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Anti-Compton system for environmental radioactivity studies at Kuwait University

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Abstract

The Center for Research in Environmental Radiation (CRER) at Kuwait University has installed an anti-Compton system of gamma spectrometry.The system was mainly intended for the detection and measurement of natural occurring radioactive matter (NORM). In this work, the ability of this system to enhance photopeak visibility by suppressing Compton counts is demonstrated. Measurements of the suppression ratio (SR) were from 12 to 45 for the ^{60}Co spectrum.In addition, the suppression factor (SF) was measured to be 6 for the ^{60}Co photopeak of 1173 keV. The performance results similar to previous anti-Compton systems research referenced. Plans to improve and optimize our system's performance were set for future work.

Keywords: Compton suppression; gamma spectrometry; NORM; radioactivity

1. Introduction

Gamma spectrometry is an effective tool for the measurement of environmental radiation. This technique enables the detection and quantification gamma emitting radioisotopes. It also measures the levels of emitted gamma radiation (Knoll, 2010). For any gamma spectrometer, the main hardware component is the detector, inside which the energies of photon-matter interactions are deposited. The data of these energy depositions are displayed on a spectrum showing the quantities of energy deposited inside the detector and the occurrence frequency of each deposition. Therefore, the gamma spectral profile is primarily dependent on the interaction of photons with the detector's material.

For incoming photons with energy less than twice the electron's rest energy, there are three main modes of interaction, namely photoelectric absorption, Compton scattering, and Rayleigh scattering. The Rayleigh interaction mode is often insignificant compared to the others. In the case of photoelectric absorption, the incoming photon loses all of its energy to the detector, thus contributing to the corresponding counts in the gamma spectrum. With the build-up of this interaction mode, a spectral peak rises. This uniquely identifies the radioisotope from which the photon was emitted. Hence, the visibility of this peak—commonly known as the photopeak—is of great importance in identifying and quantifying the investigated radioisotope. Nonetheless, photopeak visibility is often obscured by spectral counts within its energetic vicinity that are caused by the other interaction mode, namely Compton scattering. For this type of interaction, the incoming photon is scattered by an inelastic collision with an orbital electron, thus causing a partial energy deposition inside the detector. Due to the wide range of scattering angles (0 to 180 degrees with respect to the direction of incident photon), the partial energy deposition varies through a wide range of energy values. Spectrally, this spread (the Compton Continuum), can negatively affect the visibility of the sought photopeaks. In fact, in cases where the radioisotope is weakly present in the investigated sample, the sought photopeak may very well be concealed by the Compton Continuum. This spectral masking is often encountered in studies involving natural occurring radioactive matter (NORM).

To reveal a specific photopeak that may be obscured, an anti-Compton system (Knoll, 2010) can be used. In this system, the main detector is surrounded by a secondary detector that acts as a guard against unwanted interactions. This secondary detector is typically made of material that is of a relatively high efficiency, such as Sodium Iodide (NaI) (Beetz *et. al.* 1977; Cooper *et. al.* 1972; Masse *et. al.* 1991) or Bismuth Germinate (BGO) (De Voigt *et. al.* 1995; Fukuda *et. al.* 1996; Moszyriski *et. al.* 1989). Thus, a photon detected inside the secondary detector is likely to indicate a prior Compton scattering event inside the main detector. With this knowledge, the signal from the main detector is electronically voided, thus preventing it from contributing to the Compton Continuum counts. Depending on the efficiency of the secondary detector, such spectral suppression can be very effective in enhancing the visibility of small photopeaks. It is necessary to note that such suppression may kill desirable events, especially in cases of complicated decay schemes.

Anti-Compton systems have a wide-range of applications. In addition to neutron activation analyses (Lin *et. al*. 1997; Mauerhofer *et. al*. 1996) and photon activation analyses (Fukuda *et. al*. 1996), anti-Compton systems are used for environmental measurements (Baburajan *et. al*. 2014; Cooper *et. al*. 1972).

The Center for Research in Environmental Radiation (CRER) at Kuwait University has installed an anti-Compton gamma spectrometry system. This important step was taken to improve the Center's ability to detect and measure NORM. The present work describes the performance of this system, as well as its utility for environmental radiation studies.

It is believed that this discussion will be useful to many radiation labs, especially ones considering installing a similar system.

