Original Article

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Gamma Spectrometry in the Presence of Fast Neutrons

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Abstract

Purpose: In some gamma spectroscopy experiments, neutrons may also be present, so depending on experimental conditions, Gamma spectroscopy can be influenced by the presence of neutrons.

Materials and Methods: In this study, a NaI(Tl)(63 mm×63 mm) detector is used to investigate the effects of fast neutrons on the spectrum of gamma photons. The radiation source used in these experiments is made up of two point sources: an AmBe (50 mCi) neutron source and a ^{137}Cs(10 mCi) gamma source.

Results: Results were determined through both measurements and Monte Carlo simulation (MCNPX) under two different experimental conditions and were compared. When the detector is placed under an angle to the source, gamma photon energy peaks resulting from inelastic interactions of the fast neutrons with the detector materials and surrounding materials in the energy range of 0.1-0.9(MeV) are pretty visible in the gamma main spectrum. These results can be used to optimize industrial tomography experiments carried out with NaI(Tl) scintillators.

Conclusion: Also, the results show that the detection of fast neutrons with a NaI(Tl) scintillator is possible with low efficiency.

1. Introduction

In some industrial applications of radioisotopes, such as hygrometry and densitometry, gamma and neutron sources are used together in one device. Hence, both gamma spectroscopy and neutron detection can be influenced by the presence of each other's sources. Neutrons interact with environmental materials and produce gamma or X-ray by reaction of (n, n'), it affects the main spectrum of gamma detector. The gamma ray of (n, n') will be observed with low efficiency by NaI(Tl) detector. Randy Jones and his colleagues (2011) examined the effects of neutrons on the NaI(Tl) detector. According to their results, neutron interacts with NaI(Tl) detector and with other testing environment materials and new energy lines are added to spectrum test. Examples of these spectral lines are seen in 58 keV and 202 keV energies due to the recoil of ^{127}I nuclei 850 keV due to the interaction of neutrons with steel as one of the shield materials [1]. In studies which are done in the field of industrial tomography using NaI(Tl) detector and 662 keV photons, gamma source, ^{137}Cs (10 mCi) and a neutron source, AmBe (50 mCi) was used that they were technically inseparable [2,3]. This research is done to estimate the contribution of fast neutrons` second gamma rays in the gamma spectrum detected by NaI(Tl) (63 mm×63 mm) scintillator under two different experimental conditions. The interaction of fast neutrons with the elements of the detector such as sodium, iodine, iron, and the surrounding lead was also considered. Interference of neutron and gamma radiations were determined through both measurements and Monte Carlo simulation (MCNPX [4]) under two different experimental conditions. The simulation results were

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compared with the measured ones. The results of this study showed that when the detector is placed under an angle to the source (to perform tomography experiments), the effects of neutrons are significant in the main gamma-ray spectrum. Neutrons collision with detector materials and steel shield produce gamma ray in energies of 58 keV, 440 keV, and 580 keV, that their effects should be considered in the gamma spectrum of tomography. In addition, according to the only origination of gamma 58 keV and 440 keV, are in order the reactions of ^{127}I (n, n')^{127}I and ^{23}Na (n, n')^{23}Na that will be the clear attendance of fast neutrons in the environment.

2. Materials and Methods

In gamma spectroscopy and detection experiments, neutrons may also be present. The gamma-ray energy spectrum is measured near neutron fields. Neutrons interact with detector materials and other materials in the test environment and these interactions affect the main gamma spectrum. In order to study these works, experiments were conducted with two different orders: when the detector is placed at a 90 ° compare to the source (in the application of the industrial tomography, the NaI(Tl) detector is placed at a 90 ° compared with the gamma photons.), Figure 1-a and when the detector is placed along the output beam, Figure 1-b.

