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RELATIVE INTENSITY CALIBRATION OF A Ge(Li) GAMMA-RAY SPECTROMETER*

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Abstract

Portions of the gamma-ray spectra of ^{182}Ta and ^{180m}Hf have been remeasured with a Ge(Li) spectrometer system to determine accurate relative intensities. For ^{182}Ta the eleven strongest transitions in the energy range of 100-1300 keV were measured. The $I_\gamma(443)/I_\gamma(501)$ relative gamma-ray branch in ^{180m}Hf was remeasured to be 5.70 ± 0.15. The intensity values derived from these measurements are recommended for use with a IAEA standard intensity set in the calibration of relative photopeak efficiencies for Ge(Li) detectors. An overall accuracy of ±4 % for the relative intensity calibration over the energy range of 100-1300 keV can be expected and ±3% for the 500-2800 keV energy range.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

1. Introduction

The development of energy calibration standards for Ge(Li) detectors has advanced to a state where many standards in the energy range of 60-2800 keV are determined with errors of less than 0.1 keV. However, the absolute or relative gamma-ray intensities of these standards are often uncertain by as much as 5 %. In a few exceptional cases relative intensity determinations have been performed with errors of less than 2 % by careful consideration of gamma-ray cascades corrected for internal conversion[10]). The criteria of either simple cascades with no cross-over transitions or highly accurate decay schemes place a severe restriction on both the availability and on the use of absolute transition intensities for intensity calibrations. However, relative transition intensities for complex decay schemes can be determined accurately, and these data are generally more easily applied.

It is the purpose of this paper to suggest ^{182}Ta and ^{180m}Hf as isotopes spanning the energy range of 100-1300 keV to supplement the IAEA[1]) or similar standard intensity source sets for relative photopeak efficiency determinations of Ge(Li) detectors. Relative intensity measurements have been performed on ^{182}Ta in the energy range of 100-1300 keV and are compared with others[3,4,23]). The absolute gamma-ray intensities for ^{180m}Hf are presented and compared with values reported in the literature[10,30,33]) based upon the remeasured $I_\gamma(443)/I_\gamma(501)$ gamma-ray branching ratio. Relative intensity values for isotopes are included in the tables in order to collect the best sets of data necessary to calibrate Ge(Li) detectors over the energy range of 100-2800 keV to ±4 %.

2. Experimental

The 115.1d ^{182}Ta was produced in the Berkeley Research Reactor by irradiation of 1.0 and 0.5 mil foils of natural Ta (99.9877% ^{181}Ta)[2]) which has a large thermal neutron cross-section of 21 barns. The small 0.07 barn cross-section to produce the 16.5 m ^{182m}Ta did not interfer after a short decay period following irradiation. The intensities of the eleven strongest gamma-rays were measured on a calibrated 10-cm^3 Ge(Li) detector. This detector had been calibrated with two sets of absolute intensity sources obtained from the IAEA. ^{180m}Hf was also used to define the efficiency curve in the critical 100-335 keV region. The accuracy of the photopeak efficiency determination was checked by measuring several radioisotopes whose relative intensities are known[10,11]) to 2%. These measured intensities agreed to 3% with those in Kane and Mariscotti[10]) and Donnelly et al.[11]). The efficiency curve for the 10-cm^3 detector obtained in this way is shown in fig. 1. The detector resolution ranged from 1.4 keV at 122 keV to 2.3 keV at 1332.5 keV. The areas of photopeaks were determined using two separate computer codes, SAMPO[6]) and SPECT[7]), which use gaussian functions with exponential tails to approximate the experimental photopeak shapes. Photopeak areas from the codes agreed to within 1% in the selected peaks. Measurements of photopeak intensities were made for each of the two ^{182}Ta foils which were corrected for attenuation[45]) due to source thickness, and these were verified with an isotopically separated ("mass free") source. The results are given in Table 1 and are compared to other results[4,5,24]).

