Measurements of Gamma-Ray Energies from Eu^{152} by the Scintillation Spectroscopy

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The scintillation spectroscopic energy determination of some gamma-rays from a highly enriched Eu^{152} source has been performed by the use of a 3 inch diameter by 3 inch long NaI(Tl) crystal and a 256-channel pulse-height analyzer. The observed channel numbers of the photo-peaks of the rays to be measured are determined as precisely as possible by comparing with those of some standard rays of known energies from calibration sources. The fifteen gamma-rays are used as standards. The determined energies of ten rays from Eu^{152} are (121.9±1.1), (243.6±0.7), (346.6±0.6), (428.7±2.9), (683.9±6.0), (779.1±0.8), (868.2±6.1), (963.9±1.5), (1096.4±1.1) and (1408.9±1.1) keV. The quoted errors are the standard errors derived from a series of measurements using different couples of standard rays for each ray. These gamma-rays are concluded to be attributed to the decay of Eu^{152}.

Two years ago the energy determination of some gamma-rays emitted from a source of mixture of Eu^{152} and Eu^{154} by the scintillation spectroscopy was attempted in our Laboratory. The work has been published by Mukoyama and Shimizu[1]. In their paper the determined energies of eleven strong gamma-rays in the decay of $Eu^{152,154}$ mixture have been compared with those measured by other workers using various methods. However, because of the use of a mixed source assignments of some lines to which of the isotopes, Eu^{152} or Eu^{154}, could not be conclusive. Since a highly enriched Eu^{152} source has recently become available for our use, the similar scintillation spectroscopic determination of some gamma-ray energies from this isotope has been carried out. The present paper reports the outline of the experiment as well as the result obtained.

Eu^{152} decays complicatedly with a half-life of about 13 years either by electron emission to Gd^{152} or by K-electron capture and weak positron emission to Sm^{152}. Many gamma-rays are known to be emitted in this decay, however, in the present experiment it was attempted to determine the energies of ten lines with reasonable standard errors.

The principle of the energy determination of gamma-rays from Eu^{152} in the present work is that the scintillation photo-peaks induced in a NaI(Tl) crystal by the gamma photons to be measured are compared with those of standard gamma-rays with known energies. The gamma-ray energy of unknown value was estimated by the inter- or extrapolation method using a pair of standard gamma-rays. The measurements were performed by assuming the response of

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the scintillator to be linear over the energy region covering the unknown and standard energies. The details of the method, including inter- or extrapolation and error estimation, were quite similar to those reported by Mukoyama and Shimizu[1].

The gamma-ray spectra were measured by a 3 inch diameter by 3 inch long NaI(Tl) crystal mounted on a DuMond 6363 photomultiplier tube. The output pulses from this scintillation probe were fed to an RCL 256-channel pulse-height analyzer *via* a cathode-follower amplifier.

The Eu^{152} source was prepared from radioactive europium oxide, which was produced from highly enriched (97.8%) Eu^{151}-oxide by reactor irradiation at Oak Ridge National Laboratory. The source was in the form of evaporated deposit of about 3 mm diameter of $EuCl_3$ in HCl solution on a thin polystyrene disc and its strength was estimated to be about 40μC. The standard rays with precisely determined energies used in the present work are listed in Table 1. These gamma-ray sources were also used in the form of small evaporated deposits.

Table 1. Energies of standard gamma-rays used.

No.	Source	Energy (keV)	Reference
1	$Sb^{125}(Te^{125m})$	35.2±0.3	der Matheosian and McKeown[2]
2	Tm^{170}	84.2±0.3	*ibid.*
3	Sb^{125}	174.7±0.4	*ibid.*
4	Sb^{125}	428.6±0.6	Mukoyama and Shimizu[1]
5	m_e*	510.976±0.007	DuMond and Cohen[3]
6	Sb^{125}	601.7±0.9	Mukoyama and Shimizu[1]
7	Ag^{110m}	655.9±0.9	*ibid.*
8	Cs^{137}	661.6±0.2	Way *et al.*[4]
9	Ag^{110m}	886.0±0.9	Mukoyama and Shimizu[1]
10	Y^{88}	898.8±1.2	Peelle and Love[5]
11	Zn^{65}	1119.6±1.1	Mukoyama and Shimizu[1]
12	Co^{60}	1172.8±0.5	Lindström *et al.*[6]
13	Na^{22}	1275.0±0.5	Ajzenberg and Lauritsen[7]
14	Co^{60}	1332.5±0.3	Lindström *et al.*[6]
15	Y^{88}	1840.0±2.0	Peelle and Love[5]

* Annihilation radiation.

During the course of the present work in every measurement the source was always placed 25 cm above the scintillation crystal. To avoid the scattered rays from surroundings the scintillation probe was placed vertically in the center of the experimental room. To diminish the so-called "count-rate drift" an applied voltage to the photomultiplier was always set to be 670.0 V, and the room temperature was maintained as constant as possible. As the general procedure gamma-rays from Eu^{152} to be measured and a pair of standard rays were superimposed in the same spectrum in order to eliminate the effect of the residual drift of the measuring system.

