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A Compton-suppression detection system for use in manganese bath measurements

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HIGHLIGHTS

- A Compton-suppression system (CSS) consists of eight NE102 plastic and one NaI scintillators is proposed.
- The motivation for the proposed CSS is to improve the minimum detectable activity in a manganese bath system (MBS).
- Both MCNPX and experimental studies have been undertaken to obtain the optimum source-to-detector distance in CSS.

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ABSTRACT

The manganese sulfate bath technique is a standard tool for neutron source strength measurement (Park et al., 2005). However, the dominate Compton continuum of most sodium iodide scintillators used in manganese bath systems (MBSs) does not allow the precise identification of induced gamma rays required for such measurements. In this research, to resolve this problem, a Compton-suppression system has been proposed which consists of a 2 in. by 2 in. NaI(Tl) right cylindrical scintillator as the main and a set of eight rectangular NE102 plastic scintillators of $12 \times 12 \times 15$ cm^3 dimensions as suppression detectors. Both detectors operate in anti-coincidence circuit to suppress the Compton continuum. The proposed system has been simulated with the MCNPX code with two different approaches and the corresponding measurements with ^{137}Cs gamma-ray source and neutron-activated $MnSO_4$ solution have been undertaken that give rise to a promising agreement.

1. Introduction

The radioisotope neutron sources are frequently used in radiation physics studies due to their relatively high neutron emission rate, their portability and economic effectiveness. However, their physical characterizations have to be performed prior to any kind of application which is not generally an easy task. Although several methods have been utilized for neutron emission rate measurements (Kamboj et al., 1976), the method of manganese sulfate bath has remained the most reliable way for measuring the absolute neutron emission rate of well-known neutron sources such as ^{241}Am–Be and ^{252}Cf (Roberts and Parfitt, 2010). Fig. 1 shows a typical manganese bath system in which a spherical tank contains a high-purity manganese sulfate solution. The source neutrons are moderated as they pass through the solution via elastic scattering off hydrogen nuclei. The thermal neutrons are normally captured by hydrogen, manganese, sulfur and oxygen nuclei. The number of 846.8 keV de-excitation gamma rays of ^{56}Mn detectable with an NaI(Tl) scintillator together with the information on the (n,γ) cross sections of all elements in the solution (i.e., ^{32}S, ^{16}O, ^{1}H and ^{55}Mn) are necessary data for measuring neutron emission rate of the source (B), that are related via the following equation (Park et al., 2005):

$$B = \frac{1}{f} \cdot R \tag{1}$$

where, R and f are the ^{56}Mn production rate through neutron capture reaction and the fraction of thermal neutrons absorbed by manganese nuclei, respectively. Ideally, all source neutrons are thermalized mainly by hydrogen and then absorbed by manganese nuclei via ^{55}Mn$(n,\gamma)^{56}$Mn reaction if the bath is infinitely large. The fraction of neutron capture reactions with manganese nuclei may be obtained as following (Park et al., 2005),

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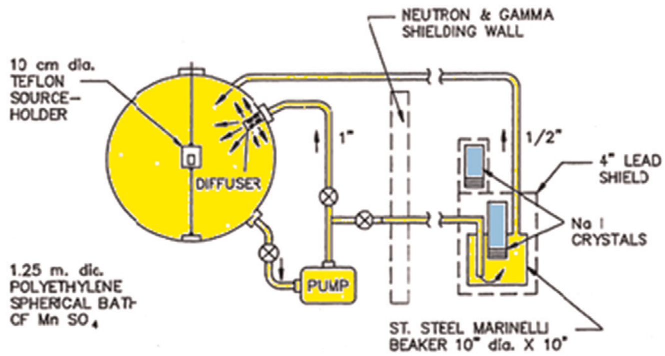

Fig. 1. The sketch of a typical manganese sulfate bath system consists of neutron source, spherical bath, pump, transmission pipes and gamma-ray detector (Dale McGarry and Boswell, 1988).

$$f = \frac{N_{\mathrm{Mn}}.\ \sigma_{\mathrm{Mn}}}{N_{\mathrm{Mn}}\cdot(\sigma_{\mathrm{Mn}} + \sigma_{\mathrm{S}} + 4\sigma_{\mathrm{O}}) + N_{\mathrm{H}}\cdot(\sigma_{\mathrm{H}} + \frac{1}{2}\sigma_{\mathrm{O}})} \tag{2}$$

where, N_H and N_{Mn} are the numbers of manganese and hydrogen nuclei per solution volume and σ_{Mn}, σ_O, σ_S and σ_H are thermal neutron capture cross sections of manganese, oxygen, sulfur and hydrogen nuclei, respectively.