The measured ^{182}Ta relative intensities should be accurate to 3% over the energy range of 100-1300 keV. Previously, Edwards et al.[4]) quoted errors

of 4-5% over the energy range of 100-264 keV. White et al.[5]) measured the relative intensities of ^{182}Ta gamma-rays in the energy range of 152-1300 keV with errors of 4-5%. Over the smaller energy range of 1000-1300 keV, errors quoted were in the range, 1.5-2 %.

^{180m}Hf was produced by reactor irradiation of the separated isotope ^{179}Hf. ^{180m}Hf is very convenient[10,11]) in the energy region between 93-501 keV where calibration points for efficiency curves are sparse. The decay scheme[31,33]) of ^{180m}Hf (fig. 2) allows absolute gamma-ray intensities to be derived by correcting for internal conversion if the $I_\gamma(443)/I_\gamma(501)$ gamma-ray intensity branching is accurately known. With reference to fig. 2 and the ^{180m}Hf decay scheme the following equations apply.

$$I_t(93) = I_t(215) = I_t(332) = I_t(443) + I_t(501) \qquad (1)$$

$$I_t(443) = I_t(501) = (1 + \alpha(443))I_\gamma(443) + (1 + \alpha(501))I_\gamma(501) \qquad (2)$$

I_t and I_γ are the transition and gamma intensities, respectively; α is the total internal conversion coefficient. The $I_\gamma(443)/I_\gamma(501)$ relative gamma-ray branch was measured to be 5.70 ± 0.15 on the above detector in agreement with ref. 31. The mixing ratio of 3.5% M2 and 96.5% E3 reported by Bodenstedt et al.[34]) for the 500.7 keV transition was used in calculating absolute gamma intensities from the transition intensities of eq. (1). The other transitions are of E2 multipolarity. Theoretical conversion coefficients used were those of Hager and Seltzer[35]). The calculated absolute gamma-intensity results obtained from eq. (1) are shown in Table 2 with other results[10,30,33]). Included are the 93.3 and 500.7 keV transitions not given by ref. 10. The calculated 14.5 ± 0.4%

for the 500.7 keV transition is in agreement with the values ~ 15% given by Gvozdev et al.[37]) and 14.8 ± 0.8% of Goldhaber and McKeown[31]) and Paul et al.[32]).

Table 3 shows the intensity values used for the IAEA calibrated set and ^{24}Na. The intensity values are those recommended by the IAEA. They are given to collect the necessary intensity values, along with the ^{182}Ta and ^{180m}Hf, into one paper to be used for the efficiency calibration of Ge(Li) spectrometer systems. ^{24}Na is also listed since it is useful for extending the curve to higher energies.

3. Conclusions

The ^{182}Ta intensities determined in this work were used to derive the relative photopeak efficiency curve of a 40-cm^3 coaxial detector together with ^{180m}Hf, ^{24}Na, and the IAEA calibrated set for which the results are shown in fig. 3. A third detector has been recently calibrated[9]) at this laboratory using this method and showed similar results. These isotopes and intensity values, when combined with the IAEA intensity sources and ^{24}Na, should determine the relative photopeak efficiency of Ge(Li) spectrometers to ±4% over the energy range of 100-500 keV and ±3% over the energy range of 500-2800 keV.

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Table 1. Energies and Relative Intensities of ^{182}Ta in Energy Range 100-1300 keV

E_γ [a]	Edwards et al.[4] I_γ [b]	White et al.[5] I_γ [c]	Sapyta et al.[23] I_γ [c]	Present Work I_γ [c]
100.104±0.002	40.2		40.7±4.1	40.2±1.0
152.435±0.003	20.5±0.8	21.3±1.0	19.5±2.0	20.5±0.5
156.387±0.003	8.04±0.4	8.07±0.4	7.5±0.75	7.6±0.2
179.393±0.004	9.2±0.4	9.57±0.5	8.7±0.9	8.8±0.3
222.109±0.005	22.5±0.9	22.6±1.2	21.2±2.1	21.3±0.55
229.322±0.005	11.1±0.5	10.9±0.5	10.5±1.1	10.3±0.3
264.072±0.009	10.8±0.5	10.6±0.4	10.3±1.0	10.1±0.3
E_γ [d]				
1121.298±.013		100.	100.	100.
1189.046±.013		47.4±0.7	46.3±3.2	46.5±0.7
1221.399±.013		79.3±1.2	77.3±5.4	77.3±1.2
1231.010±.013		33.4±0.5	32.7±2.3	32.8±0.5

[a] Energies listed in keV are those reported by Edwards et al.[4])

[b] Intensities[4]) are renormalized to the 100 keV transition of present work

[c] Intensities are normalized to 1121 keV transition

[d] The energies listed in keV are those reported by White and Birkett[3]).

