Determination of relative and absolute efficiency functions in the range of 122 keV ÷ 8.5 MeV of HPGe detector

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(Received on April 6 th 2015, accepted on June 5 th 2015)

ABSTRACT

Construction of detector is necessary. However, on large energy range the manufacturers could not also support the explicit function of relative and absolute efficiencies of detectors. One of the reasons is a restriction of energy range of gamma sources (normally < 3 MeV). This paper presents the results of construction of relative and absolute efficiency functions within a range from 122 keV to 8.5 MeV. The sources are used combining ^{152}Eu point source and ^{36}Cl activated isotope by thermal neutron captured reaction ^{35}Cl of Dalat nuclear reactor (DNR) by ^{35}Cl(n, γ)^{36}Cl reaction. This result can be applied in determining quantitative analysis of samples of neutron activation and radioactivity chemistry.

Keywords: *Relative efficiency; absolute efficiency; prompt gamma; ^{35}Cl(n, γ)^{36}Cl reaction.*

INTRODUCTION

In the experimental nuclear physics and radiation applications, the determination of relative and absolute efficiencies of spectrometry is necessary and research condition exactly. However, the construction of efficiency in large energy range is a restriction of energy range of gamma sources and method.

In the previous papers, the authors used point sources of a radioisotope, so the absolute efficiency functions were < 3 MeV limited range [1,2,3]. There was also some simulated MCNP method for absolute efficiency functions in large energy range [4].

In this research, ^{152}Eu point source was used to select photo peaks, which are 122 keV ÷ 1408 keV range, and use neutron activation analysis method. The ^{35}Cl was activated on the 3rd channel of DNR, measuring prompt gamma by ^{35}Cl(n, γ)^{36}Cl reaction. The result was used to construct relative efficiency, absolute efficiency in 122 keV ÷ 8.5 MeV range, and determine the transformation factor corresponding to E energy of detector as well.

Detector efficiency functions in large energy range are the logarithm or exponential functions. There has been a large energy range to construct efficiency function, and usage of prompt gamma from activated thermal neutron of target is necessary. When targets capture thermal neutron, some of compound nucleus of target emit prompt gamma, and do not have any delayed gamma emission.

In the compound nucleus mechanisms, particle (a) interacts target (A), then a production of nuclear compound (C) occurs. Nuclear compound (C) produces particle (b) and nucleus (B) by the following function:

$$a + A \rightarrow C \rightarrow b + B \quad (1)$$

Compound reactions happen during a time of the order of about 10^{-16} s, so the activity of target is constant when the experimental time is about some hours, and the neutron flux and geometry arrangement are unchanged.

Let's consider the case of the target and the point source are placed in the same geometry, the absolute photo peak efficiency relates the counter of detector and the number of gamma ray emitted by the the sources, by following function:

$$\varepsilon_{abs}(E) = \frac{\text{The counter of detector}}{\text{The number of emitted gamma ray}} = \frac{N}{A \times I_{\gamma} \times t} \quad (2)$$

where: $\varepsilon_{abs}(E)$ is absolute efficiency value at of energy E,

N is the area of the photo peak of energy E,

A is the activity of the gamma source (Bq),

I_{γ} is branching ratio of gamma ray (%),

t is the live time of the counting number (s).

The absolute efficiency error is:

$$\sigma_{\varepsilon_{abs}}(E) = \left[\left(\frac{\sigma_A^2}{A^2} + \frac{\sigma_N^2}{N^2} \right) \left(\varepsilon_{abs}(E) \right)^2 \right]^{1/2} \quad (3)$$

where σ_A^2 is the error of the gamma source activity; σ_N^2 is statistical counting error of the detector.

