Determination of absolute gamma-ray emission probabilities for ^{88}Kr

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Abstract In preparation of homogeneous ^{88}Kr and ^{88}Rb sources, the ^{88}Kr activity was determined by the decay relationship between ^{88}Kr and ^{88}Rb using an HPGe detector. The peak efficiencies of ^{88}Kr and ^{88}Rb γ-rays were calibrated. The results show that the absolute probabilities of 196.3, 834.8,1529.8, 2195.8 and 2392.1 keV γ-rays of ^{88}Kr were 25.1(5)%, 12.9(2)%,10.7(2)%,13.3(2)% and 34.9(5) %, respectively.

Key words Kr-88 and Rb-88, Gamma-ray emission probability, Decay relationship, Activity, Peak efficiency

1 Introduction

Gamma-ray emission probability is of importance for studying nuclear-reaction products or radioisotope applications. By emitting beta-rays, ^{88}Kr decays to ^{88}Rb with a half-life of 2.84 h, while ^{88}Rb emits also beta-rays and decays with a half-life of 17.78 min[1].

As ^{88}Kr is a gaseous radioisotope of short half-life, it is difficult to determine its absolute γ-ray emission probability with routine methods. Recently, in preparation of homogeneous sources of ^{88}Kr and ^{88}Rb[2], we obtained the ^{88}Kr activity by using the decay relationship between ^{88}Kr and ^{88}Rb. After calibrating γ-ray efficiency of the HPGe detector with a group of standard sources, the ^{88}Kr absolute γ-ray emission probabilities were determined.

2 Methodology

2.1 Activity of ^{88}Kr

The ^{88}Kr activity was measured in the following ways. Assuming an initial activities of $A_{0\text{Rb}}$ and $A_{0\text{Kr}}$ respectively for ^{88}Rb and ^{88}Kr when the gases were filled into the source boxes, the full-energy peak area of ^{88}Rb γ-rays at T time, $N_\gamma(T)$, is

$$N_\gamma(T) = \varepsilon P \frac{T_\text{L}}{T_\text{R}} \int_T^{T+T_\text{R}} [A_{0\text{Rb}} \text{e}^{-\lambda_2 t} + \frac{\lambda_2}{\lambda_2 - \lambda_1} A_{0\text{Kr}} (\text{e}^{-\lambda_1 t} - \text{e}^{-\lambda_2 t})] \text{d}t \tag{1}$$

where ε is full-energy peak efficiency of ^{88}Rb γ-rays; P is emission probabilities of ^{88}Rb γ-rays (P =22.7% at 1836 keV)[3]; λ_1 and λ_2 are decay constants of ^{88}Kr and ^{88}Rb, respectively; T_R is real (elapsed) time of the count; and T_L is live time of the count.

Eq.(1) can be transformed into

$$\frac{N_\gamma(T)\text{e}^{\lambda_2 T}}{T_\text{L}\varepsilon P} \frac{\lambda_2 T_\text{R}}{1-\text{e}^{-\lambda_2 T_\text{R}}} = A_{0\text{Rb}} + \frac{\lambda_2}{\lambda_2 - \lambda_1} A_{0\text{Kr}} (\frac{1-\text{e}^{-\lambda_1 T_\text{R}}}{1-e^{-\lambda_2 T_\text{R}}} \frac{\lambda_2}{\lambda_1} \text{e}^{(\lambda_2 - \lambda_1)T} - 1) \tag{2}$$

Eq.(2) can be written as

$$y = A_{0\text{Rb}} + A_{0\text{Kr}} x \tag{3}$$

$$x = \frac{\lambda_2}{\lambda_2 - \lambda_1} (\frac{1-\text{e}^{-\lambda_1 T_\text{R}}}{1-\text{e}^{-\lambda_2 T_\text{R}}} \frac{\lambda_2}{\lambda_1} \text{e}^{(\lambda_2 - \lambda_1)T} - 1)$$

$$y = \frac{N_\gamma(T)\text{e}^{\lambda_2 T}}{T_\text{L}\varepsilon P} \frac{\lambda_2 T_\text{R}}{1-\text{e}^{-\lambda_2 T_\text{R}}}$$

Therefore, measuring the γ-ray spectra with an HPGe detector in different time intervals, the activity of ^{88}Kr can be obtained by applying the least square method to Eq.(3).