Prior to the measurements it was necessary to know how to correct the

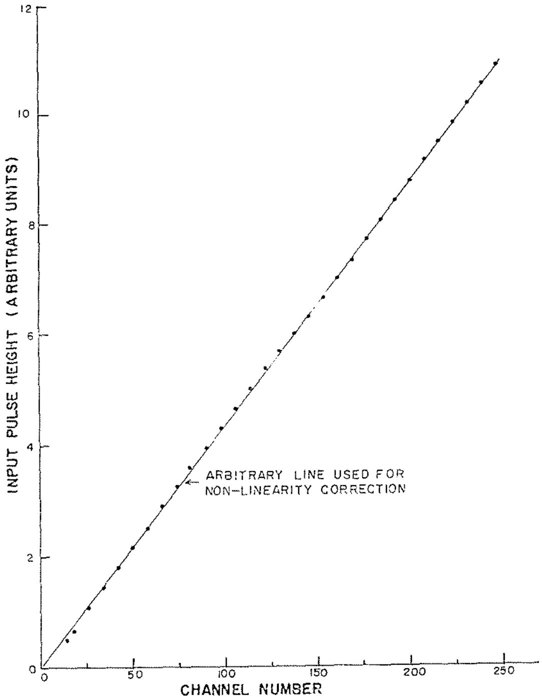

Fig. 1. Pulse generator response curve used for non-linearity corrections.

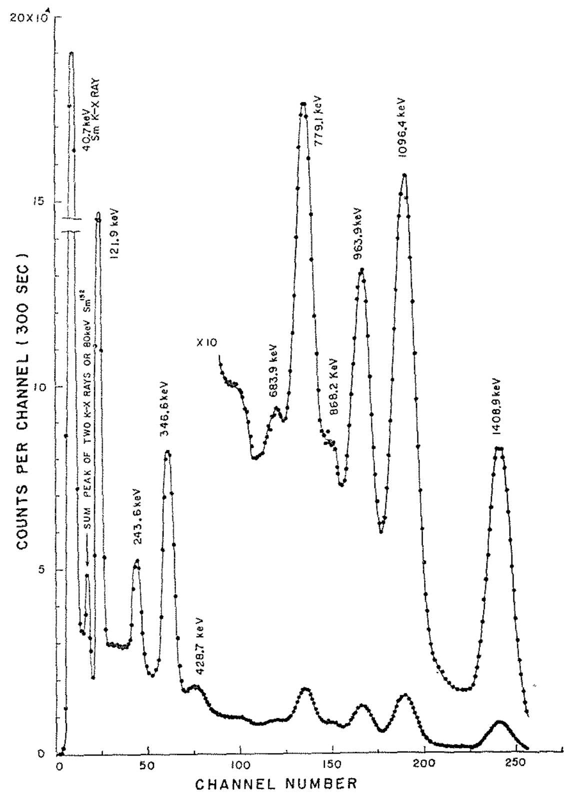

Fig. 2. Full scintillation spectrum of gamma-rays from the Eu^{152} source.

deviation from linearity of the pulse-height analyzer. For this purpose a response curve of the analyzer for known output pulses from a pulse generator was obtained, as shown in Fig. 1, which was used when non-linearity corrections were applied to the channel numbers of observed gamma-ray peaks.

The observed full spectrum of the gamma-rays from the Eu^{152} source is shown in Fig. 2. In the present work to avoid systematic errors, various combinations of calibration sources were used to determine a precise channel number of a gamma photo-peak to be measured by the inter- or extrapolation method using a pair of standard lines. An example for the case of using the standard rays of Nos. 8 and 13 is shown in Fig. 3.

A pulse-height response *vs* gamma photon energy for the crystal used was measured using fifteen standard rays under the measurement geometry adopted. It is noted that this response curve was found to be quite linear over the energy region till about 80 keV but a pulse-height value corresponding to a 35.2 keV ray from $Sb^{125}(Te^{125m})$ being located slightly beneath the extrapolation of the linear portion of the curve. A similar non-linearity of the response curve for photon energies less than about 100 keV has been also observed by other workers[8,9]. Taking account of this non-linearity for the energy region below about 80 keV a standard ray of 35.2 keV from $Sb^{125}(Te^{125m})$ was adopted as a partner of a pair only in the case of determining a precise energy of 122 keV line.