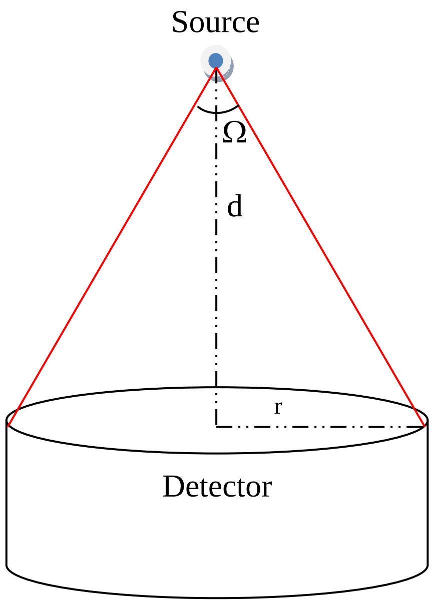

Fig. 1. Point source located along the axis of cylindrical detector.

Absolute efficiency depends on the geometrical conditions and on the energy. As the Fig.1, $\varepsilon_{abs}(E)$ is following:

$$\varepsilon_{abs}(E) = \varepsilon_G \times \varepsilon(E) \qquad (4)$$

where $\varepsilon(E)$ is geometrical efficiency, $\varepsilon(E)$ is intrinsic efficiency.

ε_G depends on only the source detector geometry, is defined by:

$$\varepsilon_G = \frac{\Omega}{4\pi}$$

$$\Omega = 2\pi\left(1 - \frac{d}{\sqrt{d^2 + r^2}}\right) \qquad (5)$$

where d is distance the sourse to face detector, r is the radius of detector.

The absolute efficiency relates the relative efficiency function as follow [2]:

$$\varepsilon_{abs}(E) = \alpha(E) \times \varepsilon_{rel}(E) \qquad (6)$$

where $\alpha(E)$ is the transformation factor corresponding to E energy; $\varepsilon_{rel}(E)$ is the relative efficiency value at energy of E.

METERIALS AND METHODS

First, an ^{152}Eu point source is used. This source is covered by polymer. Its activity is 198.99 kBq. The distance between the source to the surface detector is 5.0 cm. Fig. 2 showed the geometry of ^{152}Eu point source. In our laboratory, the gamma spectrometer based on a high purity Ge detector, GMX35, the detector diameter is 58 mm. The time of one experiment is 1 hour.

After that, to measure the background at the 3rd beam of DNR and to measure the activated target, the thermal neutron flux at the target local is ~ 9.25×10^4 n/cm^2/s, neutron beam diameter is 1.3 cm, cadmi/goal ratio is 218 (measure 1 mm thickness cadmi box). The target is NH_4Cl, which is 2.00 mm diameter, 1.00 mm thickness. The target is the same geometry of ^{152}Eu point source. The parameters of the spectrometer are unchanged completely in this research. Fig. 3 shows the experimental arrangement. The experimental time per one measurement is 5 hours. Fig. 4, Fig. 5 are ^{152}Eu spectrum, background spectrum and ^{36}Cl prompt gamma one.

Fig. 2. ^{152}Eu source.

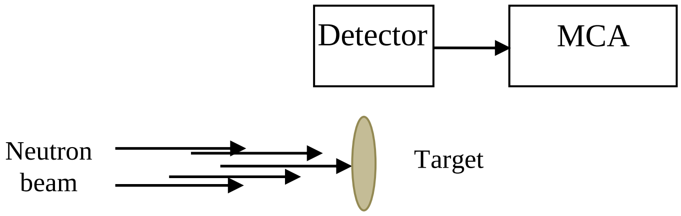

Fig. 3. Experimental diagram.