Since the low-energy region of scintillator spectrum is dominated by the Compton continuum the areas under the manganese peaks cannot be precisely determined. Therefore, the limited pulse-height resolution of inorganic scintillators restricts the minimum detectable activity and it affects the precise determination of neutron emission rate of isotopic neutron sources.

The proposed Compton-suppression system of this study is aimed to minimize the Compton continuum as efficiently as possible. The Compton-suppression systems normally contain two detectors: the main and the suppression detectors. The gamma rays incident on the main detector produce recoiled electrons and scattered lower-energy gamma rays. The recoiled electrons normally deposit almost full-energy inside the main detector whilst the scattered gamma ray, depending on its energy, may partially deposit energy and escape from the main detector. If the suppression detector is large enough and it takes advantage of appropriate geometry, it may detect the scattered gamma ray. The true Compton-scattered gamma rays may be identified and efficiently subtracted from pulse-height spectrum if both detectors operate in an anti-coincidence mode. The overall effect is that this subtraction facilitates the peak area determination.

Before proceeding to the proposed detection system especially designed for use in a MBS, it has been decided to model a simple-geometry setup to study the feasibility of the system whose results are given in Section 2. In Section 3 the proposed measurement system is introduced and both simulation and experimental results are presented. Section 4 concludes the paper and discusses different sources of discrepancies between simulation and measurement.

2. Compton-suppression system: an MCNP simulation

A detection setup consists of a $12 \times 12 \times 15\ \mathrm{cm}^3$ rectangular NE102 plastic scintillator as a suppression and a 2″ by 2″ cylindrical NaI(Tl) scintillator as main detectors has been simulated with MCNPX code (Version 2.6.0) (Hendricks et al., 2008). It is assumed that a point ^{137}Cs source is located just below the main detector emitting the gamma rays isotropically in the space (See Fig. 2).

The calculation of deposition energy, which is a measure of pulse-height spectrum, in both main and suppression scintillators can be undertaken in two different approaches: using F8 tally, or by analyzing PTRAC card of the MCNPX as explained in the following.

a. Pulse-height spectrum generation using F8 tally
The F8 tally calculates the simulation equivalent of detector pulse-height whilst FT8 PHL tally incorporates the anti-coincidence phenomenon which causes the omission of the pulse-heights corresponding to those gamma rays escaped from the main detector and detected in the suppression detector.
b. Pulse-height spectrum generation using PTRAC card
The PTRAC card output contains all the necessary information for anti-coincidence consideration required by Compton suppression system (Tajik et al., 2013). The PTRAC card output is usually a large data file of positions, direction cosines, energies and interaction times if the MCNP code is run for a large number of source particles. However, a post-processing program has to be written for the extraction of precise deposition energies in anti-coincidence mode.

Fig. 3 shows the detector spectrum when exposed to ^{137}Cs gamma rays with and without Compton suppression. The suppression factor (SF) is defined as follows:

$$\mathrm{SF} = \frac{\left(\frac{P}{C}\right)_{\mathrm{Sup}}}{\left(\frac{P}{C}\right)_{\mathrm{Unsup}}} \tag{3}$$

where, P/C is the detector count at 0.662 MeV to the mean count at the Compton continuum within 358–382 keV energy region (Farsoni et al., 2013). In order to understand the effect of different source-to-detector distance on SF, eight different distances have been considered in simulations as listed in Table 1. The highest SF value is obtained when the distance is about 15 cm as verified using both approaches.

In another investigation, the point ^{137}Cs gamma source has

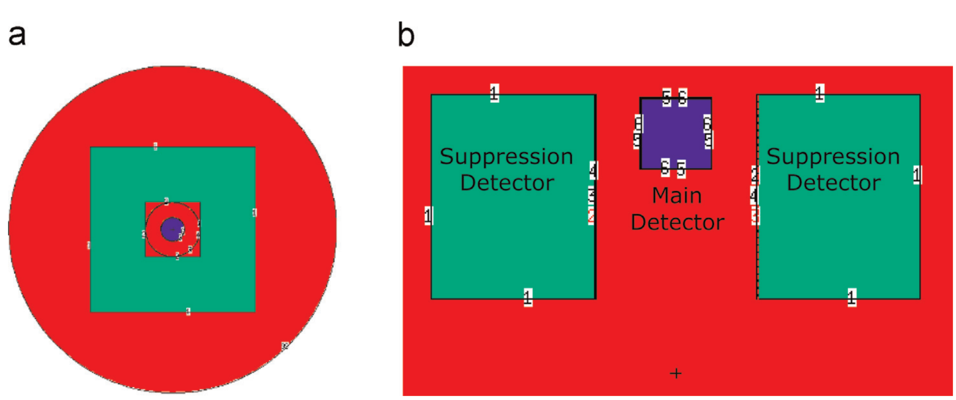

Fig. 2. A Compton-suppression system used in the MCNPX simulation (a) Upper view; (b) Side view.