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2.2 Gamma-ray emission probabilities of ^{88}Kr

Gamma-ray emission probabilities of ^{88}Kr can be determined by Eq.(4)

$$P = \frac{N_{\gamma \mathrm{Kr}}}{\varepsilon_\gamma A_{0\mathrm{Kr}} T_\mathrm{L}} \frac{\lambda_1 T_\mathrm{R}}{(1 - \mathrm{e}^{-\lambda_1 T_\mathrm{R}})} \mathrm{e}^{\lambda_1 T} \quad (4)$$

where $N_{\gamma\mathrm{Kr}}$ is the full-energy peak areas of ^{88}Kr γ-rays and ε_γ is the peak efficiency of ^{88}Kr γ-rays.

3 Results and discussion

3.1 Measurement system

The HPGe gamma spectrometer system mainly consists of a coaxial type HPGe with a 60% relative efficiency, a digital multichannel analyzer and a computer. FWHM of the HPGe detector is 1.9 keV at 1332 keV of ^{60}Co. The radiation sources were placed at 25 cm from the HPGe detector.

3.2 Preparation of the homogeneous sources

Homogeneous radiation sources (Fig.1) were full of granules of stearic acid ($C_{18}H_{36}O_2$) which can assure, especially at 25 cm from the HPGe detector, that the ^{88}Kr and ^{88}Rb are homogenous in the source box. The ^{88}Kr gas was obtained by irradiating U_3O_8(90%^{235}U) filled in a quartz glass ampoule. Details of the source preparation can be found elsewhere[2]. Seven U_3O_8 targets were irradiated, and seven homogeneous sources were prepared.

Fig.1 Photoes of the homogenous source.

3.3 Calibration of peak efficiency

The solution of calibration sources of ^{56}Co, ^{57}Co, ^{133}Ba, ^{134}Cs, ^{152}Eu, ^{182}Ta, ^{60}Co and ^{24}Na were put into the liquid source boxes, which are of the same shape and materials as the homogeneous source boxes, and the activity of calibration sources were determined by the standardized measurement system. Fig.2 shows the peak efficiency curve of HPGe detector at 25 cm from the detector. The peak efficiencies of ^{88}Kr γ-rays and ^{88}Rb were obtained by intercepting the peak efficiency curve (Fig.2), and the results are listed in Table 1.

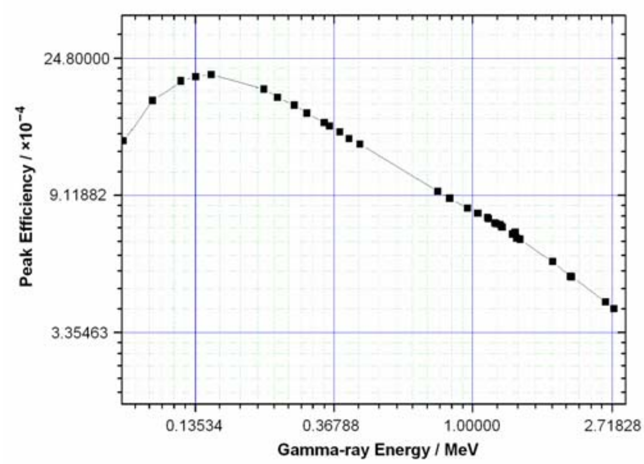

Fig.2 Peak efficiency curve of the HPGe detector.

Table 1 Peak efficiencies of ^{88}Kr and ^{88}Rb γ-rays in the solution source box.

Energy / keV	Peak efficiency / 10^{-4}	Nuclides
196.3	20.8	^{88}Kr
834.8	9.10	^{88}Kr
1529.8	6.28	^{88}Kr
2195.8	4.79	^{88}Kr
2392.1	4.50	^{88}Kr
1836.0	5.52	^{88}Rb

3.4 Correction of the self-absorption effect

The activity of ^{88}Kr was determined by measuring the homogeneous sources with HPGe detector, and the peak efficiencies of ^{88}Kr and ^{88}Rb γ-rays were calibrated by the standardized sources. Because density of the solution is larger than the granules of stearic acid, the peak efficiencies in Table 1 should be corrected with self-absorption coefficients so as to determine the emission probabilities of ^{88}Kr γ-rays Ref.[4] gave detailed method of self-absorption correction for fission gaseous radioisotopes, and the reliability of the method was validated experimentally. The corrected peak efficiencies of ^{88}Kr and ^{88}Rb γ-rays in the homogeneous sources are given in Table 2.