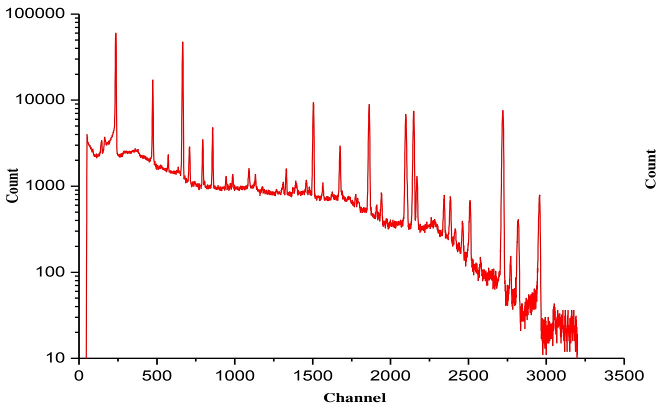

Fig. 4. ^{152}Eu spectrum

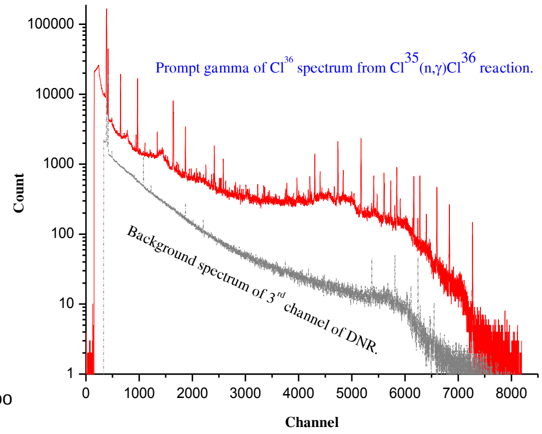

Fig. 5. The background and ^{36} Cl prompt gamma spectra by ^{35}Cl (nth, γ) ^{36}Cl reaction

RESULTS

In the experiment on point source the target is also a point source. Using the (4) and (5) formulas, the distance between detector to source is d = 5 cm, detector radius is r = 29 mm, so:

$$\varepsilon_{abs}(E) \cong 6.748.10^{-2} \times \varepsilon(E) \quad (7)$$

Thus, following the geometrical design in this research, the experimental absolute efficiency is ~ 6.748 ‰ of intrinsic efficiency detector.

To treat ^{152}Eu spectrum, the photo peaks which have high branching ratio in the 122 keV to 1408 keV range are collected. Formula (2) and (3) are used to determine the absolute efficiencies. Those results are shown in Table 1.

Table 1. Experimental values of absolute efficiency in the 122 keV to 1408 keV range.

No.	E (keV)	I_γ (%) [5]	N	σ_N^2	$\varepsilon_{abs}(E)$	$\sigma_{\varepsilon_{abs}}(E)$
1	121.78	25.60	155097	1318	8.46E-03	6.11E-07
2	244.70	7.60	36590	311	6.72E-03	4.86E-07
3	344.28	26.50	113194	962	5.97E-03	4.31E-07
4	411.12	2.20	8720	74	5.54E-03	4.00E-07
5	443.96	3.10	12037	102	5.42E-03	3.92E-07
6	488.68	2.10	7855	67	5.22E-03	3.77E-07
7	688.65	1.90	6184	53	4.55E-03	3.28E-07
8	778.80	12.80	39402	335	4.30E-03	3.11E-07
9	867.35	4.20	12314	105	4.09E-03	2.96E-07
10	964.10	14.50	40462	344	3.90E-03	2.82E-07
11	1085.80	10.20	26867	228	3.68E-03	2.66E-07
12	1112.20	13.60	35397	301	3.64E-03	2.63E-07
13	1213.00	1.40	3451	29	3.44E-03	2.49E-07
14	1299.32	1.60	3890	33	3.40E-03	2.45E-07
15	1408.14	21.10	48549	413	3.21E-03	2.32E-07

To fit experimental data of ^{152}Eu the non-linear least square method is used. And this fitting method in repeated until minimizing Chi-square**.** The absolute efficiency function of the range from 122 keV to 1408 keV is shown in Table 2 and Fig. 6.

Table 2. The parameters of absolute efficiency are curved in the 122 keV to 1408 keV range.

Functions	Parameters					
$\varepsilon_{rel}(E) = a - b.\ln(E + c)$	a	Δa	b	Δb	c	Δc
$R^2 = 0.99936$	0.01607	1.74511E-4	0.00178	2.45273E-5	-51.46279	4.21548