Table 2. Gamma Energies and Absolute Gamma Intensities of ^{180m}Hf in the Range of 57-501 keV

E_γ [a]	I_γ [a]	I_γ [b]	I_γ [c]	I_γ [d]
57.442	47.5±3.4		48.6±0.86	
93.263	18.40±0.16		16.7±0.33	17.47±0.17
215.241	81.1±2.4	81.4	83.4±2.3	81.4±0.8
332.272	94.4±4.0	94.4±0.8	94.4±4.0	94.4±0.9
443.168	84.8	83.0±1.2	81.9±4.3	82.8±1.5
500.702	15.7±1.3		17.05±5.2[e]	14.5±0.4

[a] Gujrathi and D'Auria[30]) results with stated energy errors of ±0.015 keV. The measured gamma intensities were renormalized to 332 keV.

[b] Kane and Mariscotti[10]) renormalized results.

[c] Edwards and Boehm[33]) results using a bent crystal gamma spectrometer.

[d] Present work where ~ 1% error was arbitrarily assigned for the 93, 215, and 332 keV transitions due to uncertainity in the theoretical E2 conversion coefficients.

[e] This was deduced from feeding and not measured directly (ref. 33).

Table 3. Energies and Intensities of the IAEA Standards and ^{24}Na

Isotope	Half-Life[b]	E_γ[a]	I_γ[b]
^{241}Am	432.9±0.8y [38,39]	59.538±0.008	35.9±0.6 [12,13,14,15]
^{57}Co	271.6±0.5d [40]	122.055±0.013	85.0±1.7 [8,16,27,28]
		136.47±0.008	10.65±0.4 [8]
		136.47±0.008	11.4±1.3 [16,27,28]
^{203}Hg	46.8±0.2d [40,41]	72.873±0.001	9.7±0.5 [17,18]
		82.5±0.2	2.8±0.2
		279.186±0.009	81.55±0.15
^{22}Na	2.602±0.005y [40]	511.0041±0.0016	181.1±0.2 [19,20]
		1274.55±0.04	99.95±0.02
^{137}Co	29.90±0.05y [42]	32.1±0.1	5.7±0.2 [12,21]
		36.5±0.1	1.3±0.1
		661.618±0.028	85.1±0.4
^{54}Mn	312.6±0.3d [15,19,43]	834.81±0.03	100.0 [22]
^{60}Co	5.275±0.005y [41,42,44]	1173.231±0.024	99.87±0.05 [23]
		1332.501±0.021	99.999±0.001

(continued)

Table 3. (continued)

Isotope	Half-Life	E_γ [a]	I_γ [b]
^{88}Y	107.4±0.8d [40,43])	898.021±0.023	91.4±0.7 [24,25,26])
		1836.129±0.031	99.4±0.1
^{24}Na	15.00±0.02h	1368.526±0.044	100.0
		2754.098±0.183	100.0

[a]Energy values are adopted values from Jardine[36]).

[b]Intensity and half-life values recommended by Nuclear Data and the IAEA[1]).

Figure Captions

Fig. 1. The relative photopeak efficiency curve for the 10-cm^3 Ge(Li) detector as a function of gamma-ray energy.

Fig. 2. The ^{180m}Hf decay scheme used in the photopeak efficiency determination. The energies (keV) are based on the measurements of Gujrathi and D'Auria[30]). The absolute gamma-ray intensities expressed in per cent from this study are shown in parenthesis.

Fig. 3. The relative photopeak efficiency curve for a 40-cm^3 true coaxial Ge(Li) detector as a function of energy obtained using the isotopes and intensities reported in the study.

