Investigation of the relation between limit of detection and solid angle by measuring standard radioactive sources with a $LaBr_3$:Ce detector

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Abstract. A 2”×2” $LaBr_3$:Ce detector was used to measure ambient background radiation, as well as the radiation of two standard sources with different activities, ^{22}Na and ^{60}Co. The sources have been measured at increasing distances from the detector to investigate the relation between a point-source solid angle and the detection limit of each radiation source. Results obtained during the study indicated a relation between source activity and the solid angle to such an extent that a detection limit can be extrapolated for sources with different activities, also considering background radiation. It was further shown that the solid angle is source independent.

1. Introduction

Over several years gamma-ray spectrometry has been limited to the use of NaI:Tl and Ge-based detectors. More recent development introduced the $LaBr_3$:Ce detector as an alternative detection device for several reasons. These include a more than two-fold better peak resolution compared to NaI:Tl detectors [7], a high light yield with > 65000 photons/MeV [5], and good detection efficiency [1]. No liquid nitrogen cooling is required, and the device lends itself as very practical in terms of ex-situ measurements due to its light weight and mobility [4]. Radiation is present everywhere in the natural environment due to naturally occurring radioactive materials (NORM) in the Earth’s crust as well as in the atmosphere. Sources of this radiation are the ^{238}U and ^{232}Th decay series, and radioactive ^{40}K [2]. This results in background radiation that must be corrected for during experimental radiation measurements, data interpretation and the calculation of actual source activities and detection limits, especially when measurements are done in terrestrial environments. This work forms part of a broader scope of research where the $LaBr_3$:Ce detector will be utilised as a mobile unit to investigate in-situ radiation in various environmental regions. The relation between source activity and the solid angle relative to the detector surface is important during the determination of radiation detection limits.

2. Experimental

Radiation measurements related to this study were performed inside a vault (at iThemba LABS, Cape Town) constructed with building materials such as concrete. The vault is designed and shielded from the outside environment as such that the radiation present will be from the building material of the vault itself. No significant variation in background radiation is expected. It is important to note that the detector position inside the vault is fixed which further emphasise no expected change in background radiation. Radiation sources and background measurements were done using a $LaBr_3$:Ce detector with a 2”×2” crystal. The detector was energy calibrated using three standard sources with known gamma-ray energies: ^{22}Na, ^{60}Co and ^{152}Eu. One background measurement inside the vault was performed for 10 minutes. Two standard sources, ^{22}Na and ^{60}Co, were measured at various distances from the detector. These distances were correlated with a solid angle value (Ω) where $\Omega = A/r^2$. The symbol A represents the detector surface area, and r represents the point-source distance between the detector and radiation source being measured [3]. Each source was measured for 10 minutes.

3. Results and discussion

Data obtained during the measurements of each source at various distance from the detector are summarised in table 1.

Table 1. Data for ^{22}Na and ^{60}Co: Total = total peak counts, Peak = background corrected counts.

r (mm)	Ω (Sr)	Total	Peak	Background	Total	Peak	Background
		511 keV ^{22}Na			1274 keV ^{22}Na		
228	0,038989	543386	501400	41986	128100	120757	7353
	(0,20)	(737)	(708)	(205)	(358)	(348)	(86)
545	0,006824	114367	107107	7260	26430	23132	3297
	(0,083)	(338)	(327)	(85)	(163)	(152)	(57)
2275	0,000392	12530	5875	6635	2491	1009	1482
	(0,020)	(112)	(77)	(81)	(50)	(32)	(38)
2675	0,000283	9566	4341	5228	1796	665	1131
	(0,017)	(98)	(66)	(72)	(42)	(26)	(34)
4330	0,000108	5828	1906	3922			
	(0,010)	(76)	(44)	(63)			
r (mm)	Ω (Sr)	1173 keV ^{60}Co			1333 keV ^{60}Co		
175	0,066182	32017	24779	7238	25926	22098	3828
	(0,25)	(179)	(157)	(85)	(161)	(149)	(62)
560	0,006463	6021	2897	3124	3783	2103	1680
	(0,080)	(78)	(54)	(56)	(62)	(46)	(41)
775	0,000337	3304	1302	2002	2234	1014	1220
	(0,018)	(57)	(36)	(45)	(47)	(32)	(35)

For each peak the number of counts appear as a Gaussian distribution around the centroid of the peak. Measurement of the peak area was be done by a summation of the number of counts in each channel considered to be part of the peak, referred to as the region of interest (ROI). For background correction, channels were selected at both the lower and higher energy sides of each peak, just outside the ROI. The sum of the background counts in both regions were divided by the number of channels which gave an indication of the mean number of background counts for each channel. The sum of the counts for all channels in the ROI was determined, followed by the subtraction of the mean number of background counts in the same region. The result of this is a background corrected net peak area. Except for NORM’s, also contributing to background counts is the Compton continuum associated with each radiation source. This continuum intensity is directly proportional to source activity, and the solid angle. Using the ^{60}Co source as example, this is illustrated in figure 1.