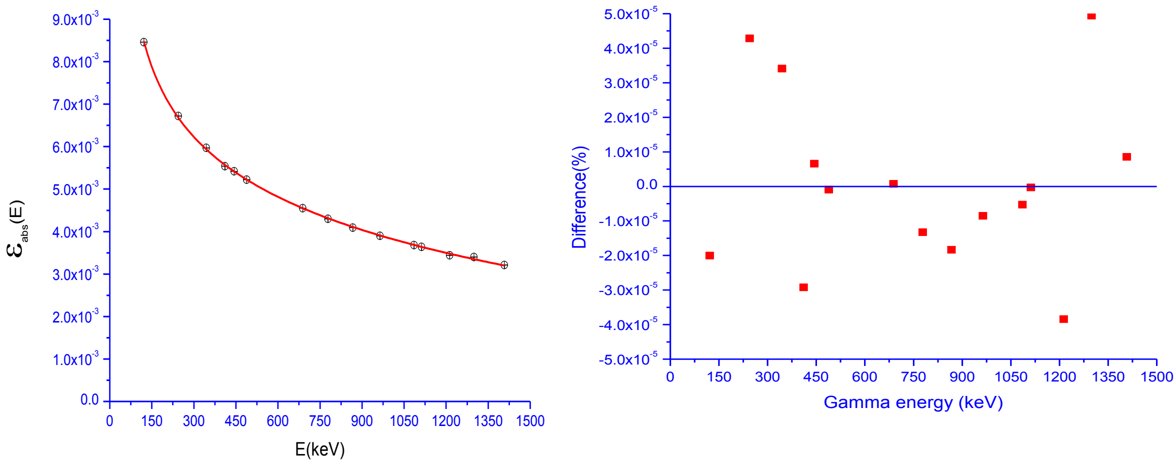

Fig. 6. The absolute efficiency curve in the 122 keV to 1408 keV range.

To treat prompt gamma of ^{36}Cl spectrum, a determination of area peaks and area peak errors must be carried out. After that, using the absolute efficiency function in the 122 keV to 1048 keV range to calculate the ^{36}Cl activity under experimental data of 788.43 keV area peak (the experimental data showed in Table 3). The activity of ^{36}Cl is calculated by the following function

$$A = \frac{N - N_P}{\varepsilon_{abs}(E) \times I_\gamma \times t} = 4890\ (Bq)$$

Thus, ^{36}Cl activity is determined. Efficiency in the 122 keV to 1408 keV assembly, we construct efficiency detector in the 122 keV to 8.5 MeV. The results are shown in Table 3, Table 4, and Fig 7, Fig. 8.

Table 3. Experimental values of relative efficiency and absolute efficiency in the 122 keV to 8.5 MeV range.

No.	**E_γ**	**(I_γ)** [5,6]	**N**	σ_N^2	$\varepsilon_{abs}(E)$	$\sigma_{\varepsilon_{abs}}(E)$	$\varepsilon_{rel}(E)$	$\sigma_{\varepsilon_{rel}}(E)$
1	121.78	25.60	155097	1318	100.00	0.10	8.46E-03	6.11E-07
2	244.70	7.60	36590	311	79.47	0.02	6.72E-03	4.86E-07
3	344.28	26.50	113194	962	70.50	0.07	5.97E-03	4.31E-07
4	411.12	2.20	8720	74	65.42	0.01	5.54E-03	4.00E-07
5	443.96	3.10	12037	102	64.09	0.01	5.42E-03	3.92E-07
6	488.68	2.10	7855	67	61.74	0.01	5.22E-03	3.77E-07
7	688.65	1.90	6184	53	53.72	0.01	4.55E-03	3.28E-07
8	778.80	12.80	39402	335	50.81	0.02	4.30E-03	3.11E-07
9	867.35	4.20	12314	105	48.39	0.01	4.09E-03	2.96E-07
10	964.10	14.50	40462	344	46.06	0.02	3.90E-03	2.82E-07
11	1085.80	10.20	26867	228	43.48	0.02	3.68E-03	2.66E-07
12	1112.20	13.60	35397	301	42.96	0.02	3.64E-03	2.63E-07
13	1213.00	1.40	3451	29	40.69	0.01	3.44E-03	2.49E-07
14	1299.32	1.60	3890	33	40.13	0.00	3.40E-03	2.45E-07
15	1408.14	21.10	48549	413	37.98	0.03	3.21E-03	2.32E-07
16	436.22	1.05	5046	423	64.52	2.98	5.46E-03	3.84E-05
17	517.08	24.30	109257	1236	60.37	0.16	5.11E-03	6.54E-07
18	788.43	16.32	61702	1136	50.76	0.39	4.30E-03	1.46E-06
19	1131.25	1.911	6063	308	42.60	0.44	3.60E-03	9.30E-06
20	1164.87	27.2	85022	381	41.97	0.01	3.55E-03	7.12E-08
21	1327.42	1.27	3811	262	40.29	0.48	3.41E-03	1.61E-05
22	1601.08	3.484	9169	268	35.34	0.13	2.99E-03	2.56E-06
23	1951.14	19.39	45278	243	31.35	0.01	2.65E-03	7.61E-08
24	1959.36	12.56	29251	166	31.27	0.01	2.65E-03	8.57E-08
25	2676.30	1.572	3100	175	26.48	0.30	2.24E-03	7.16E-06
26	2863.82	5.77	10277	208	23.91	0.04	2.02E-03	8.32E-07
27	3061.86	3.521	6155	173	23.47	0.06	1.99E-03	1.57E-06
28	3981.06	1.028	1480	111	19.33	0.27	1.64E-03	9.18E-06
29	4979.71	3.616	3716	142	13.80	0.05	1.17E-03	1.71E-06
30	5517.20	1.689	1721	108	13.68	0.15	1.16E-03	4.54E-06
31	5715.19	5.31	4600	127	11.63	0.03	9.84E-04	7.51E-07
32	6110.85	20.58	15664	176	10.22	0.01	8.65E-04	1.09E-07
33	6619.64	7.83	5158	117	8.84	0.03	7.48E-04	3.85E-07
34	6627.75	4.69	3150	71	9.02	0.02	7.63E-04	3.86E-07

