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PRECISE MEASUREMENT OF BETA-RAY MAXIMUM ENERGY BY HPGe

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Abstract: Response functions of an HPGe detector to electrons ranging in kinetic energy from 0.91 to 4.45 MeV have been investigated by both experiments and Monte Carlo calculations. The β maximum energies of $^{91-93}$Rb, ^{94}Y, ^{95}Sr, $^{139-141}$Cs, $^{142-145}$La, ^{145,146}Ce and ^{146}Pr obtained by using the On-line Isotope Separator KUR-ISOL were measured. It was found that Q_β-values could be determined with an accuracy of 20 keV.

(HPGe detector, response functions, β-ray spectrometer, Monte Carlo calculation, Q_β)

Introduction

The precise experimental data of β-decay energies of short-lived fission products are needed to check the accuracy of theoretical mass formulae. An HPGe detector has been recently used for these measurements. An HPGe has two advantages, that is, the energy resolution is excellent and the energy calibration is easily achieved with γ-rays. While the disadvantage is that observed β-spectra are distored, since the pulse height spectrum generated by the monoenergetic electrons, called a response function, is complex. In order to obtain true β-spectra from distorted ones, we need to know response functions which are dependent on the energy. But the response functions of an HPGe detector to electrons have not been investigated sufficiently. This study was designed to measure precise β-ray energies of short-lived fission products at KUR-ISOL[2].

Experimental response functions

Experimental response functions[1] have been done by using the sector type double forcusing β-ray spectrometer at KURRI in order to get monoenergetic electrons. Sources are ^{144}Ce-^{144}Pr and ^{38}Cl. ^{38}Cl sources are prepared by the irradiation of polyvinylidene chloride at KUR. The HPGe detector with a 0.05 mm Be-window used in this study has a diameter of 16 mm and a depth of 10 mm.

Response functions for energies of 0.91, 1.00, 1.30, 1.82, 2.30 2.70 (with ^{144}Ce-^{144}Pr), 2.82, 3.31, 3.78, 4.25 and 4.45 MeV (with ^{38}Cl) have been obtained. The response function for the incidence energy of 3.31 MeV is shown in Fig. 1. To investigate the energy dependence of response functions, it is assumed that the response function is composed of three parts, namely, A, B and C (shown in Fig. 3). The A and B correspond, respectively, to a full energy peak and to the escape of bremsstrahlung photons generated in the crystal. The C corresponds

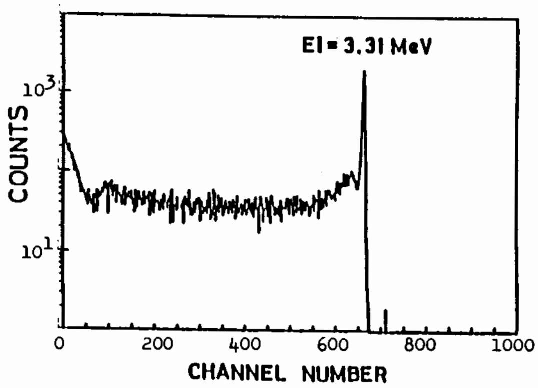

Fig. 1. Experimentally determined response function of an HPGe detector for 3.31 MeV monoenergetic electrons. Total events are about 10^4.

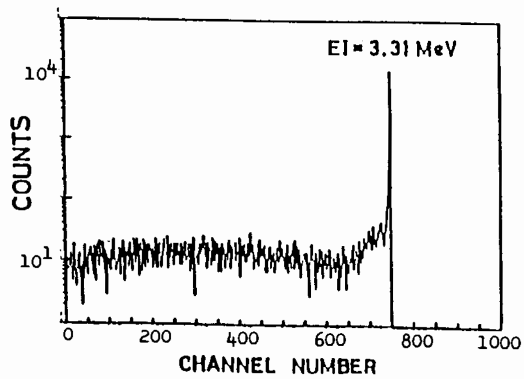

Fig. 2. Calculated response function by a modified HICOAK code for 3.31 MeV electrons. Total events are $3x10^4$.

mainly to the back and side scattering of electrons from the surface of the crystal. The energy dependence of the ratios of B and C to the total counts is shown in Fig. 4.

Calculated response functions

Monte Carlo calculations[3] by a HICOAK code[4] have been done by assuming that the point source emits monoenergetic electrons isotopically. To take accounts of scatterings and energy losses of electrons by the Be-window, a HICOAK code was modified in the present work. Results are shown in Fig. 2 and in Fig. 4 (dashed lines). It is found that Monte Carlo calculations underestimate the ratios of B and C to the total counts.

