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Efficiency Calculation Of Nai(Tl) 2x2 Well Detector

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ABSTRACT: The aim of this work to calculate the counting efficiency of NaI(Tl) 2x2 well scintillation detector (Canberra Inc.) .The advantage of this type detector its high efficiency which used to determination the low level of radiation as natural occurring radioactive material NORM.The gamma attenuation coefficients of natural radioisotopes and its daughters were calculated to find the three components of counting efficiency as shown in (Table 1). The (Table 2) presents the values of the counting efficiencies and plotted the graph as the aim of this study.

Keywords: efficiency, attenuation, coefficients, gamma ray, NORM.

1 INTRODUCTION

ALL the Studies on radiation levels and radionuclide distribution in the environment provide vital radiological baseline information .these information is essential in understanding human exposure from man – made and natural sources of radiation and necessary in establishing rules and regulations relating to radiation protection “[1], [2]”. The natural occurring radioactive material NORM has low level of radiation [3], to calculate the concentration of this level of radiation emitted by main natural gamma ray emitters radioisotopes and its daughters provides use the detector with high efficiency like NaI(Tl) 2x2 well type scintillation detector [4]. The efficiencies of the NaI(Tl) in different sizes where shown in many studies “Fig.1” as seen the absence of the curve of the 2x2 NaI(Tl) size detector [5].This work should perform the counting efficiency for this size of this scintillation detector to complete the set of curves shown in “Fig.2”. The detection efficiency of the system was determined using several calculations including linear attenuation coefficient, geometric and intrinsic efficiencies for well type 2x2 NaI(Tl) detector. The well shaped detectors are of higher efficiency for the same volume of detector, this particular characteristic allows almost a 100 percent efficiency (so called 4π geometry) for low gamma-emitting test sources that can fit the well shape [4], [6], [7].

2 MATERIALS AND METHODS.

The material used in this study is NaI(Tl) 2x2 well type scintillation detector (Canberra Inc) with full system of gamma spectrometry which exist in Spectrochemistry and Structural Pharmacology Laboratory, Chemistry Department, College of Sciences, University of Tlemcen,Algeria [8].With this system were performed many work by using this calculation of counting efficiency for natural radioactive isotopes [9], [10], [11]. The every analysis of 40K was based upon its single peak of 1460.8 keV, whereas the analysis of 226Ra and 232Th depended upon the peaks of the daughter products in equilibrium with their parent nuclides, the concentration of 226Ra must be determined from the average concentrations of 214Pb (295.10, 325.00, and 352keV) for 214Bi (609, 1120, and 1765keV), and that of 232Th was determined from average concentrations of 212Pb (115.18, 238.60, and 300.9keV), 208Tl (583.20, 2615keV), 212Bi (727.00KeV) and 228Ac (338.3, 911,20,and 969,80 keV) in each sample under study (Table 1,2). In the uranium series the decay chain segment starting from radium (Ra) is radiological the most important and, therefore, reference is often made to Radium instead of Uranium. Then the method of calculation the counting efficiencies were focusing on these peaks of natural occurring radioisotopes [4], [6], [7]. For man-made radioactive isotopes 60Co, 137Cs are also present in the tables.

3 CALCULATION

There are three factors, G, I and M, which indicate the efficient absorption of the photons emitted by the source. Their product is the detector efficiency DE.

$$DE = G \times I \times M \qquad (1)$$

G is the fraction of all space that the detector subtends. Unless the detector completely surrounds the source, the geometrical solid angle factor is less than 1. I is the fraction of the photons transmitted by the intervening materials that reach the detector surface. There are losses due to absorption by material in the path of the photon. Air, detector housing materials and light reflectors around the detector are possible absorbers. M - fraction of the photons absorbed by the detector. The detector material is not always sufficiently thick to stop the radiation. In our well detector, hence the sample placed in the hole of detector, we have specific conception for dealing with this fractions (G, I, M) [12]. The dimensions of 2x2 NaI(Tl) detector in 2-inch diameter with 2 inches high(crystal) and a 0.75 inch diameter by 1.44 inch deep well (hole), for these properties of well-detector the previous fractions seen as following: To calculate the fraction of space not subtended and then to subtract that value from 1 to get the fraction G subtended. The (absolute) total efficiencies for a right cylinder and a well-type are presented as functions of the source position and the photon energy. When the sources are located on the surface, the total efficiencies for low energy photons are 0.5 and ~ 1, respectively. This means every photon incident on the detector produces an output pulse considering the solid angles of both geometries (2π for right cylinder, ~ 4π for well type), regardless of the energy deposited.