35	6977.85	2.29	1355	89	7.95	0.20	6.72E-04	2.89E-06
36	7413.95	10.52	5473	87	6.99	0.01	5.91E-04	1.51E-07
37	7790.32	8.31	3765	63	6.08	0.01	5.15E-04	1.44E-07
38	8578.59	2.739	940	28	4.61	0.02	3.90E-04	3.35E-07

Table 4. The parameters of efficiencies are curved in the 122 keV to 8.5 MeV range.

Functions	**Parameters**					
	The parameters of relative efficiency					
$\varepsilon_{rel}(E) = a - b \times \ln(E + c)$	a	Δa	b	Δb	c	Δc
$R^2 = 0.99811$	173.30017	1.57773	18.83003	0.20733	-101.31758	7.45894
	The parameters of absolute efficiency					
$R^2 = 0.99863$	0.01454	9.17835E-5	0.00157	1.17111E-5	-80.2783	4.25766

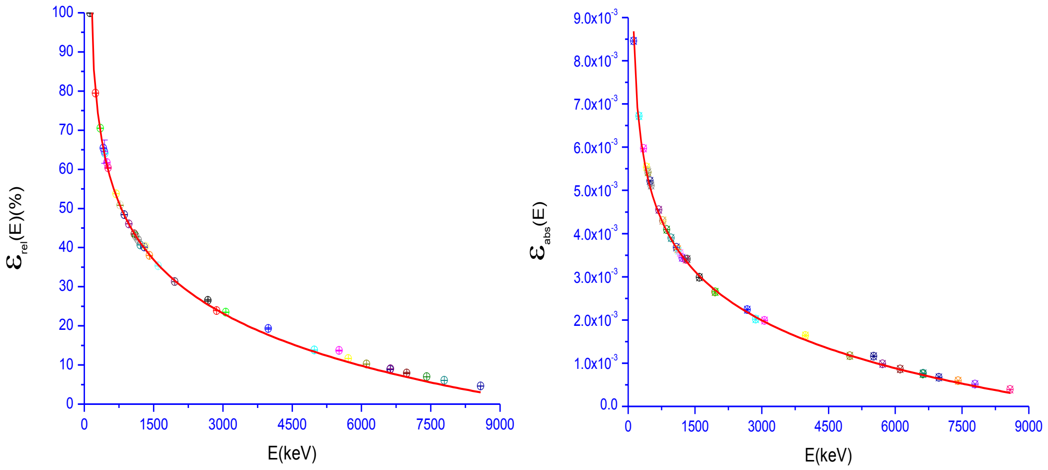

Fig 7. The relative curve in the 122 keV to 8.5 MeV range

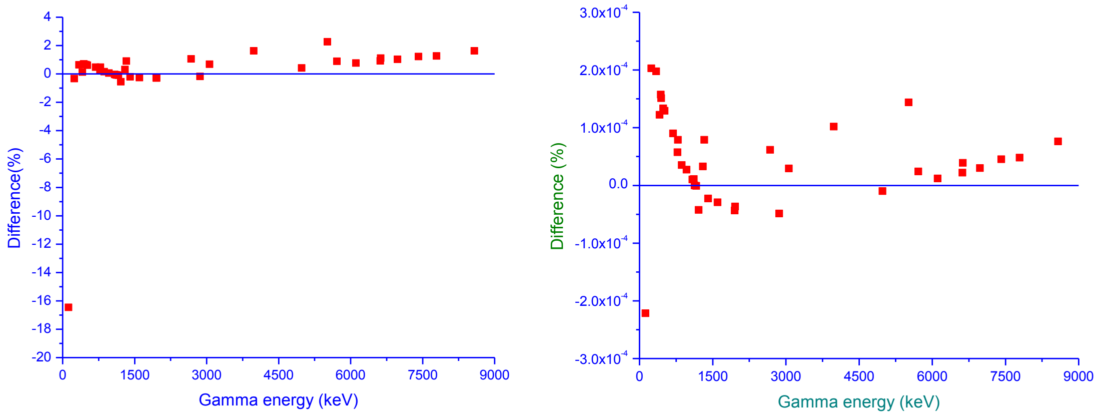

Fig 8. The absolute efficiency curve in the 122 keV to 8.5 MeV range

The result of fitting is squared $\varepsilon_{rel}(E) = a - b \times \ln(E + c)$ function in the 122 keV to 8.5 MeV range. The transformation factor corresponding to E energy $\alpha(E)$ of detector determined on experiment to be $\alpha(E)$ = 8.4615E-5 ± 1.7024E-6.

CONCLUSION

By this experiment, using ^{152}Eu point source and ^{36}Cl (^{35}Cl activated by thermal neutron of the 3rd channel of DNR), the relative and absolute efficiency functions of purity Ge detector in the 122 keV to 8.5 MeV range are constructed, determined on the transformation factor corresponding to E energy $\alpha(E)$ of detector simultaneously. The result contributed spectra treatment, and improved quantitative analysis of samples in large energy range.