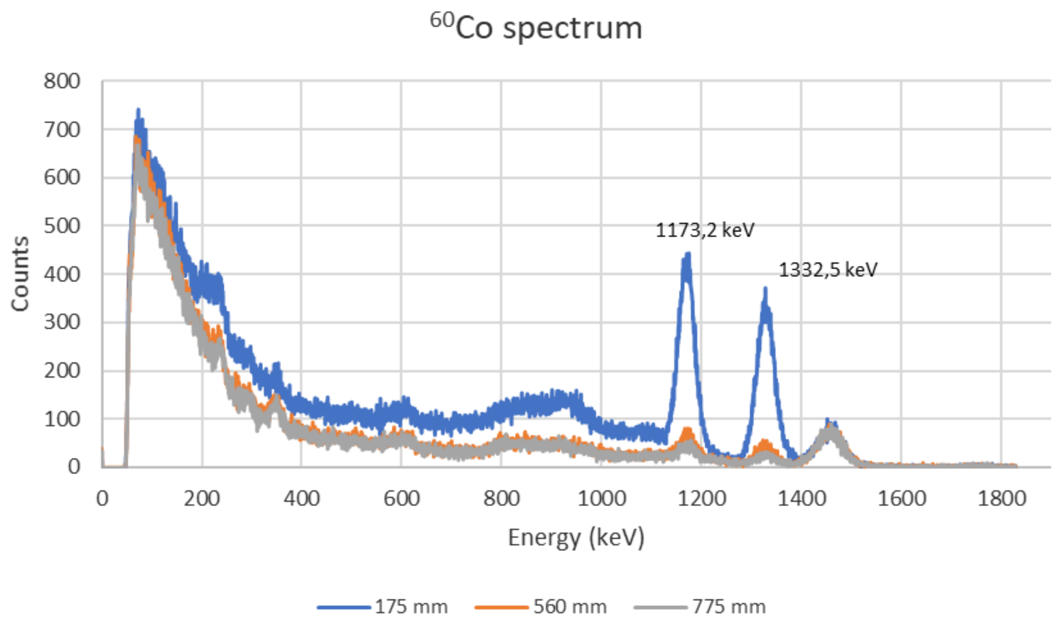

Figure 1. ^{60}Co spectrum with the source measured at increasing distances from the detector.

The results summarised in table 1 were used to determine a first order response between source activity and the solid angle. It can be assumed that the number of counts measured is directly proportional to the source activity, and the solid angle (distance between point-source and detector surface) as a first order function: Total counts = b (Ω) + c. These correlations are summarised in table 2. The lots are shown in figure 2.