$$1 - G = (\pi r^2) / (4\pi R^2) \qquad (2)$$

where: πr^2 - area of hole in detector face, and $4\pi R^2$ - area of sphere with a radius equal to the distance from the source to the hole [12].

$$1 - G = (\pi \times 0.375 \times 0.375) / (4 \times \pi \times 1.44 \times 1.44) = 0.017,$$

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and G = 0.983

This detector subtends or intercepts 98% of all space, the great advantage of the well geometry is, of course, the large solid angle (~ 4π sr), which leads to a high efficiency.
To calculate I we have

$$I = \exp - (\mu_l \times d) \quad \text{where:} \qquad (3)$$

μ_l = the linear attenuation coefficient for gamma ray in aluminum.

d = 0.025 cm (0.010 inch), the thickness of the aluminum container.

The fraction of the photons absorbed by the detector M is calculated by subtracting the fraction that pass through the detector from 1:

$$M = 1 - \exp - (\mu_l \times d) \qquad (4)$$

μ_l = the linear attenuation coefficient for gamma ray in NaI(crytal).

d = 1.422 cm (0.56 inch), the minimum distance traveled in NaI(Tl) at the bottom of the well.

Linear attenuation coefficient calculations:
For calculation detecting efficiencies we try to find the values of μ_l for each aluminum and NaI(crytal).firstly we investigate the references in this item [13] ,and do an comparison between them to take the main values of its, then we calculate the μ_l for mixture NaI using the following formulas:

$$\mu_m(NaI) = \sum \mu_i . w_i = (\mu_1 . w_1)_{Na} + (\mu_2 . w_2)_I .$$

$$\mu_l (NaI) = \mu_m(NaI).\rho \qquad (5)$$

where ρ is the density of NaI = 3.7g/cm3

the calculation result of μ_l (NaI) presents in (Table1) are compared with that values from references, to view the fit value with the graph of linear attenuation coefficient, this lead us to chose proper solution to this calculations. Finally we calculate the DE of the our detector for each gamma energy (Table2).Using above work, the activity concentrations for the 40K, 232Th, 238U and 226Ra radionuclides we can calculated using the detected photopeaks in the spectra.

$$A = N / (T.I\gamma.\varepsilon.W) \qquad (6)$$

Where N is net peak counts (background subtracted), T is the measured time (sec), ε is the efficiency of detector, Iγ is the branching ratio of gamma emission for decay mode and W is the sample weight.

4 RESULTS AND DISCUSSION

As we see above the calculation of attenuation coefficients were done to find each fraction of counting efficiency and which are present in (Table 1), thus the values of efficiencies are also present in the (Table 2). Finally the curve of efficiency in "Fig.1" are done to be added to the curve set shown by others studies [4], [6], [7].where the efficiency curve of the detector with 2x2 crystal size was absent, with the result of this study the set of curves for counting efficiency is become complete. Using the above "(5)" of specific activity with values of efficiency for well-shaped 2x2 NaI(Tl) detector for each gamma ray emitted by radionuclide, the activity concentrations due to 226Ra,232Th and 40K we can determined.

5 CONCLUSION

The gamma spectroscopy method was mainly used for assessment of the U-238 and Th-232 series and K-40 concentration in different samples, this need the detector with fine ability to detect the low level of radiation emitted from gamma ray sources [4], [6], [7]. The NaI(Tl) 2x2 well-type scintillation detector is the fit device to perform this task. From this research, we deduce the following: Performance new table for linear attenuation coefficients of gamma ray in Al and NaI for used in efficiency calculation (Table 1). Calculation the efficiencies of well-shaped 2x2 NaI(Tl) detector. The values of DE were showing in (Table 2) and "Fig.1", these values are closely to that in "Fig.2" exactly between line 1.5 and 2.5, thus our work show new line which can add to this figure "[4], [5]", which can used in the study to calculation the radioactivity concentrations of NORM.