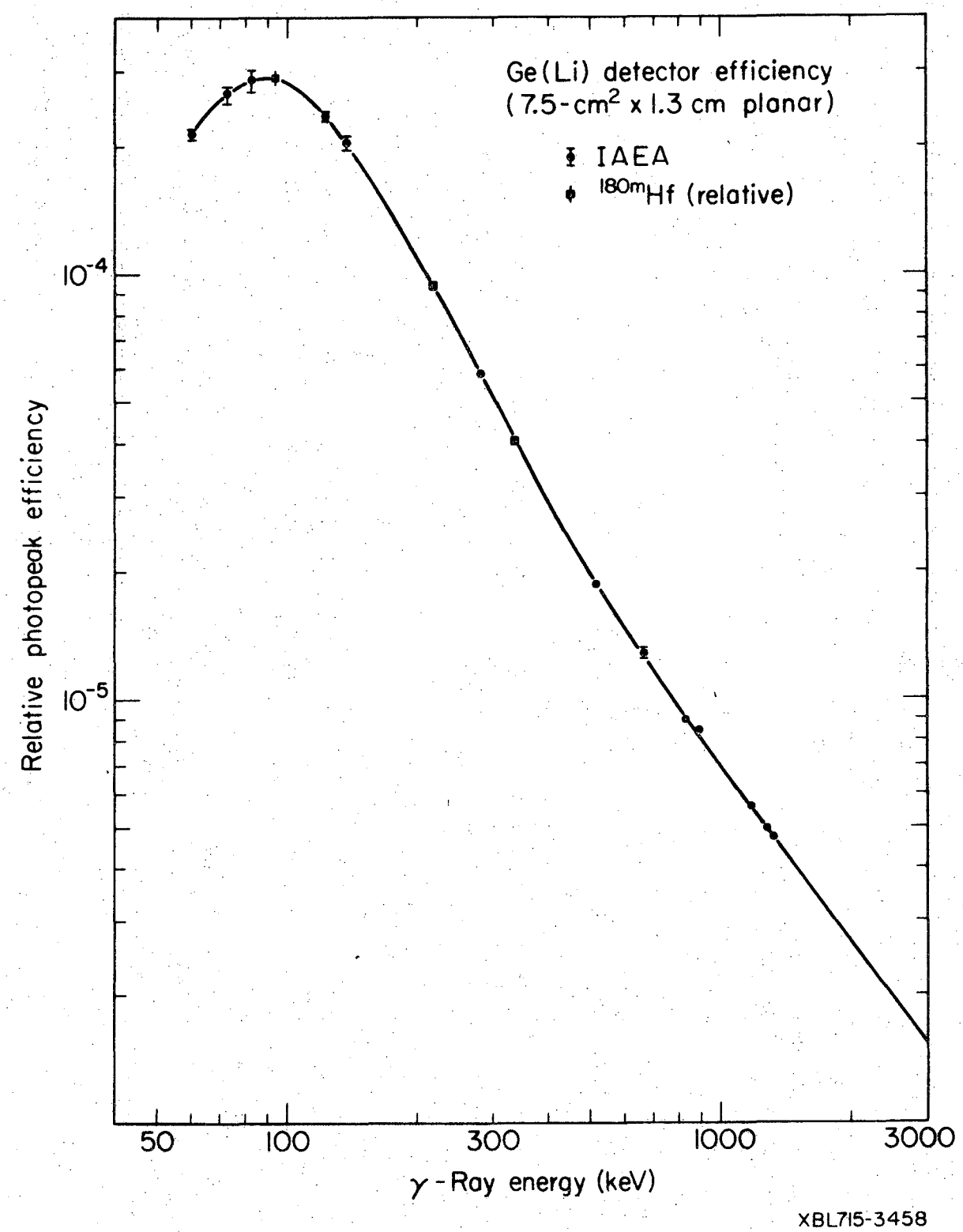

Ge(Li) detector efficiency
(7.5-cm² x 1.3 cm planar)
IAEA
180mHf (relative)
10⁻⁴
10⁻⁵
Relative photopeak efficiency
50
100
300
1000
3000
γ-Ray energy (keV)
XBL715-3458

