the non-destructive elemental analysis method which is widely used in industries such as cement and coal. In the present study, optimization of the moderator and gamma radiation shield of a ^{252}Cf neutron source in a PGNAA setup, utilizing Monte Carlo simulation is succeed. The objective is to enhance the thermal neutron spectrum and minimize potential gamma rays. The results show that high density polyethylene (HDPE) with a thickness of 5 cm as the moderator and lead with a thickness of 4 cm as the gamma radiation shield are the best options for the intended purpose. As a result of this optimization, increased efficiency of the PGNAA setup through (n_{th},γ) reaction and elevated prompt gamma flux which provides higher accuracy for the detector system.

Introduction

PGNAA[1] is a fast, online and the non-destructive elemental analysis method which is implemented in wide range of application including environmental [1,2], health sciences [3] and industrial [4,5]. In this method, the concentration and percentage of the elements in a sample are determined by the characteristic gamma intensity, which is generated by the collision of thermal neutrons with the sample through (n, $n'\gamma$) and (n_{th},γ) interactions [6,7]. With the high prompt gamma energy derived from the absorption reaction of thermal neutrons, in elemental analysis of industries such as cement plants, this reaction formulates the basis of PGNAA setup. PGNAA Analyzer contains three main parts including neutron sources and its shield, sample material and gamma detector system. Neutron sources used in this system usually consist of a radioisotope sources such as ^{252}Cf, Am–Be or 14 MeV neutrons generated by an accelerator. The most common source used in PGNAA system is ^{252}Cf which is a spontaneous fission source with neutron mean energy of 2.1 MeV and neutron most probable energy of 0.7 MeV. Given the high average of the neutrons, they need to be moderated to the limit of thermal energy to improve the efficiency of the device

* *Corresponding author*. Department of Nuclear Engineering, Shiraz University, Mollasadra St, 71348-51154, Shiraz, Iran.
E-mail address: nema@shirazu.ac.ir (M. Nematollahi).
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through increasing prompt gamma flux for (n_{th},γ) reactions. Materials used as the neutron moderator should contain light elements with high scattering cross sections and low absorption. Also, ^{252}Cf source emits a continuous spectrum of gamma with the energy range 0–10 MeV, which should be shielded as much as possible to minimize their destructive effects and potential interaction with the main spectrum of prompt gamma.

In this study, Monte Carlo calculations were performed for the gamma shield design and the suitable moderator for a ^{252}Cf neutron source used in the elemental analysis instrument by PGNAA in CBX™ Analyzer. The purpose of the design is:

1. Maximizing neutron moderation to enhance thermal neutron flux which results in an increase in prompt gamma ray flux of sample material,
2. Minimizing the fast and epithermal neutron flux,
3. Minimizing the gamma-ray radiated from the source and any delayed (n,γ) reaction.

It should also be noted that the moderation enhancement should not significantly increase the background gamma.

Material and methods

Using Monte Carlo code, the geometry of CBXTM online analyzer was modeled for Monte Carlo analysis. This model (Fig. 1) consists of ^{252}Cf source container, moderator, conveyor belt, sample substance and the detector box containing two Na–I detectors (7.62 Cm × 7.62 Cm) (3 × 3 inch). In this study, the main goal is to design a source container.

^{252}Cf source modeling

20 mg of ^{252}Cf with 400 MBq (10.7 mCi) activity and radiation of 4.6 × 10^7 n/s, which is inside the standard X.1 capsule code CVN7 were modeled by the Monte Carlo coded. In this model, ^{252}Cf neutron energy spectrum is measured in terms of Watt Fission Spectra, and its spectrum of gamma energy measured based on the distribution function obtained from the experimental data reported by Glassel, [8]. The spectra for neutron and gamma are given in Eqs. (1) and (2) as:

$$Scf_n(E_n) = 0.30033e^{(-E/1.025)}Sinh(2.926E_n)^{1/2} \quad (1)$$

$$Scf_\gamma(E_\gamma) = \begin{bmatrix} 375E^2e^{-E/0.109} + 0.468e^{-E/1.457}E \le 1.5\text{ MeV} \\ e^{-E/0.851}E > 1.5\text{ MeV} \end{bmatrix} \quad (2)$$

where E is in terms of MeV and the ratio of gamma multiplication to neutron is 2.132 for each fission.

Modeling of gamma shield

Gamma radiated from ^{252}Cf has a continuous energy spectrum from 0 to 10 MeV. Thus, when this radioisotope is used as a neutron source, the effect of gamma rays should be taken into account because the high concentration of gamma rays emitted from the source in the detector may prevent the spectrum in the detector from representing the prompt gamma rate generated by the thermal neutron reaction. Shield of gamma radiated from the source should be designed in a way that neither reduces the neutron flux or the source nor generates prompt gamma rays with high energy and rate through the reaction of neutrons with shield material. The most common materials used as gamma shields are lead and bismuth. To determine the optimum thickness for gamma shield and choose the proper material, cubes of different sizes were inserted around the sources in both materials and gamma and neutron flux were measured. The results are shown in Figs. 1 and 2.

Moderator modeling

Since ^{252}Cf is a source with a relatively high neutron flux of fast neutrons, and given that the PGNAA technique is based on the collision of high intensity thermal neutrons with the sample, neutrons are needed to be slowed down before reaching to sample [9,10]. Thus, the aim is to increase the thermal neutron flux rate and reduce the rate of the fast neutron flux in PGNAA analysis. To this end, a moderator need to be used, and the selected materials should not increase the background gamma. In this research, the materials considered being suitable as moderator are: high density

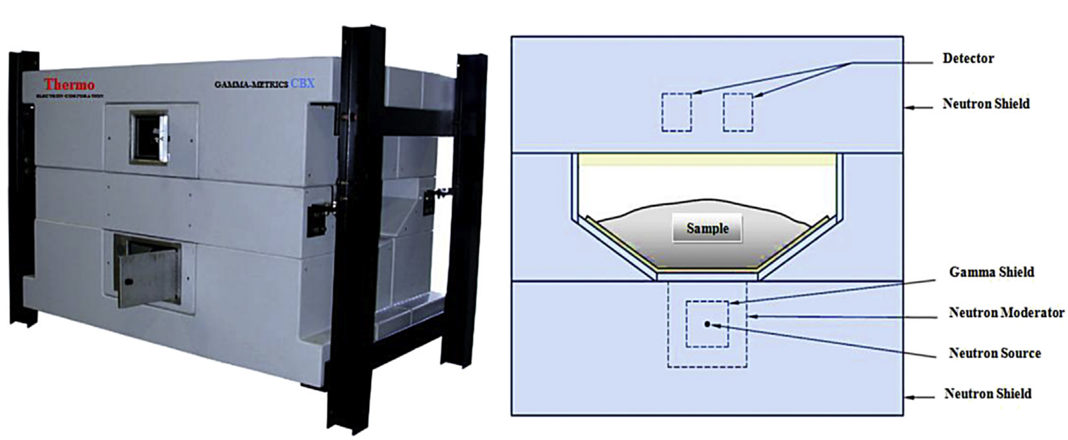

Fig. 1 – Geometry of the CBX analyzer.