TABLE 1

LINEAR ATTENUATION COEFFICIENTS OF GAMMA RAY IN (AL) AND (NaI)

	Gamma Energy KeV	Probab. Of γ Emission %	μ_1(Na) Cm²/g W_1=0.153	μ_2 (I) Cm²/g W_2=0.846	Σ μ_i·w_i μ_m cal. (NaI)	μ_m (NaI) Ref. aver.	μ_m (NaI) average for all studies	μ_l(NaI), μ_m·ρ, ρ = 3.67 g/cm³	μ_l (NaI) for low energy ref. [13]	μ_l(Al) 1/cm many ref[13]	μ_l(Al) 1/cm average
(A) U238											
226Ra	186.10	03.51	0.123	0.500	0.4188	0.425	0.420	1.541	1.450	0.343	0.343
	241.98	07.12	0.110	0.250	0.2173	0.278	0.245	0.899	0.860	0.310	0.310
	295.21	18.15	0.102	0.163	0.1486	0.153	0.151	0.554	0.629	0.290	0.290
	351.92	03.51	0.095	0.130	0.1151	0.130	0.122	0.448	0.480	0.260	0.260
	609.31	44.10	0.077	0.079	0.0762	0.078	0.077	0.283		0.205	0.205
	768.6	04.76	0.069	0.070	0.0675	0.068	0.068	0.249		0.188	0.188
214pb	295.10	19.24	0.102	0.160	0.1456	0.153	0.149	0.547	0.629	0.290	0.280
	325.00	37.20	0.099	0.145	0.1331	0.142	0.138	0.506	0.530	0.280	0.270
	351.93	35.34									
214BI	609.30	46.36	0.077	0.079	0.0762	0.078	0.077	0.283		0.205	0.205
214BI	1764.5	15.80	0.046	0.043	0.0420	0.043	0.043	0.158		0.126	0.126
214BI	1120.3	15.1 0	0.057	0.053	0.0520	0.051	0.051	0.187		0.156	0.156
234Th	63.280	04.47	0.200	07.32	6.016	6.100	6.05	22.20	20.94	0.710	0.710
	92.370	02.60	0.155	2.600	2.1477	2.220	2.18	8.000	7.400	0.490	0.450
235U	185.70	57.25	0.125	0.510	0.4360	0.425	0.43	1.578	1.460	0.345	0.345
	143.70	10.96	0.128	0.600	0.5096	0.516	0.51	1.872	2.400	0.385	0.385
(B) 232Th											
228Ac	338.30	11.40	0.097	0.151	0.1379	0.140	0.139	0.510	0.500	0.274	0.265
	911.20	27.70	0.065	0.060	0.0589	0.062	0.060	0.220		0.174	0.174
	969.80	05.20	0.062	0.058	0.0565	0.059	0.058	0.213		0.171	0.171
212BI	727.00	11.80	0.075	0.072	0.0709	0.071		0.257		0.197	0.193
212Pb	115.18	0.62	0.146	1.800	1.4913	1.500	1.495	5.487	4.300	0.430	0.430
	300.09	03.40	0.101	0.162	0.1475	0.153	0.150	0.550	0.600	0.285	0.275
	238.60	43.60	0.117	0.150	0.2200	0.190	0.205	0.752	0.866	0.293	0.300
208Tl	583.20	84.50	0.079	0.080	0.0731	0.081	0.077	0.283		0.215	0.215
	2615.0	99.79	0.038	0.039	0.0378	0.038	0.038	0.140		0.054	0.054
228Ra	338.32	11.26	0.097	0.151	0.1372	0.140	0.139	0.510	0.500	0.274	0.274
	911.07	26.60	0.065	0.060	0.0589	0.062	0.060	0.220		0.175	0.175
	969.11	16.23	0.062	0.058	0.0565	0.059	0.058	0.213		0.172	0.172
(c)											
60Co	1173.0	100	0.057	0.055	0.0527	0.054	0.0530	0.195		0.156	0.156
60Co	1332.0	100	0.052	0.050	0.0488	0.050	0.0495	0.182		0.145	0.145
134Cs	604.70	97.10	0.077	0.079	0.0763	0.079	0.078	0.286		0.210	0.210
	795.50	85.40	0.067	0.065	0.0649	0.065	0.065	0.239		0.183	0.183
137Cs	661.60	85.00	0.070	0.075	0.0720	0.075	0.0735	0.270		0.196	0.196
(D) k-40	1460.8	10.66	0.050	0.045	0.0384	0.042	0.040	0.147		0.137	0.137