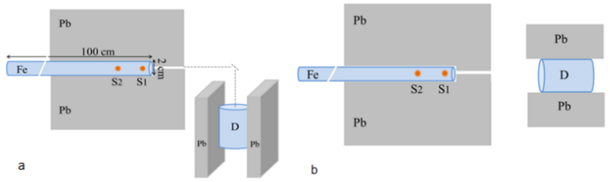

Figure 1. Test procedure, a: detector at 90 degrees angle relative of the source, b: detector along the source (S1: ^{137}Cs, S2: AmBe , Pb: Lead, D: NaI (Tl) (63 mm ×63 mm))

In this work, two point sources, ^{137}Cs (10 mCi) and AmBe(50 mCi) have been used. These two point sources are spaced at 3 cm and are in a cylindrical steel of 2 cm in diameter and 100 cm in length. Sources are technically inseparable. ^{137}Cs is gamma source with energy 662 keV. AmBe is a source of fast neutrons and has half-life 432.7 years. Also, at the same time, it produces gamma photons with 4.438 MeV energy [5, 6]. According to Figures 1-a and 1-b, we put the source at the center of a 5 cm thick collimator (Lead), so that the axis of the source should be aligned with the collimator output hole. The diameter of the collimator output hole is 5mm. In both conditions, the NaI(Tl) detector is used with dimensions of 63 mm (thickness) × 63 mm (length). It is shielded by 3 cm thick lead blocks. The interaction of fast neutron of the AmBe source with sodium, iodine, steel, and lead produces second gamma ray.

2.1. Simulation Studies

To find the effects and contribution of each radiation in the measured spectrum, the interaction of photons and neutrons with detector components and other peripheral materials were simulated by the MCNPX code. Monte Carlo N-Particle Transport Code (MCNP) is a software package for simulating nuclear processes. In the simulation, we can do things that we cannot do in the experiment, for example, to separate the inseparable sources or to examine the interaction of the neutron with any of the elements in this group, for instance, the interaction of the neutron with only sodium or just iodine. We simulated the tomography experiment at different steps. At the first step, we separated the gamma and neutron sources, (Figure 2.).

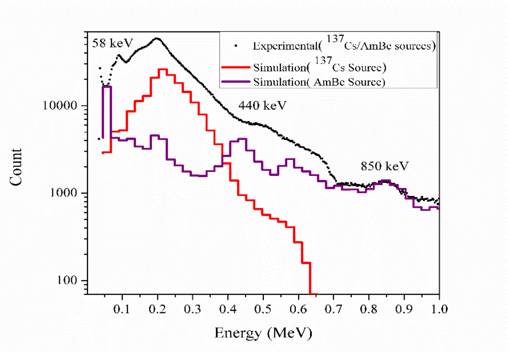

Figure 2. Comparing of the measured gamma spectrum of AmBe and ^{137}Cs with the simulated spectrum of separate sources AmBe and ^{137}Cs

The red curve is related to the second X-ray of the ^{137}Cs source alone when the neutron source is not present. In spectrometry experiments, the detector is placed at an angle to the source (such as industrial tomography tests), due to the number of gamma reduction in the detector, the peak of 662 keV is not visible. Only X-rays of gamma interactions with the environment are visible. The blue curve is related to the interaction of the neutron source only with the materials in the experiment that 58 keV, 440 keV, and 850 keV peaks are visible. At the second step of simulation, we removed the gamma source, Lead blocks, and steel. The order of Figure 2. only includes the NaI(Tl) detector and the neutron source. It is noteworthy, we did not use GEB to determine the exact location of the peaks at the next simulation. For this order, 58 keV, 202 keV, and 440 keV energy peaks were observed, (Figure 3.).

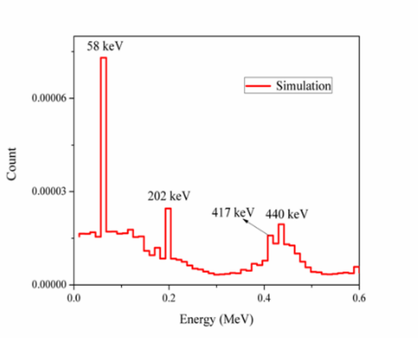

Figure 3. Gamma spectrum of neutrons interaction with NaI(Tl) without GEB

These peaks can be the interaction of neutrons with one of the detector elements. To find out which element plays a role in the production of peaks, we simulate each of the detector elements separately with the neutron source. At the third step of simulation, we defined the only considered interaction of neutrons with the detector material,^{127}I. In this case, the 440 keV has been deleted and peaks of 58 keV and 202 keV were observed (Figure 4.).

