Effect of Co-60 Single Escape Peak on Detection of Cs-137 in Analysis of Radionuclide from Research Reactor

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Abstract

The effect of the single escape peak of 1173 keV gamma-rays from Co-60 on the detection of Cs-137 activity is analyzed. The single escape peak of 1173 keV gamma-rays from Co-60 is located at the 662 keV, which is very close to the energy of gamma-rays from Cs-137. This single escape peak may be mistaken for the gamma-ray peak from Cs-137 activity in the case of large area of 1173 keV peak. The detection of Cs-137 is very important to the judgment of the contamination or the leakage of the material containing the fission product like reactor pool water and in the several experiments for reactor physics such as burn-up estimation.

In this work, the areas of the single escape peak of the 1173 keV gamma-rays from Co-60 are measured with several full energy peak areas by using the HPGe detector. The critical limit by which we can decide whether the net count of 662 keV peak due to Co-60 would be significant or not is deduced. For this detection system, when the area of full energy peak is larger than 4.5 million, the single escape peak of 1173 keV gamma-rays from Co-60 can be regarded as the single significant peak. Therefore, it is confirmed that the detection of the Cs-137 activity is affected by the Co-60 in this case. Conservatively, for this detection system, it is recommended that the area of 1173 keV peak of Co-60 would be less than 2 million for neglecting the effect of Co-60.

KEYWORDS: Co-60, Cs-137, Escape peak, HPGe detector, Research reactor, Critical limit

1. Introduction

The Cs-137 isotope that emits the gamma-rays with almost unique energy of 661.660 keV is a representative radionuclide originated from the nuclear fission. It is very useful isotope in the various experimental reactor physics such as burn-up estimation of the nuclear fuel. Therefore, the detection of Cs-137 activity is very important in the operation of nuclear facility such as research reactor and in the evaluations of nuclear facility accident.[1] The Co-60 isotope is also produced in the significant amount by the neutron activation in the nuclear reactor. It emits the prevailing two gamma-rays with energies of 1173.238 and 1332.502 keV. Since the energies of these gamma-rays are larger than 1022 keV, the single escape(SE) and double escape(DE) peaks

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can appear on the gamma-ray spectrum of Co-60. There are very few measurements of these escape peaks because of very low pair production probability of Co-60 gamma-rays. The centroid energy of the single escape peak of 1173 keV gamma-rays is very near to that of gamma-ray peak from Cs-137. Considering the energy resolution of the detection system, the uncertainty of the energy calibration and the Doppler broadening of the single escape peak, it is highly probable that the single escape peak of 1173 keV gamma-rays from Co-60 gives the misjudgment for the existence of the Cs-137 and the interference for the area determination of the Cs-137 gamma-ray peak.[2]

Actually, we had collected the water from a beam tube for the neutron application in HANARO, 30 MW research reactor, and in order to confirm the origin of that water, the radionuclide in the water had been analyzed. In the gamma-ray spectrum of the water measured using HPGe detector, not only very high peak at 1173 keV due to Co-60 but also very small peak near to the energy of 662 keV had been discovered. If this peak at 662 keV was originated from the Cs-137 activity, there was some doubt about whether the beam tube was reliable. Fortunately, this peak could be originated from the Co-60 as the single escape peak of 1173 keV gamma-rays.

Therefore, in this work, we analyzed the effect of the single escape peak of 1173 keV gamma-rays from Co-60 on the detection of Cs-137. And then, we set the critical limit by which we can decide whether the net count of 662 keV peak due to Co-60 would be significant or not.

2. Radionuclide Analysis for Water from Beam Tube

HANARO has 7 horizontal beam tubes for various neutron beam applications. Fig. 1 shows the schematic view of the HANARO beam tube. The nose of the beam tube is located at a position of heavy water reflector tank, and it passes through the heavy water tank, the light water pool and the biological shield. In order to monitor the leakage of the water, the moisture leak detector has been installed at the front of the beam exit. The moisture gathered through the drain piping can activate the detector.

We can judge the reliability of the beam tube from whether this water contains the radionuclide in the water from pool of the reactor core or reflector tank. Therefore, we measured the gamma-ray spectrum of the water with HPGe detector for a long time to identify even small peaks. Fig. 2 shows the gamma-ray spectrum of the water gathered in the moisture detector.

Most of the nuclide shown in the spectrum are generated by the neutron activation of the structural materials of the beam tube such as stainless steel, and they are not related to the nuclear fission. However, when we see the detail of the spectrum near 660 keV as shown in the figure, the small peak at the 662 keV can be found. The commercial gamma-ray spectrum analysis program had regarded this as gamma-ray peak with even low peak search sensitivity. The area of the 1173 keV peak is 4.5 million, and that of the 662 keV peak is 2366±725.