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TABLE 2
EFFICIENCIES OF WELL-SHAPED 2X2 NaI(Tl) DETECTOR

Radio nuclides	Decay series	Photopeak Energy KeV	I	M	G	DE
Ra-226	Bi-214	609.30	0.975309912	0.336304179	0.983	0.32236311
		1120.3	0.996107595	0.246494955	0.983	0.24113213
		1764.5	0.996854956	0.185569411	0.983	0.18182091
	Pb-214	295.20	0.992776217	0.542600005	0.983	0.529571059
		351.90	0.993024400	0.47247744	0.983	0.461100321
Th-232	Pb-212	238.60	0.992701762	0.656766295	0.983	0.640889613
	Ac-228	338.30	0.993173407	0.51378197	0.983	0.5015525
		911.60	0.995649447	0.268633078	0.983	0.262920121
		969.10	0995734124	0.261316696	0.983	0.25577852
	Tl-208	583.00	0.994639419	0.343270417	0.983	0.33512621
		2614.0	0.99865091	0.180515668	0.983	0.174875589
K-40		1460.8	0.996854956	0.223101565	0.983	0.20225655

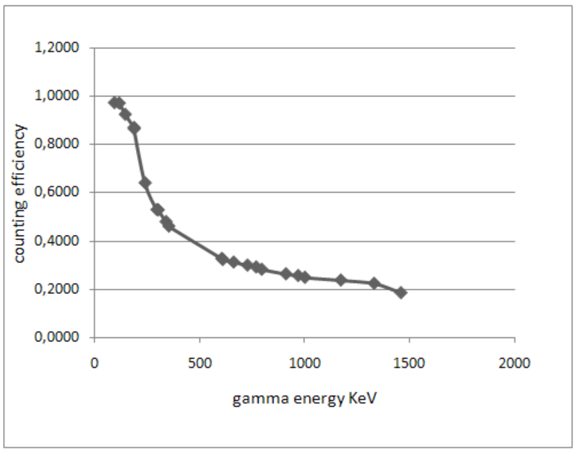

Fig. 1-Efficiency of well-shape 2x2 NaI(Tl) detector

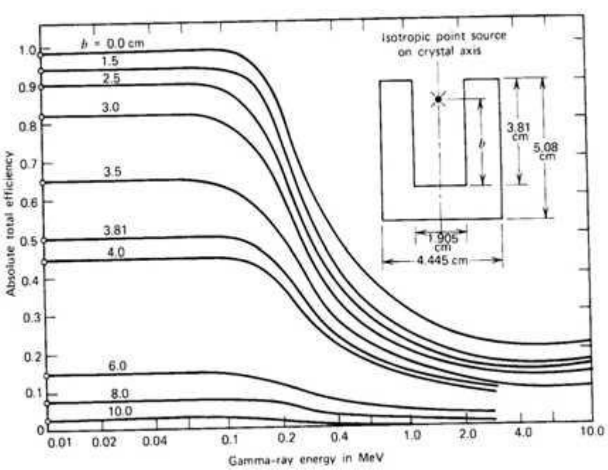

Fig. 2- Absolute total efficiency for a well-type NaI(Tl). "[4], [5]"

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