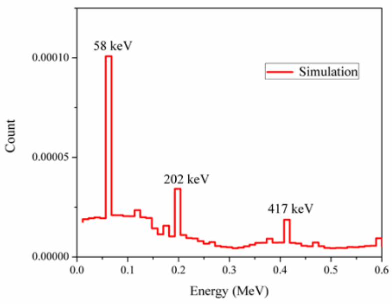

Figure 4. Gamma spectrum of the neutrons interaction with ^{127}I without GEB

Fourth step, the interaction of neutrons was simulated with ^{23}Na, the 440 keV peak is visible (Figure. 5).

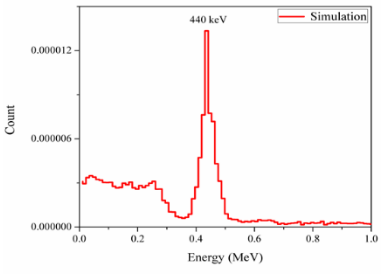

Figure 5. Gamma spectrum of the neutrons interaction with Na without GEB

The 850 keV peak was not seen in any of the simulations from the first to fourth steps. This shows that this peak is not due to the interaction of neutrons with detector material. It is because of the presence of Lead blocks or steel. In simulating the second step, also if we enter the steel, the 850 keV peak appears (Figure 6.).

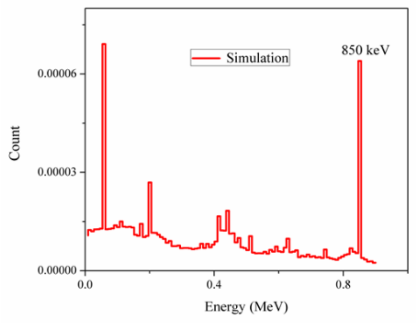

Figure 6. Gamma spectrum of the neutrons interaction with ^{56}Fe without GEB

In the simulation of the interaction of neutrons with the detector materials and any of the constituent elements were studied separately in the simulation. In this way, it is more confident that the peaks observed in the spectrum are derived which elements. Furthermore, the ratio of neutrons and gamma-ray photons should be considered in the simulation [5,6].

3. Results

3.1. The Detector Based on 90 Degree to the Source

In the first experiment, the NaI(Tl) detector was placed at a 90° to the source. In this experiment, gamma spectra of two neutrons and gamma source were measured simultaneously by a NaI(Tl) scintillator detector for 30 minutes. This spectrum was recorded by the 1024-channel analyser. Figure 7. shows the experimental spectrum with the final simulated spectrum.

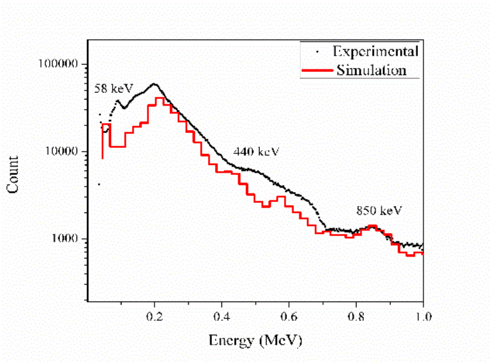

Figure 7. Comparing the energy spectrum of gamma measured and simulated AmBe and ^{137}Cs

Peaks of 58 keV, 440 keV, and 850 keV are visible in the experiment. We realized the origin of these peaks by simulation. Study of ^{127}I nuclear structure [7], 58 keV, and 202 keV peaks arise from $^{127}I(n,n')^{127}I$ interactions. ^{127}I has excited states with energies of 57.608 keV and 202.86 keV, and spin - parity $\frac{7}{2}^{+}$ and $\frac{3}{2}^{+}$ orderly. When iodine is excited to these energy levels by fast neutrons, gamma-rays release in those energies at 1.95 ns and 0.387 ns to reach the base (Figure 8.). The 202 keV peak is not visible in the experimental, because the second X-ray is produced from the lab environment. Peak 417 keV is derived from neutron inelastic interaction with [7] (Figures 3, 4). This peak overlaps with the 440 keV peak because of the existence of GEB. It cannot be seen as a separate peak, in the experimental spectrum. The graph of ^{127}I energy levels is shown in Figure 8.