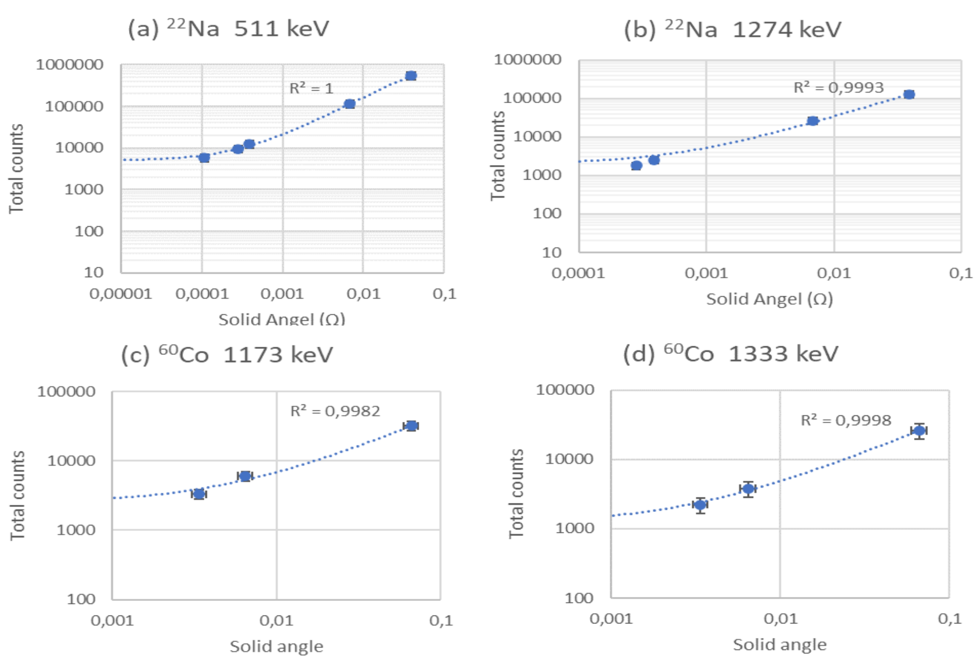

Figure 2. Plots for ^{22}Na 511 keV (a), 1274 keV (b) and ^{60}Co 1173 keV (c), 1333 keV (d).

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Table 2. Response curves for ^{22}Na and ^{60}Co.

Source/Energy	Activity (kBq)	C (Slope error)	b	R
^{22}Na 511 keV	375.2	1.376×10^7 (59505)	8915	1
^{22}Na 1274 keV	375.2	3.244×10^6 (225080)	2001	0.9993
^{60}Co 1173 keV	47.48	1.118×10^6 (656)	2445	0.9982
^{60}Co 1333 keV	47.48	9.359×10^5 (9410)	1162	0.9998

The regression value (R) confirms the linear proportionality between the number of counts and the solid angle. Using these equations, it is possible to calculate the number of peak counts at any selected source activity. This should give an indication in terms of counts detected as a function of solid angle and source activity. The results are summarised in table 3.

Table 3. Calculated peak counts for different solid angles and activities.

511 keV			Ω		
Activity (kBq)	0,0389895	0,0068238	0,0003916	0,0002832	0,0001081
376	545583 (739)	102840 (321)	14305 (120)	12814 (113)	10403 (102)
300	437107 (661)	83855 (290)	13216 (115)	12026 (110)	10102 (101)
200	294377 (543)	58875 (243)	11782 (109)	10989 (105)	9706 (99)
100	151646 (389)	33895 (184)	10349 (102)	9952 (100)	9311 (96)
50	80280 (283)	21405 (146)	9632 (98)	9433 (97)	9113 (95)
10	23188 (152)	11413 (107)	9058 (95)	9019 (95)	8955 (95)
5	16052 (127)	10164 (101)	8987 (95)	8967 (95)	8935 (95)
0	8915 (94)	8915 (94)	8915 (94)	8915 (94)	8915 (94)
1274 keV			Ω		
Activity (kBq)	0,0389895	0,0068238	0,0003916	0,0002832	0,0001081
376	128548 (359)	24149 (155)	3272 (57)	2920 (54)	2352 (48)
300	102969 (321)	19672 (140)	3015 (55)	2735 (52)	2281 (48)
200	69313 (263)	13782 (117)	2677 (52)	2490 (50)	2188 (47)
100	35657 (189)	7891 (89)	2339 (48)	2246 (47)	2094 (46)
50	18829 (137)	4946 (70)	2170 (47)	2123 (46)	2048 (45)
10	5367 (73)	2590 (51)	2035 (45)	2025 (45)	2010 (45)
5	3684 (61)	2296 (48)	2018 (45)	2013 (45)	2006 (45)
0	2001 (45)	2001 (45)	2001 (45)	2001 (45)	2001 (45)

1173 keV Activity (kBq)	Ω 0,066182	0,0064631	0,0033745	1333 keV Activity (kBq)	Ω 0,066182	0,0064631	0,0033745
47	9785 (99)	3162 (56)	2819 (53)	47	7304 (85)	1762 (42)	1475 (38)
40	8692 (93)	3055 (55)	2764 (53)	40	6389 (80)	1672 (41)	1429 (38)
30	7130 (84)	2903 (54)	2684 (52)	30	5082 (71)	1545 (39)	1362 (37)
20	5568 (75)	2750 (52)	2604 (51)	20	3776 (61)	1417 (38)	1295 (36)
10	4007 (63)	2598 (51)	2525 (50)	10	2469 (50)	1290 (36)	1229 (35)
5	3226 (57)	2521 (50)	2485 (50)	5	1815 (43)	1226 (35)	1195 (35)
0	2447 (49)	2445 (49)	2445 (49)	0	1163 (34)	1162 (34)	1162 (34)

From this data a limit of detection can be estimated for each line: For ^{22}Na 511 keV at roughly 10000 counts and for ^{22}Na 1274 keV at roughly 3000 counts. At these values, counts from the source become indistinguishable from background counts. These values correlate well with the intercept values obtained for each line as summarised in table 3. By scaling these b-coefficients for 511 keV and 1274 keV on the same plot, a limit of detection at each solid angle can be extrapolated, as shown in figure 3.