To determine a channel number of a faint peak at about 868 keV, hardly observed in the spectrum shown in Fig. 2, the following procedure was pursued. The position of this weak intervening peak was made evident by subtract-

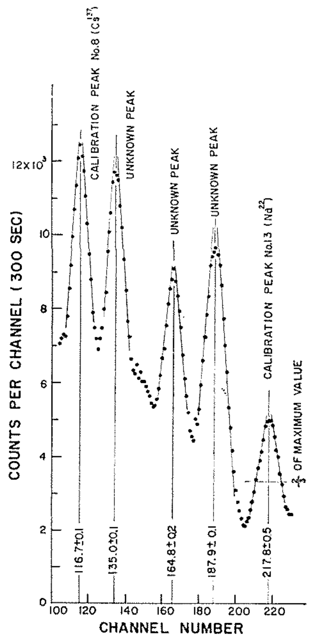

Fig. 3. An example of channel determinations of photo-peaks of Eu^{152} using two standard sources, Cs^{137} and Na^{22}.

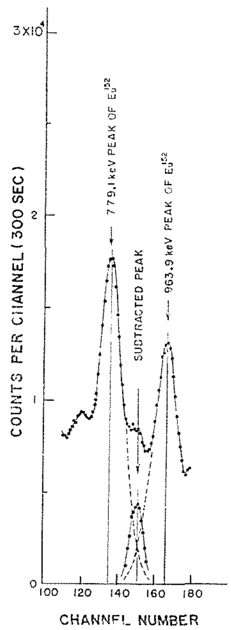

Fig. 4. An example of determination of position of a weak photo-peak.

ing the contributions from two nearest strong peaks at both sides by assuming the pulse-height distribution of the peak to be Gaussian and the Compton contribution to be neglected as a first approximation as shown in Fig. 4. For a weak peak at about 684 keV its position was made clear by subtracting an assumed contribution from a strong peak at 779 keV. However, it should be noted here that the determined values for these both lines, as given in Table 2, are less reliable than the other values because of the procedure of making these faint peaks evident by subtracting the contributions from the nearest peaks under a bold assumption as mentioned above.

The procedures and calculations for non-linearity correction, inter- or extrapolation and error estimation in the present experiment were quite similar to those described in the paper of Mukoyama and Shimizu[1].

The final values of determined energies of observed ten gamma-rays from Eu^{152} are given in Table 2. The values given are averaged values derived by the use of couples of standard rays shown in the parentheses in the right-hand column of the table. The errors given are standard errors.

Table 2. Determined energies of ten gamma-ray from Eu^{152}.

Determined energy and error (keV)	Couples of standard gamma-rays used*
121.9±1.1	(1,3), (1,4), (2,3), (3,6).
243.6±0.7	(2,6), (2,7), (2,8), (3,4), (3,6), (3,8).
346.6±0.6	(2,6), (2,7), (2,8), (3,4), (3,6), (3,7), (3,8), (3,9), (3,10), (3,12).
428.7±2.9	(2,7), (2,8).
683.9±6.0**	(346.6±0.6 and 779.1±0.8 keV lines)
779.1±0.8	(3,12), (4,13), (5,9), (5,10), (5,11), (5,13), (6,10), (6,11), (6,12), (6,13), (6,14), (7,9), (7,12), (7,13), (7,14), (8,10), (8,11), (8,12), (8,13), (8,14).
868.2±6.1**	(779.1±0.8 and 963.9±1.5 keV lines)
963.9±1.5	(4,13), (5,13), (6,11), (6,13), (7,12), (8,11), (8,13), (9,12), (9,14), (10,12), (10,14), (10,15).
1096.4±1.1	(4,13), (5,13), (6,13), (7,12), (7,13), (7,14), (8,13), (9,12), (9,13), (9,14), (10,12), (10,13), (10,14), (10,15).
1408.9±1.1	(4,13), (5,9), (5,11), (5,13), (6,11), (6,13), (7,13), (8,11), (8,13), (9,13), (10,12), (10,13), (10,14), (10,15), (11,13), (12,14).

* Numbers in parentheses showing standard rays used are given in Table 1.

** In these cases couples of Eu^{152} lines determined by the present work were used as calibration lines. In the parentheses energies of these lines are shown.

All rays shown in the table with an exception of a 428.7 keV line can be found in the decay scheme of Eu^{152} given by other workers[10,11]. The observed line at 428.7 keV may be a photo-peak which is contributed from both a ray of about 444 keV of Sm^{152} and that of about 413 keV of Gd^{152}; in the present measurement these two rays could not be observed separately.

When a mixed source of $Eu^{152,154}$ was used there appeared an evident peak at about 1282 keV (see Fig. 1 of reference (1)), while with the present source no peak was observed in this energy region. It can be, therefore, concluded that a 1282 keV ray should be attributed to Eu^{154}. With a source of $Eu^{152,154}$ a peak at about 580 keV was also evident in the spectrum[1]. In our case a very faint peak seems to exist at about 580 keV as shown in Fig. 2, but by the present measurement we could not determine its precise energy because this peak was too weak. This line may be due to a slight contamination of Eu^{154} in the source used in the present work. These two rays are shown in the decay scheme of Eu^{154} given by other workers[12,13].

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