440 keV is the neutron interaction with sodium. Referring to the ^{23}Na nuclear structure tables [8], this element has an excited state (the first excited state of sodium) in level with spin-parity. The half-life of this excited state is 1.24 ps. When sodium is excited to this level of energy, it emits a gamma of 439.986 keV energy for 1.24 ps to return to the base. According to the simulation results (Figure 6.) and using the ^{56}Fe nuclear structure data [10], 850 keV peak arises from $^{56}Fe(n,n')^{56}Fe$ interaction.

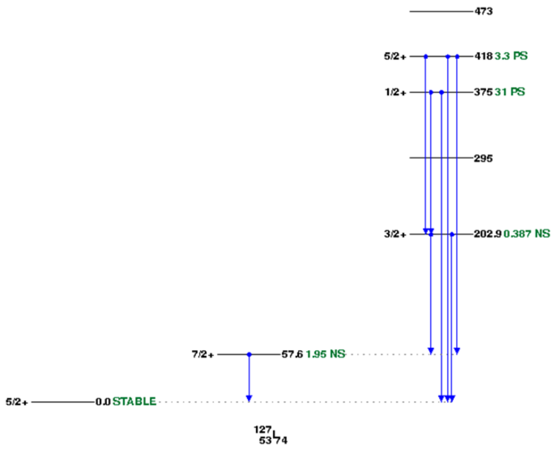

Figure 8. Decay diagram of ^{127}I in ^{127}I(n, n')^{127}I interaction

Incoherence is seen to the experimental spectrum and simulation spectrum in the low energy region. These comparisons are relative and there is a relative difference between experimental results and simulation. This difference is often in low energy which can be due to the following factors:

1. Dispersing effects of surrounding materials such as a metal table, metal wardrobe, wall and ... that has not been considered in the simulation. This produces secondary X-ray, a curve of red (Figure 2.). Especially in the first experiment, the detector is located at an angle to the source.

2. Electronic noises that appear at the beginning of the spectrum.

3. The inaccuracy of the cross-sections of the low-energy region in the simulation.

3.2. Detector along the Source

In the second test, the detector axis is located along the source. The gamma spectrum of two neutron and gamma sources was measured at the same time for 2 minutes by a NaI(Tl) scintillator detector. This spectrum was recorded by a 1024-channel analyser. Figure 9. shows the experimental spectrum with the simulated spectrum.

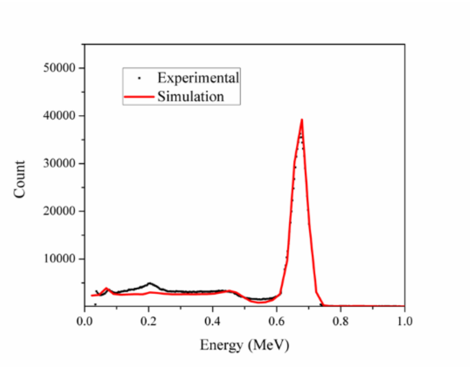

Figure 9. Comparison of the energy spectrum of gamma measured and simulated AmBe and ^{137}Cs

According to Figure 9., the gamma spectrum of observed and the effects of neutron interactions are not visible in this group.

4. Discussion

In some gamma spectroscopy experiments that the detector is placed at 90° to the source (Such as industrial tomography experiments), because of the number of gamma reduction in the detector, the effects of neutron interactions will be measured in the main gamma spectrum. In the first experiment, ^{137}Cs gamma photons do not reach the detector directly. So the effects of the ^{137}Cs source will not appear in the gamma spectrum. 58 keV, 440 keV, and 850 keV peaks are to the interaction of neutrons only. In the second experiment, the effects of the interaction of neutrons are as the first experiment. The invisibility of the peaks is not due to the absence of neutrons in the experiment, because there is no neutron absorbent material or neutron moderator in this test. The detector's position has changed to the source only and the number of gamma into the detector has increased. The effects of neutrons should be considered in gamma spectroscopy and the necessary corrections are made on the spectrum. In applications of gamma-ray tomography when neutrons are present, using the results corrected tomography images. Although the AmBe source is used in this work, but these results for other neutron source are also valid. The X-rays produced less in the lab, the effects of neutrons are higher in efficiency. These results are accord with the results of references [1, 11]. In addition to according to these peaks of 58keV and 440 keV in the experimental spectrum, if there is no access to neutron detectors such as plastic scintillator or we can use the NaI(Tl) detector to detect low-efficiency fast neutrons.

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