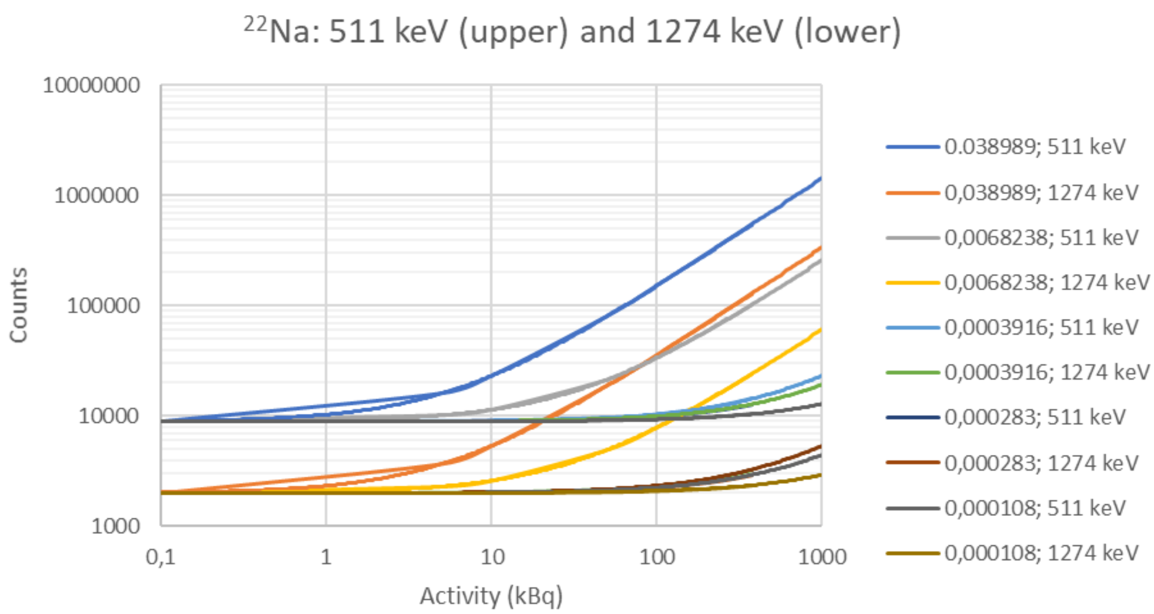

Figure 3. Scaled plots for ^{22}Na at 511 keV and 1274 keV

In the same way, limits of detection can be estimated for ^{60}Co 1173 keV at roughly 2000 counts and for ^{60}Co 1333 keV at roughly 3000 counts. This allows for the calculation of a detection limit in terms of activity at a specific solid angle. Results obtained are summarised in table 4.

Table 4. Limit of detection expressed as activity at specific solid angles.

Distance (mm)	Solid angle (Ω)	511 keV LD Activity (kBq)	1274 keV LD Activity (kBq)
228	0,03899	0.761 (0,87)	0.761 (0,87)
545	0,006824	4.35 (2.1)	4.35 (2.1)
2275	0,0003916	75.7 (8.7)	75.7 (8.7)
2675	0,0002832	104.7 (10.2)	104.7 (10.2)
4330	0,0001081	274.3 (16.6)	274.3 (16.6)
mm	Ω	1173 keV LD Activity (kBq)	1333 keV LD Activity (kBq)
175	0,06618	0,415 (0,64)	0,420 (0,65)
560	0,006463	4,25 (2,1)	4,30 (2,1)
775	0,003375	8,14 (2,85	8,32 (2,9)

4. Conclusion

This investigation showed that the extrapolation of activity detection limits for different radiation sources - taking into consideration background counts, source activity and the distance between the detector and a point source (solid angle), and measurement time - is possible. When measurements are done in terrestrial environments it is most likely that the main source of radiation will be NORM's, hence the predominant source of background radiation. The intensity of this radiation is also regional-dependent as it will differ from one location to another. It is worthy to mention that the results obtained during this study is related to the specific experimental conditions such as the environment where the measurements were taken, the detector used, and counting time. Data obtained during terrestrial measurements will vary. For example, longer measurement times (compared to the 10 minutes during this study) might yield lower detection limits. This emphasises the importance of being able to estimate a limit of detection in terms of source activity, as well as optimising measurement time should there be some other source of radiation present, other than NORM's. By using two different radiation sources during this research, it is also evident that the activity limit of detection is source independent.

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