The most important source of the 662 keV gamma-rays is the Cs-137 isotope. There are few ways to produce the Cs-137 without nuclear fission, i.e., the detection of the Cs-137 means that the water could be originated from the light water pool of the reactor core. The reactor pool water may contain small amount of Cs-137 due to the fission of the contaminated uranium on the fuel surface.

Figure 1: Schematic view of the HANARO beam tube.

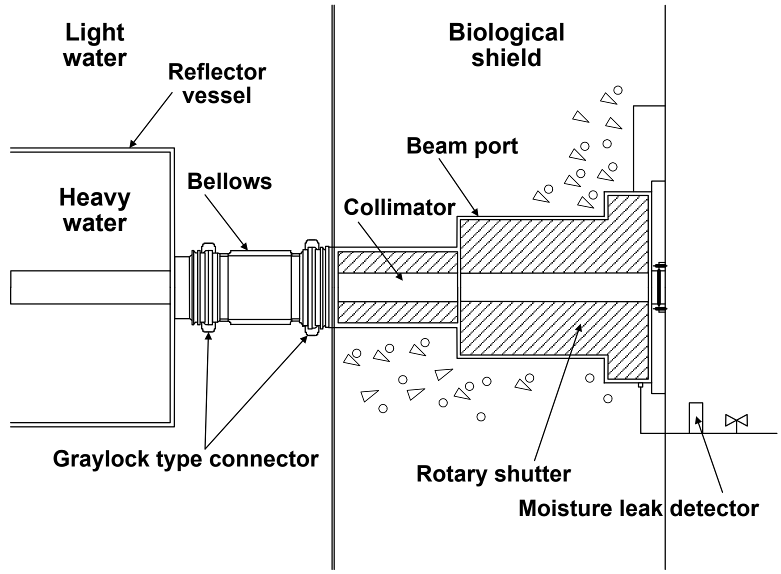
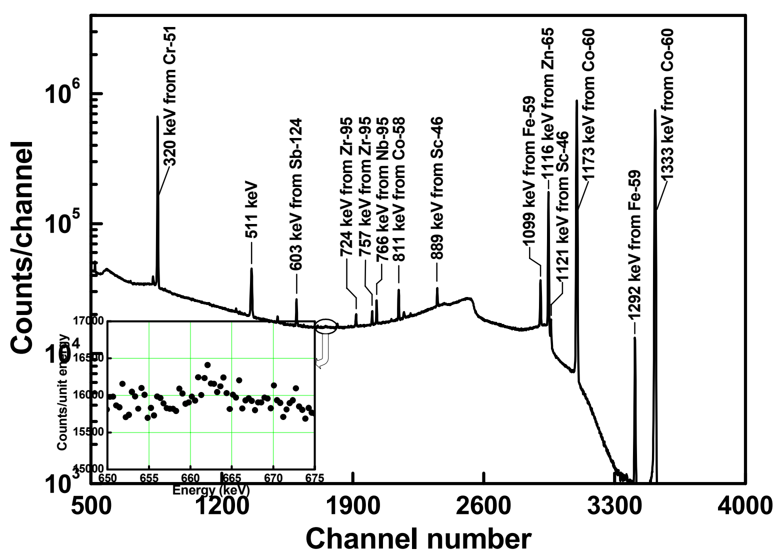


Figure 2: Gamma-ray spectrum of the water gathered in the moisture detector of beam tube.



The other special feature of the above spectrum is very high gamma-ray peaks from Co-60. Co-60 can be produced by the neutron activation in the beam tube of the research reactor. The single escape peak of 1173 keV gamma-rays from Co-60 is located at the 662 keV, which is very near to the energy of gamma-rays from Cs-137. Although the build-up probability of single escape peak of 1173 keV is very small, we may mistake this single escape peak for the gamma-ray peak from Cs-137 in the case of very large area of 1173 keV full energy peak.