2. Materials and methods

2.1 Compton suppression system

The Compton Suppression System (Canberra, Meriden, CT, USA) at the CRER consists of two main components: a primary detection unit and a Compton suppression unit. Although both units are physically and electronically connected, the user is given the choice to switch the Compton suppression feature on or off, thus adding to its utility. The primary detection unit is composed of a high-purity germanium detector (HPGe) with a crystal diameter of 61.0 mm and a length of 45.8 mm. The unit must by liquid-nitrogen cooled. The shaping time constant for the detector was selected to be 6.0 μs, thus giving an energy resolution of 2.0 keV at 1.33 MeV. Compared to a standard 3×3 inch Sodium Iodide with thallium activated (NaI(Tl)) detector, the primary detection unit exhibits a relative efficiency of 30% at 1.33 MeV.

The Compton suppression apparatus is depicted in Figure 1. The unit consists of an annulus detection system of a NaI(Tl) crystal that has a diameter of 230 mm and a height of 230 mm. This scintillation system, which is connected to four photomultiplier tubes (PMTs), surrounds the primary detector. It functions to identify scattered photons leaving the HPGe medium from the sides. To cover the upper part, a NaI(Tl) plug detector (76-mm diameter × 76-mm height) connected to a PMT is used to detect photons escaping upward.This plug detector is held on a mechanical support that allows for its temporary displacement before the positioning of the investigated sample. To provide low background counting, the arrangement of HPGe and NaI(Tl) detectors is housed inside a 100-mm thick lead shield with 1 mm tin and 1.6 mm copper inner linings.

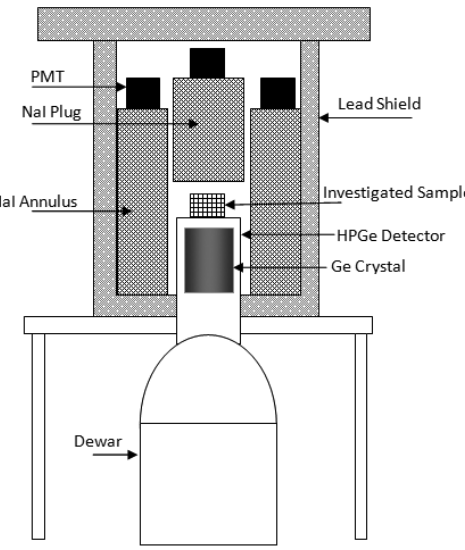

Fig 1. Anti-Compton system.

All PMTs are connected to a high voltage power supply. A voltage of 1000 V was applied to the NaI(Tl) detectors. As for the HPGe detector, it was set under a bias voltage of -4000 V. The signals from the HPGe and the NaI(Tl) detectors are collected at a coincidence gate after being properly amplified. When switched on, the gate cancels the coinciding signals from the solid state and scintillating detectors, thus electronically performing Compton suppression. Non-coinciding signals are analyzed by a multi-channel analyzer (MCA) and then spectrally displayed on the output screen. A simplified electronic schematic is depicted in Figure 2.

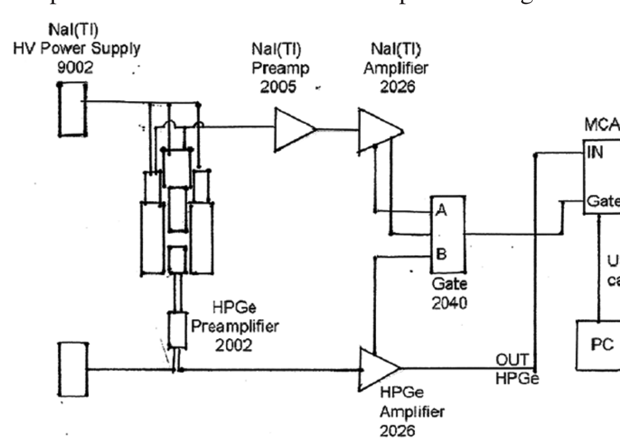

Fig 2. Electronic depiction of anti-Compton system

2.2 Experimental procedure

A set of point sources was used to experimentally measure the performance of the anti-Compton system. Specifically, ^{137}Cs and ^{60}Co point sources (Spectrum Technologies, Oak Ridge, TN, USA) were counted individually for a period of 1000 seconds each. The output was composed of two spectra:

suppressed and unsuppressed. As such, the suppression ratio (SR) was measured at different energies for each of the counting experiments. The SR is defined by:

$$SR = \frac{P}{C}, \tag{1}$$

where P is the photopeak count, and C is the Compton edge count. The suppression factor (SF), was moreover measured which is defined as:

$$SF = \frac{(SR)_{suppressed}}{(SR)_{Unsuppressed}} \tag{2}$$

Officially, the Compton edge is defined as the flat region between 358 and 383 keV for ^{137}Cs (photopeak at 662 keV), and 1040 and 1096 keV for ^{60}Co (photopeak at 1173 keV) (Aarts et.al. 1980).