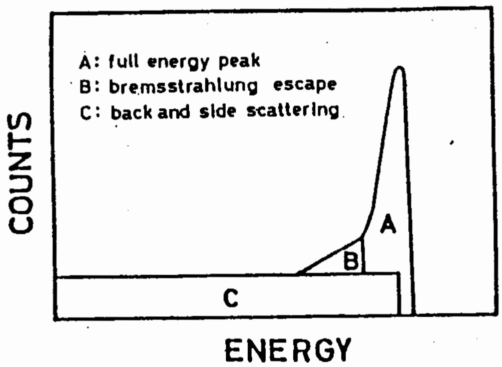

Fig. 3. A schematic diagram of the detector response adopted in this work.

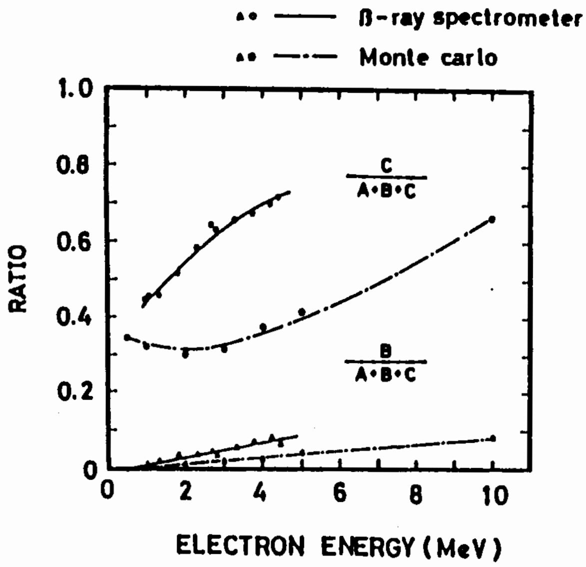

Fig. 4. Energy dependence of response functions. The solid lines represent determined values and the dashed lines represent calculated values by a HICOAK code.

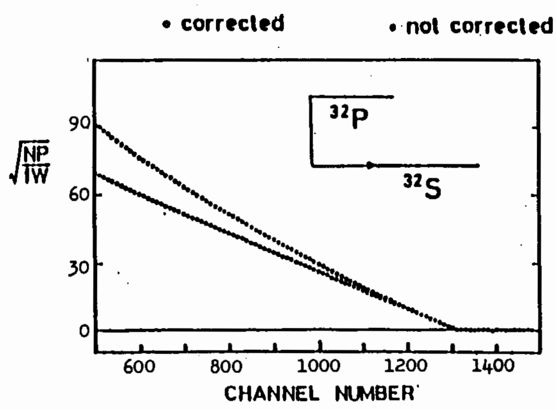

Fig. 5. A Fermi-Kurie plot of singles β-ray spectrum of ^{32}P with a HPGe detector.

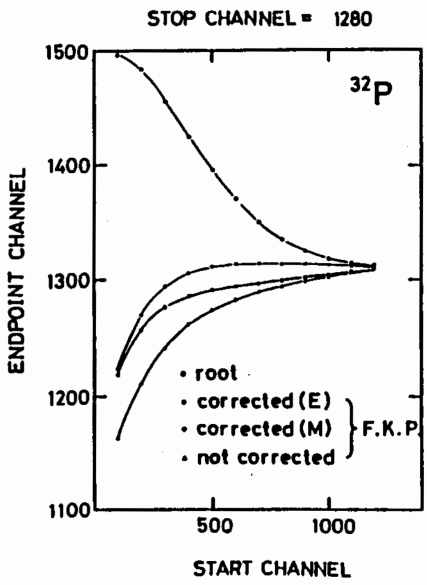

Fig. 6. The effects of changing fitting regions on endpoints for a β-ray spectrum of ^{32}P.

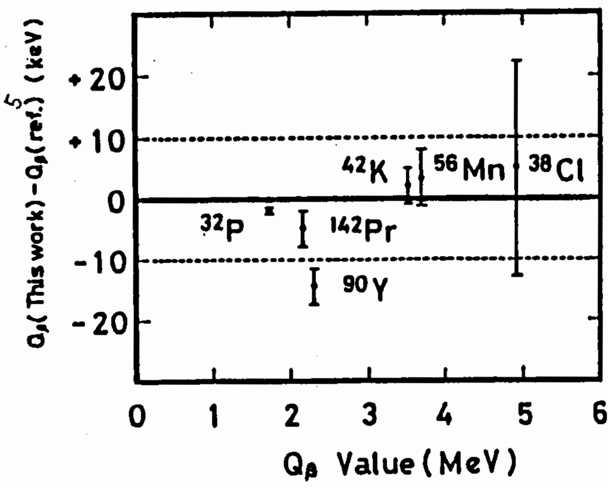

Fig. 7. Systematic error estimation of the present Q_β measurements.