Fig. 1

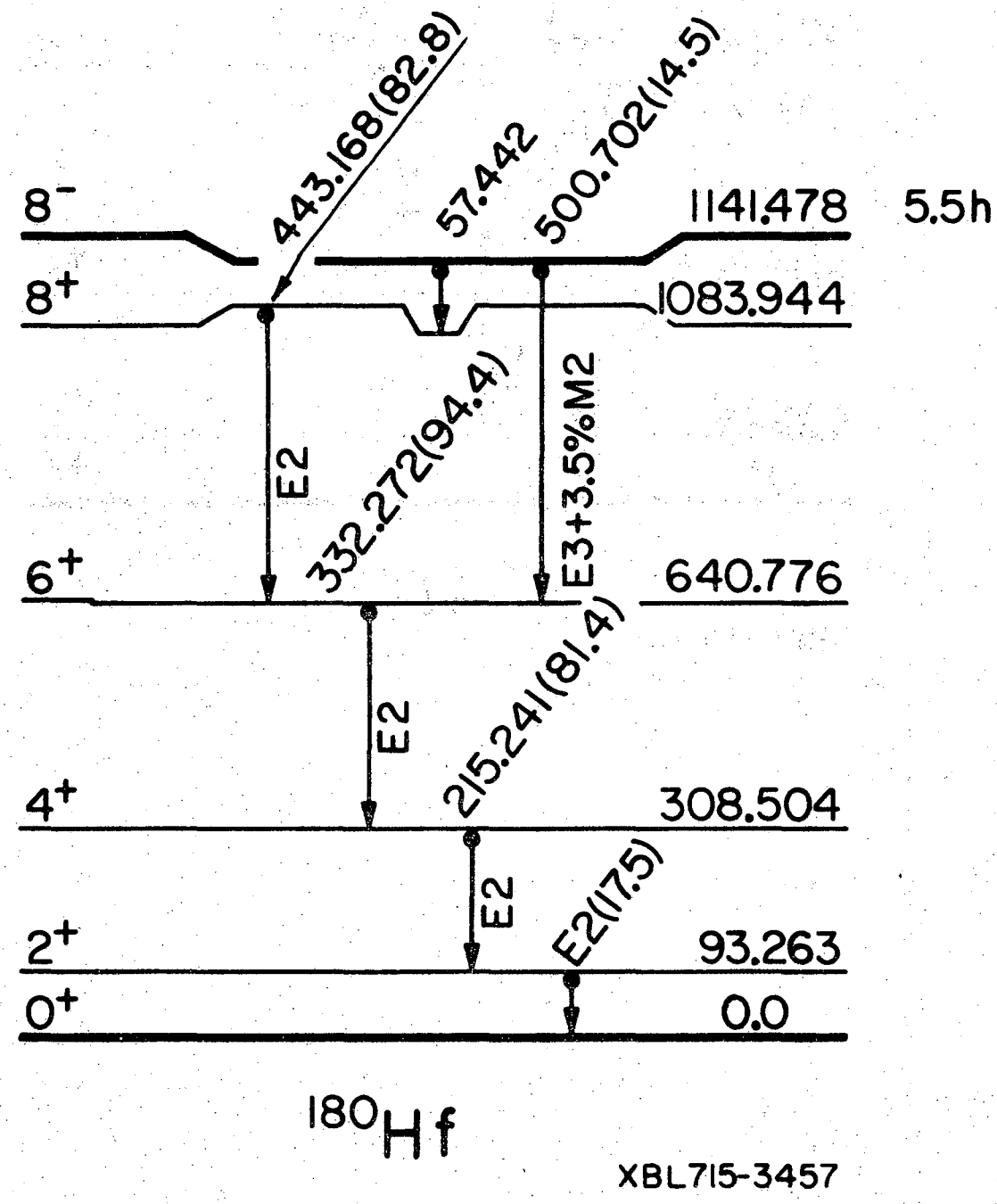
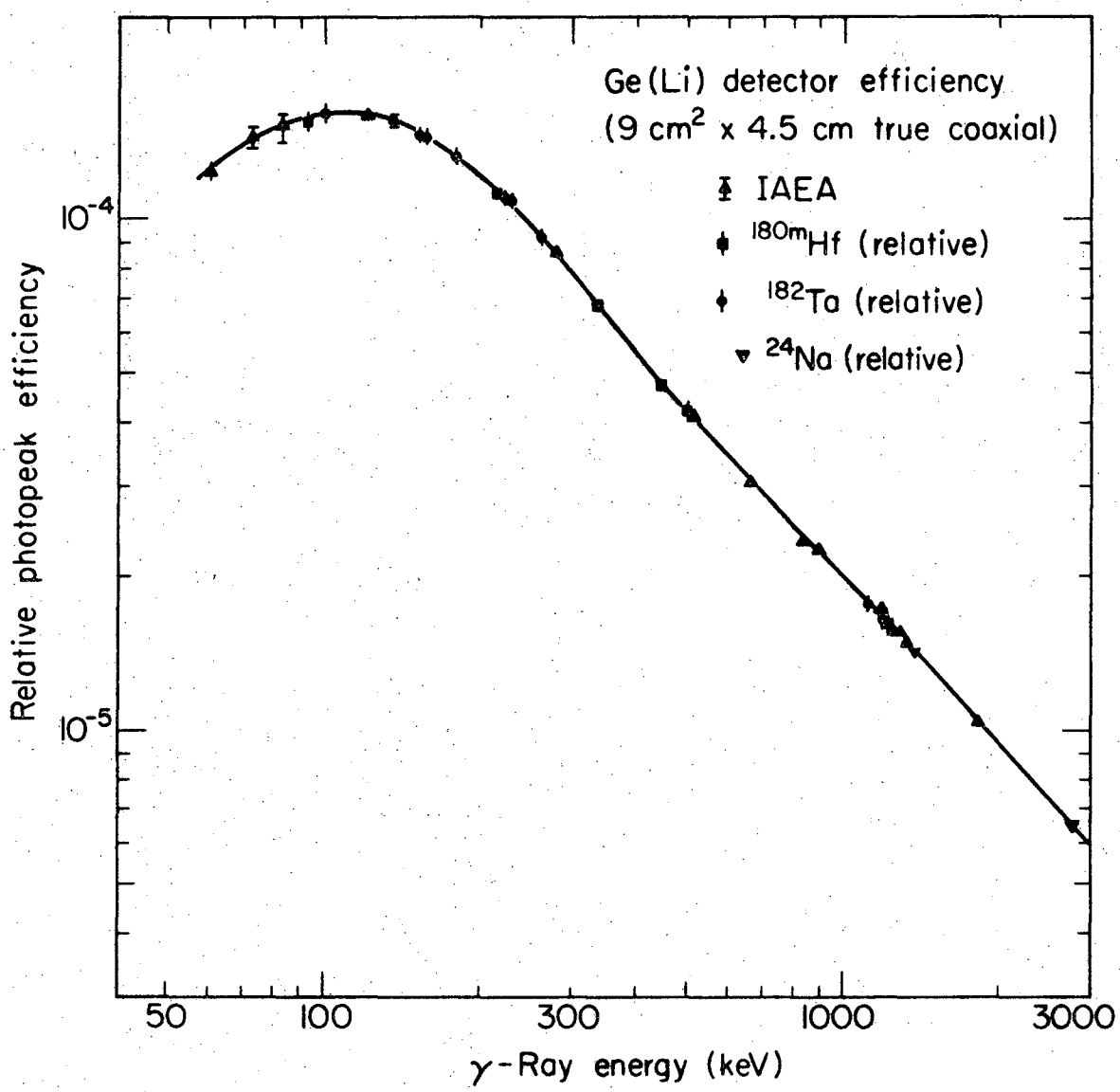

8⁻
8⁺
6⁺
4⁺
2⁺
0⁺
1141.478
5.5h
1083.944
640.776
308.504
93.263
0.0
443.168(82.8)
57.442
500.702(14.5)
332.272(94.4)
215.241(81.4)
E2(17.5)
E2
E3+3.5%M2
E2
E2
180Hf
XBL715-3457

Fig. 2



XBL715-3459

Fig. 3

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