Environmental samples were also counted. In particular, a crude oil sample was measured for a period of 86400 seconds (24 hours), in addition to a tea sample which was measured for the same period after proper lab preparation. The preparation of the tea sample involved powdering it and then drying it under an infrared lamp to remove moisture. The output of both samples gave suppressed and unsuppressed spectra that were comparatively analyzed. Furthermore, a background count was measured for a period of 10^6 seconds with an output of suppressed and unsuppressed spectra for purposes of comparison.

3. Results

Figure 3 shows the suppressed and unsuppressed spectra of the ^{137}Cs point source, where values of SR are displayed at certain energies. The figure reveals the effectiveness of the Compton suppression, which is evident across the continuum. Besides the significant reduction in the counts, some typical features of the continuum were effectively removed. Examples are the Compton edge and the multiple collisions region, where the latter is typically located between the edge and the photopeak. Such effective suppression is also evident in Figure 4. The graph depicts the suppressed and unsuppressed spectra of the ^{60}Co point source and the SR at certain energies.

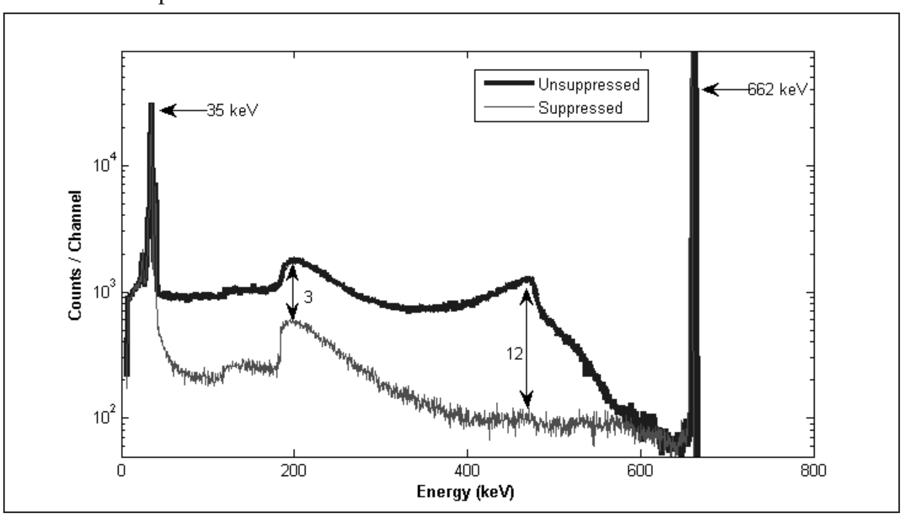

Fig 3. Suppressed and unsuppressed spectra of ^{137}Cs point source. Suppression ratio (SR) is shown at certain regions.

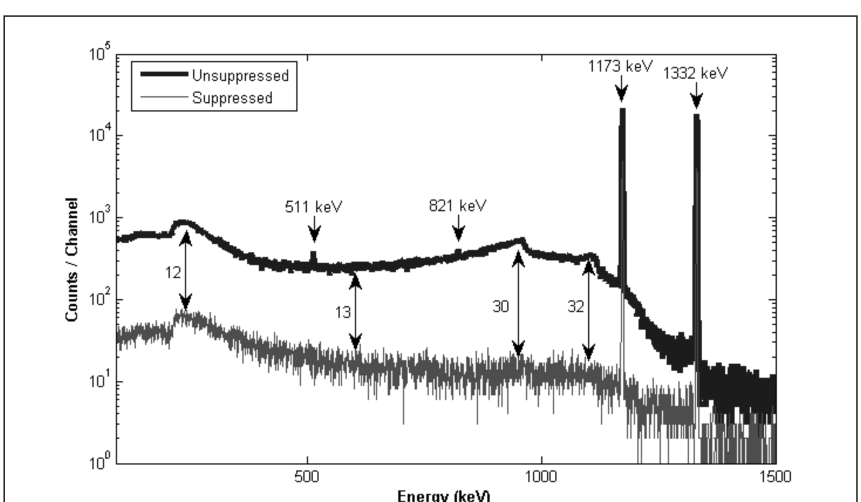

Fig 4. Suppressed and unsuppressed spectra of ^{60}Co point source. Suppression ratio (SR) is shown at certain regions.

Figure 5 shows the suppressed and unsuppressed spectra for the background count. These data present a significant reduction in the unwanted Compton events. Evidently, such achievement is resembled by the prominence of the ^{214}Pb photopeak at 352 keV in the suppressed counts. This peak is barely visible in the unsuppressed spectrum. Similarly, the ^{214}Pb photopeak at 295 keV is clearly visible in the suppressed spectrum, while it is totally concealed in the unsuppressed counts.