ACKNOWLEDGMENTS: The authors would like to thank Nuclear Research Institute (NRI) - Vietnam to support facility for carrying out this research.

Xác định hàm hiệu suất tương đối và tuyệt đối trong dải 122 keV ÷ 8.5 MeV của detector HPGe

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TÓM TẮT

Xây dựng hàm hiệu suất cho detector là cần thiết. Tuy nhiên, trên dải năng lượng rộng thì nhà sản xuất cũng không thể cung cấp hàm hiệu suất tương đối và tuyệt đối một cách tường minh cho các detector. Một trong những lý do là hạn chế của dải năng lượng của các nguồn đồng vị phát gamma (thông thường < 3 MeV). Kết quả của bài báo này trình bày việc xây dựng hàm hiệu suất tương đối và tuyệt đối trên dải năng lượng từ 122 keV đến 8.5 MeV. Các nguồn sử dụng kết hợp là nguồn điểm ^{152}Eu phát gamma và kích hoạt ^{36}Cl bởi phản ứng bắt neutron nhiệt của ^{35}Cl tại Lò phản ứng hạt nhân Đà Lạt bởi phản ứng ^{35}Cl(n, γ)^{36}Cl. Kết quả này được ứng dụng rộng rãi trong việc xác định định lượng của bia mẫu bằng phân tích kích hoạt neutron và hóa phóng xạ.

Từ khóa: *Hiệu suất tương đối, hiệu suất tuyệt đối, Gamma tức thời, phản ứng ^{35}Cl(n, γ)^{36}Cl.*

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