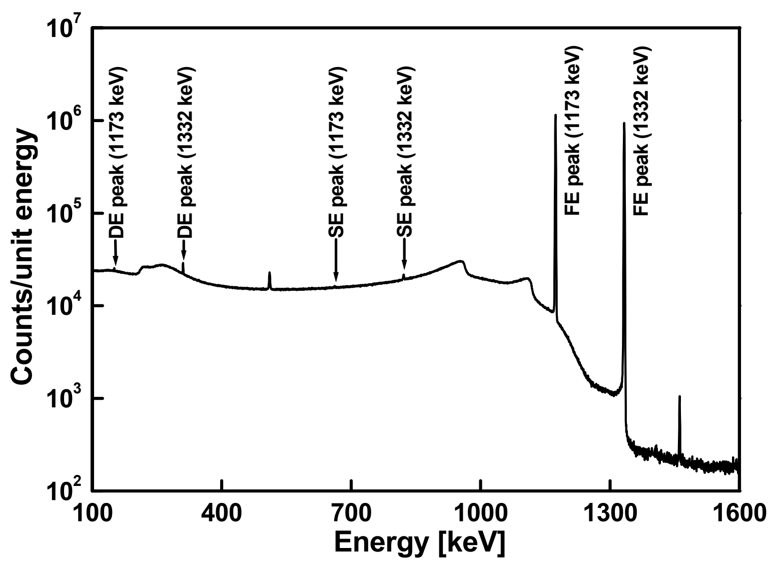
3. Experimental Methods

The detector used in this work is a closed-ended coaxial HPGe detector, and its specifications are given in Tab. 1. The gamma-ray spectroscopy system was set up, and the shaping time of the spectroscopy amplifier was set at 6 μsec. The Co-60 gamma-ray spectra with various full energy peak areas were obtained by using the HPGe detector and the standard sources. An example of the spectra is shown in Fig. 3. The source-to-detector distance was 25 cm. The dead time of the detection system was less than 5%.

Table 1: Specifications of the HPGe detector.

Relative efficiency	15 %
Resolution	1.80 keV(FWHM) at 1.33 MeV 0.825 keV(FWHM) at 122 keV
Peak to Compton ratio, Co-60	44
Crystal diameter	55.0 mm
Crystal length	37.2 mm
Al end cap thickness	1.27 mm
Inactive Ge thickness	700 μm
End cap to crystal	3 mm
Detector bias voltage	+2600 V

Figure 3: Photon spectrum of Co-60 obtained with the HPGe detector.



In the above spectrum, the areas of full energy(FE) peaks of 1173 and 1333 keV gamma-rays are 5.3 and 4.7 million, respectively. The single and double escape peaks of 1333 keV gamma-rays and the double escape peak of 1173 keV gamma-rays are clearly resolved. However, the single escape peak of 1173 keV gamma-rays is fairly collapsed due to the small peak area and the Doppler broadening. If the smaller detector is used, the larger and more apparent escape peaks will be represented because the escape probability of the annihilation photon is increased.

When the peak area was calculated, in order to estimate the background beneath the peak, m channels beyond each side of the peak region were used as follows.[3]

$$A = \sum_{i=L}^{U} C_i - n\left[\sum_{i=L-m}^{L-1} + \sum_{i=U+1}^{U+m}\right] / 2m , \quad (1)$$

where, C_i are the counts in the ith channel, and n is the number of channels within the peak region.

The critical limit by which we can decide whether the net count of a peak is significant or not, for 95% confidence, is given by

$$L_C = 1.645[B(1 + n / 2m)]^{1/2} , \quad (2)$$

where, B is the background count. In the analysis of 662 keV peak, n and m were equal to 21 and 3, respectively.

4. Results

Fig. 4 shows the portion of interest in two spectra with different full energy peak area at 1173 keV. Through the long-term detection of background, it was confirmed that the effect of natural background was negligible. From the figure, it is confirmed that when the full energy peak area is several millions, the single escape peak of 1173 keV gamma-rays from Co-60 at 662 keV looks like a single peak which is statistically significant. For the case of full energy peak area below one million, it is difficult to find the explicit gamma-ray peak near the 662 keV.

Tab. 2 shows the experimental result and the critical limit obtained by using the measured Co-60 gamma-ray spectra. Since the 662 keV peak is located on the high Compton continuum of the 1173 and 1332 keV gamma-rays from Co-60, the gross count of the peak region is rather big in comparison with the net count of the peak. Therefore, the uncertainty in the determination of the area of 662 keV peak is fairly large while that in the case of 1173 keV full energy peak is negligible.

The last column of the table, the ratio of the areas of the single escape and full energy peaks, depends on the characteristics of the detection system, mainly the size of the detector.[4] The weighted average for the last four values in this column is 0.000655. This value becomes smaller for larger detector, i.e., the area of the single escape peak of the Co-60 becomes smaller for larger detector. Thus, it is advantageous to adopt the large detector in the simultaneous detection of the Co-60 and Cs-137 in order to reduce the effect of the single escape peak of the 1173 keV gamma-rays on the detection of the Cs-137.

Figure 4: A portion of the Co-60 gamma-ray spectra showing the region of the single escape peak of 1173 keV gamma-rays.