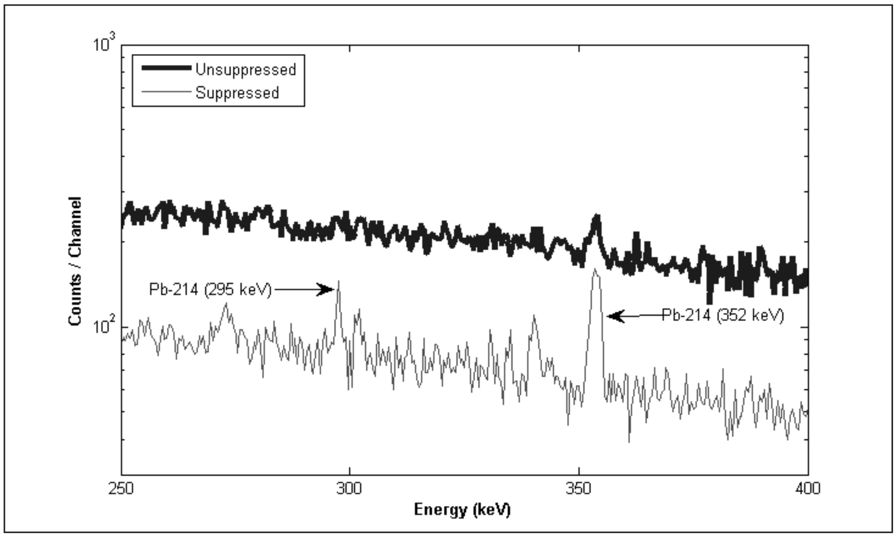

Fig 5. Suppressed and unsuppressed spectra of background count. ^{214}Pb peaks are present in suppressed spectrum, while almost concealed in unsuppressed spectrum.

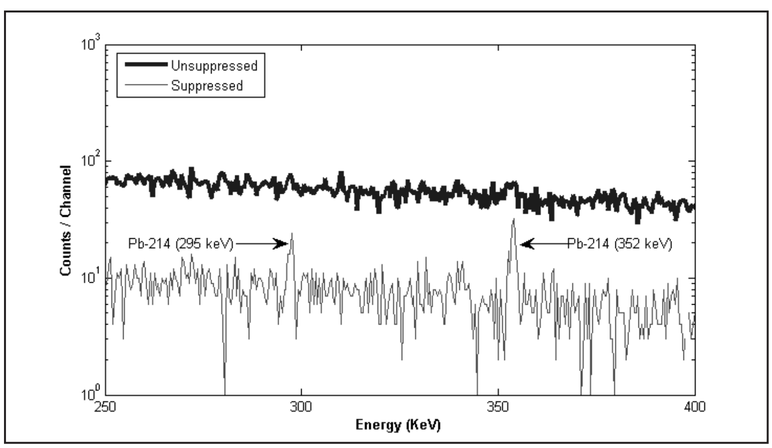

Fig 6. Suppressed and unsuppressed spectra of tea sample. ^{214}Pb peaks are present in suppressed spectrum, while concealed in unsuppressed spectrum.

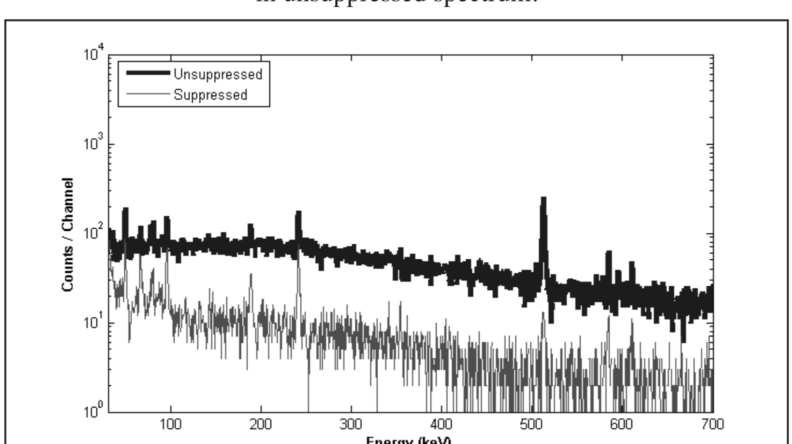

Fig 7. Suppressed and unsuppressed spectra of crude oil sample.