Table 2 Peak efficiencies of gamma-ray for ^{88}Kr and ^{88}Rb in the homogeneous source box

Energy / keV	Correction coefficients for self-absorption effect	Efficiencies / 10^{-4}
196.3	1.033	21.5
834.8	1.020	9.28
1529.8	1.015	6.37
1836.0	1.014	5.60
2195.8	1.012	4.85
2392.1	1.012	4.55

3.5 Activity of ^{88}Kr

By measuring the seven homogeneous sources with the HPGe system and calculating the data using Eq.(3), the ^{88}Kr activity was determined by the least square method. Table 3 gives the ^{88}Kr activity, and Fig.3 gives a linear fitting.

Table 3 Activity of ^{88}Kr(Bq)

No.	Measurement duration / hours	$A_0(^{88}Kr)$ / 10^5	Correlative coefficient of linear-fitting
1	4.1	2.93	0.999
2	3.8	4.92	0.999
3	0.7	2.28	0.999
4	2.2	0.86	0.999
5	1.1	0.60	0.999
6	3.3	5.37	0.999
7	4.2	5.75	0.999

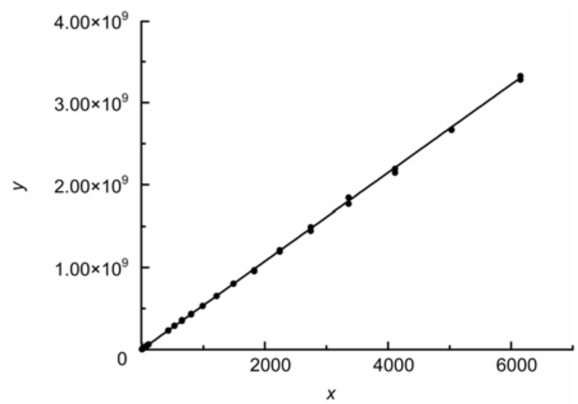

Fig.3 Fitted activity of ^{88}Kr.

3.6 Emission probabilities of ^{88}Kr γ-rays

Applying the counting rate of ^{88}Kr γ-rays and data in Tables 2 and 3 to Eq.(4), the emission probabilities were calculated as 25.1±0.2, 12.9±0,1, 10.7 ±0.1, 13.3 ±0.1, and 34.9±0.1, for ^{88}Kr γ-rays of 196.3, 834.8, 1529.8, 2195.8 and 2392.1 keV, respectively.

The uncertainties are of just statistical sources. They are small compared with systematic uncertainties, which were estimated at 1.0% from the efficiency calibration, 0.5% from the self-absorption correction, and 1.0% from the nuclear parameters, such as the half-life and emission probability of the 1836 keV ^{88}Rb γ-ray.

Combining all these uncertainties, the absolute emission probabilities were 25.1(5)%, 12.9(2)%, 10.7(2)%, 13.3(2)% and 34.9(5)% for of ^{88}Kr γ-rays of 196.3, 834.8, 1529.8, 2195.8 and 2392.1 keV, respectively. The results are compared with Ref.[1] in Table 4.

Table 4 Comparison between the present work and Ref.[1]

Energy / keV	Emission probabilities / %		Relative deviation
	Present work	Ref.[1]	
196.3	25.1(5)	26.0(12)	3.79%
834.8	12.9(2)	13.0(6)	0.70%
1529.8	10.7(2)	10.9(5)	2.25%
2195.8	13.3(2)	13.2(6)	-0.45%
2392.1	34.9(5)	34.6(16)	-0.94%

References

1 Richard B. Firestone, S.Y. Frank Chu Virginia S. Shirley. Table of isotopes (8th Edition), Lawrence Berkeley National Laboratory (University of California), 1998.

2 Chen Z Y, Xie F, Wang X H. J Radioanal Nucl Chem, 2007, **273:** 257−261.

3 Miyahara H, Yoshida A, Wurdiyant G. Appl Radiat Isot, 2002, **56:** 163−167.

4 Xie F, He X B, Bao M. Atom Energy Science and Technology, 2010, **44:** 1153−1156.