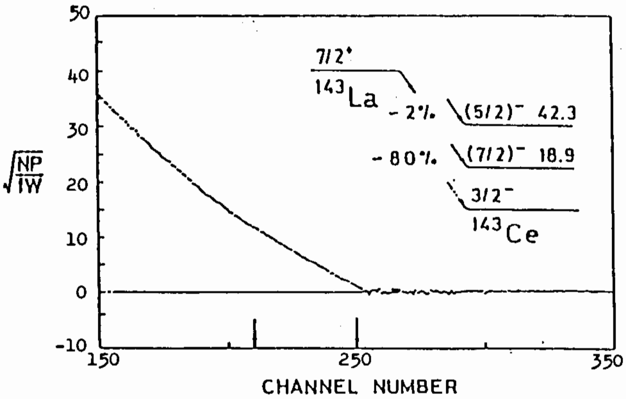

Fig. 8. The Fermi-Kurie plots of ^{143}La.

Results

In order to estimate systematic errors of Q_β measurements, β-rays (^{32}P, ^{142}Pr, ^{90}Y, ^{42}K, ^{56}Mn and ^{38}Cl) whose Q_β-values are known precisely were measured with the HPGe detector. By using experimental response functions, true β-spectra are obtained from distorted ones. Endpoints of β-spectra are determined by a Fermi-Kurie plot. For example, the Fermi-Kurie plot of ^{32}P which is corrected by the experimental response functions is straight, as shown in Fig. 5. In order to investigate the change of the endpoint energy, the start channels in fitting regions of Fermi-Kurie plot of ^{32}P were varied as shown in Fig. 6. It assumed that the stop channels were 1280 ones. The results are shown in Fig. 6. It appears that by using experimental response functions, the Fermi-Kurie plots of β-ray spectrum are almost straight and statistical errors of β-ray endpoints are small. Correcting energy losses to the Be window, Q_β-values are derived. The energy differences between obtained and evaluated Q_β-values[5] are shown in Fig. 7. The Q_β-values of these nuclides were obtained with errors within 20 keV.

Experimental response functions above 4.5 MeV were not measured. Ratios of B and C to the total counts obtained by experimental response functions were calculated with least-squares fit. In order to determine high endpoint energies above 4.5 MeV, the obtained fitting curves were extrapolated from 4.5 to 8 MeV. The results analyzed by the extrapolated fitting curves are in good agreement with previous works.

The Q_β-values of $^{91-93}Rb$, ^{94}Y, ^{95}Sr, $^{139-141}Cs$, $^{142-145}La$, $^{145,146}Ce$ and ^{146}Pr have been measured in the present work. Fission products of these nuclides were ionized and separated by KUR-ISOL . Energy calibration was achieved up to 6 MeV with γ-rays of a ^{56}Co source and with neutron capture γ-rays of ^{56}Fe that are background γ-rays at the reactor room. The Fermi-Kurie plot of ^{143}La is shown in Fig. 8. The Q_β-value of ^{143}La was determined to be 3416 ±13 keV. The experimental results obtained in this study are summarised in Table 1. Theoretical Q_β-values calculated by Tachibana et al. are given in column 4 for comparison. The obtained Q_β-values are in agreement with the previous data within experimental errors. As satisfactory statistics were achieved in the Q_β measurements of ^{143}La, ^{145}Ce and ^{146}Ce, these Q_β-values were obtained with errors within 20 keV.

Table 1. Experimental Q_β-values

Nucleus	This work	T.R.I[7]	Ref.6
^{91}Rb	5837(76)	5867(7)	5690
^{92}Rb	8082(110)	8120(12)	8340
^{93}Rb	7441(95)	7443(13)	7080
^{94}Y	4920(43)	4920(5)	5670
^{95}Sr	6103(60)	6120(60)	5950
^{139}Cs	4189(33)	4213(5)	4260
^{140}Cs	6210(50)	6218(13)	6390
^{141}Cs	5170(47)	5256(14)	5320
^{142}La	4520(36)	4517(6)	4560
^{143}La	3416(13)	3290(50)	3460
^{145}La	4041(108)	4120(90)	4280
^{145}Ce	2538(11)	2530(50)	2560
^{146}Ce	1114(11)	1020(60)	1120
^{146}Pr	4108(68)	4150(70)	4110

Summary

Response functions of an HPGe detector on the energy region from 0.91 to 4.45 MeV have been investigated by experiments and Monte Carlo calculations. By using experimental response functions, the precise Q_β-values of $^{91-93}Rb$, ^{94}Y, ^{95}Sr, $^{139-141}Cs$, $^{142-145}La$, $^{145,146}Ce$ and ^{146}Pr were obtained. It was found that Q_β-values could be determined with an accuracy of 20 keV.

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