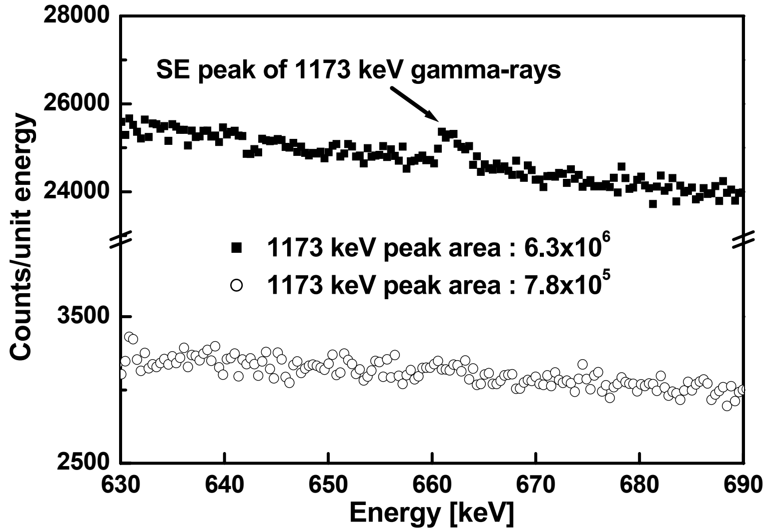
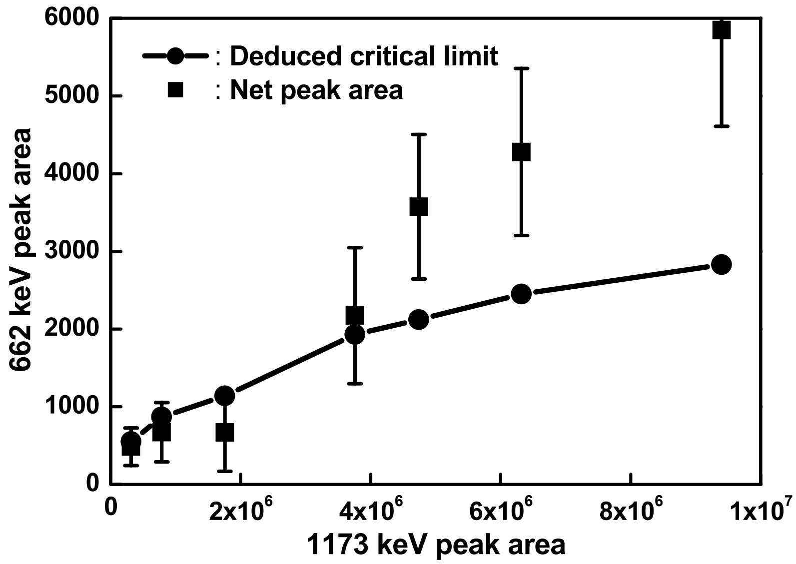


Table 2: Experimental result and the critical limit obtained by using the measured Co-60 gamma-ray spectra.

1173 keV peak area	662 keV peak area		Deduced critical limit	Ratio of peak areas(SE/FE)
	Gross	Net		
313350	25335	485±241	550	0.001548
782848	62601	671±381	869	0.000857
1755004	107136	669±499	1139	0.000381
3758085	307918	2172±875	1930	0.000578
4741680	373273	3573±930	2122	0.000754
6318229	497531	4278±1074	2451	0.000677
9400921	663275	5848±1240	2830	0.000622

Fig. 5 shows the deduced critical limit and the single escape peak area according to the area of the 1173 keV full energy peak. The critical limit apparently becomes smaller than the 662 keV peak area, when the 1173 keV peak area is over about 4.5 million, considering the uncertainty of the net area. Thus, when the area of full energy peak is larger than 4.5 million, the single escape peak of 1173 keV gamma-rays from Co-60 can be regarded as the single peak which is statistically significant. Therefore, it is confirmed that the detection of the Cs-137 activity is affected by the Co-60 in case the area of the 1173 keV gamma-ray peak is larger than 4.5 million. Conservatively, it is recommended that the area of 1173 keV peak of Co-60 would be less than 2 million for neglecting the effect of Co-60. Using the above result, the detection limit or sensitivity of Cs-137 can be set up for each detection system.

Figure 5: Deduced critical limit and the single escape peak area according to the area of the 1173 keV full energy peak.



Therefore, from the above work, it is confirmed that the 662 keV peak shown in Fig. 2 is originated from a large amount of 1173 keV gamma-rays from Co-60, i.e., no doubtful nuclide about leakage of reactor pool water is found in the water collected from the beam tube of HANARO.

5. Conclusion

For the HPGe detector used in this work, when the area of full energy peak is larger than 4.5 million, the single escape peak of 1173 keV gamma-rays from Co-60 can be regarded as the single significant peak. Therefore, it is confirmed that the decision for existence or quantitative analysis for Cs-137 activity are not sure in the simultaneous measurement with Co-60 giving rise to a large amount of full energy peak area. By using this work, simultaneous detection technique of Co-60 and Cs-137 without interference may be deduced. And, this work is expected to be helpful for the evaluation of reliability for the application facility of the research reactor and for precise determination of Cs-137 activity in the various experimental reactor physics.

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