Interestingly, these observations with the ^{214}Pb photopeaks are also evident in Figure 6, which shows the suppressed and unsuppressed spectra of the tea sample. Hence, this feature provides a means for accurate measurement of NORM radioisotopes that are minutely present in investigated samples. In such cases, the amount of the detected progeny, ^{214}Pb for example, can indicate the amount of its parent radioisotope, ^{238}U, assuming that secular equilibrium is established. This effective suppression is also seen in Figure 7. It shows the suppressed and unsuppressed spectra of the counted crude oil sample.

4. Discussion

The performance of the CRER anti-Compton system was compared to that of similar instruments in other research studies. This comparison was done on the basis of the ^{60}Co SF, the values of which are shown in Figure 8 for ten anti-Compton systems, inclusive to that of the CRER. Table 1 shows SF for ^{60}Co for eight similar instruments, including that of CRER. Apparently, the SR and SF values exhibited by the CRER system, fell within the range of values reported by others for the covered energies (Aarts *et. al.* 1980; Baburajan *et. al.* 2014; Beetz *et. al.* 1977; Cooper & Perkins 1972; De Voigt *et. al.* 1995; Fukuda *et. al.*, 1996; Lin *et. al.* 1997; Masse *et. al.* 1991; Mauerhofer *et. al.* 1996; Moszyński *et. al.* 1989; Peerani *et. al.* 2002). In some cases, the CRER values exceeded the average, while in other cases they fell slightly below. Although such fairly relative performance is not superior, it is sufficiently acceptable for the CRER applications. Nonetheless, plans to optimize the performance of the system are being considered as future research investigations.

Table 1. The suppression factor (SF) rounded to nearest whole number for anti-Compton system at the CRER and similar instruments reported in the literature

Reference	SF
This work	**6**
Aarts	**7**
Baburajan	**6**
Fukuda	**6**
Mauerhofer	**9**
Monzynski	**12**
De Voigt	**4**
Average	**7**

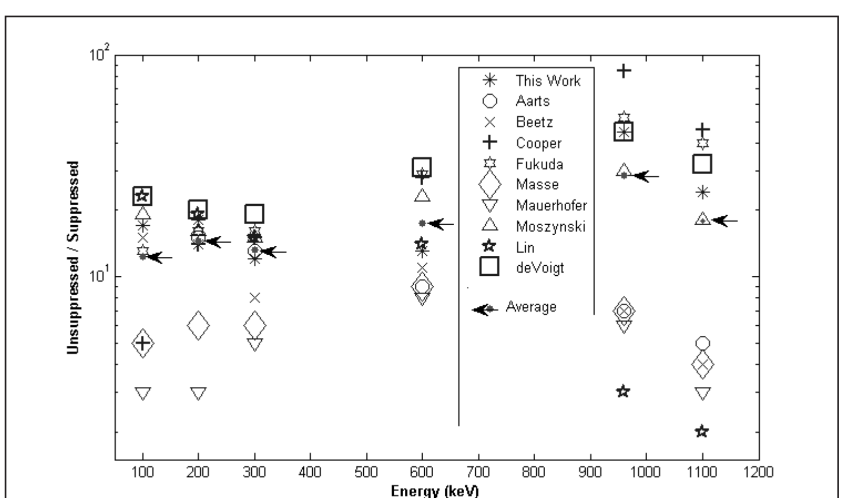

Fig 8. SR for ^{60}Co spectrum is shown for CRER anti-Compton system and that of others.

5. Conclusion

This study presented the anti-Compton system at the CRER of Kuwait University. By providing experimental output from the instrument, its ability to enhance photopeak visibility was demonstrated. The magnitude of such enhancement was quantified in accordance to standard procedures. The performance of the CRER system was compared to those of similar instruments in previous studies. This comparison showed a relatively fair, yet acceptable level of performance of the CRER system, which sufficiently fits the requirements for NORM studies. Nevertheless, plans were set to further improve and optimize such performance.

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قياس الإشعاع البيئي بنظام إلغاء التفاعلات الكومبتونية في جامعة الكويت

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الخلاصة

إن مركز أبحاث الإشعاع البيئي في كلية العلوم، جامعة الكويت، يستخدم نظام إلغاء التفاعلات الكومبتونية لقياس الإشعاع في البيئة الكويتية. ويعمل هذا النظام على تقوية الإشارات الفوتونية المرغوبة عن طريق إضعاف غيرها من الإشارات الغير مرغوبة، حيث يؤدي ذلك إلى رصد وقياس الكثير من النظائر المشعة التي يصعب رصدها وقياسها بدون استخدام هذا النظام. يحتوي هذا البحث تفاصيل عمل هذا النظام وإمكانياته.