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Energies and Intensities of Gamma Rays Emitted by a ^{226}Ra Source

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ABSTRACT

Energies and intensities of 64 gamma rays emitted by ^{226}Ra and its decay products have been measured for gamma-ray energies between 186 and 2979 keV. The tabulated results are of primary use for efficiency calibration of Ge(Li) detectors.

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I. INTRODUCTION

Efficiency calibration of Ge(Li) gamma-ray detectors requires sources whose disintegration rates are well known and sufficiently strong enough to allow a spectrum to be obtained in a reasonable period. There are several isotopes easily produced yielding gamma rays with energies up to 4.8 MeV. The resulting source strengths may be well calibrated using a detection system of known efficiency. Subsequent later use of the source requires either an experimental recalibration or else a recomputation of the strength from its known half-life. After three or four half-lives, the uncertainty associated with the half-life becomes the dominant uncertainty in the source strength. Probably also the source has become too weak to yield a reasonable count rate. The usual technique for efficiency calibration involves obtaining a few well-defined points (e.g. using ^{137}Cs, ^{60}Co) and then to study a short-lived isotope emitting many gamma rays (e.g. ^{56}Co, ^{66}Ga). The relative intensity function from these sources is then matched to the lower energy absolute values.

There are several good sources having many gamma rays with sufficiently long life times so that an absolute disintegration rate can be obtained and relied upon. These include, e.g. ^{152}Eu($\tau_{1/2}$ = 12y, 122 keV $\leq E_\gamma \leq$ 1770 keV), ThC" (^{228}Th, $\tau_{1/2}$ = 1.91 y, 238 keV $\leq E_\gamma \leq$ 2614 keV), and ^{226}Ra($\tau_{1/2}$ = 1602y, 46.5 keV $\leq E_\gamma \leq$ 3183 keV). The last named provides the best series of strong gamma-ray lines in the energy region between 1400 and 2450 keV. The spectrum obtained from ^{226}Ra has been reported upon by several groups[1] and although the agreement among the reports of the intensities may be sufficient for a study of the nuclear properties of the nuclei involved, there are sufficient discrepancies among reported

values to reduce the effectiveness of the source for calibration purposes. Indeed, a careful study of the spectrum obtained from ^{226}Ra would be of considerable benefit. This report is necessarily of a preliminary nature; however, the present results do not agree well with prior reported work, at least not so that efficiency calibrations can be obtained to, say, $\pm 5\%$ accuracy.

II. EXPERIMENTAL DETAILS

The source material ^{226}Ra was obtained from International Chemical and Nuclear Corporation. The source was fabricated by C. E. Bemis at the Transuranium Research Laboratory, Bldg. 5505. (Some care must be exercised in handling of ^{226}Ra because of the gaseous radioactive product ^{222}Rn.) Spectra were obtained using two detectors; (a) the first, shown in Fig. 1, involved a previously calibrated 42 cm^3 detector during a break in a Van de Graaff run studying (n,xγ) reactions; and (b) the second involved a recently repaired diode of nominally 35 cm^3 active volume. The first spectrum was obtained several weeks after the preparation of the source with the intention of obtaining an absolute calibration of the source disintegration rate. The second spectrum was obtained about six weeks later with efficiency calibration of the smaller diode as the goal. Although neither spectrum was obtained with the intention of studying the source in detail, it became evident that for both diodes the individual gamma-ray intensities observed were not in as good agreement with prior results as expected. Either the previous calibration of the 42 cm^3 detector was not as accurate as believed, or else the previously reported gamma-ray intensities in ^{226}Ra are in error.

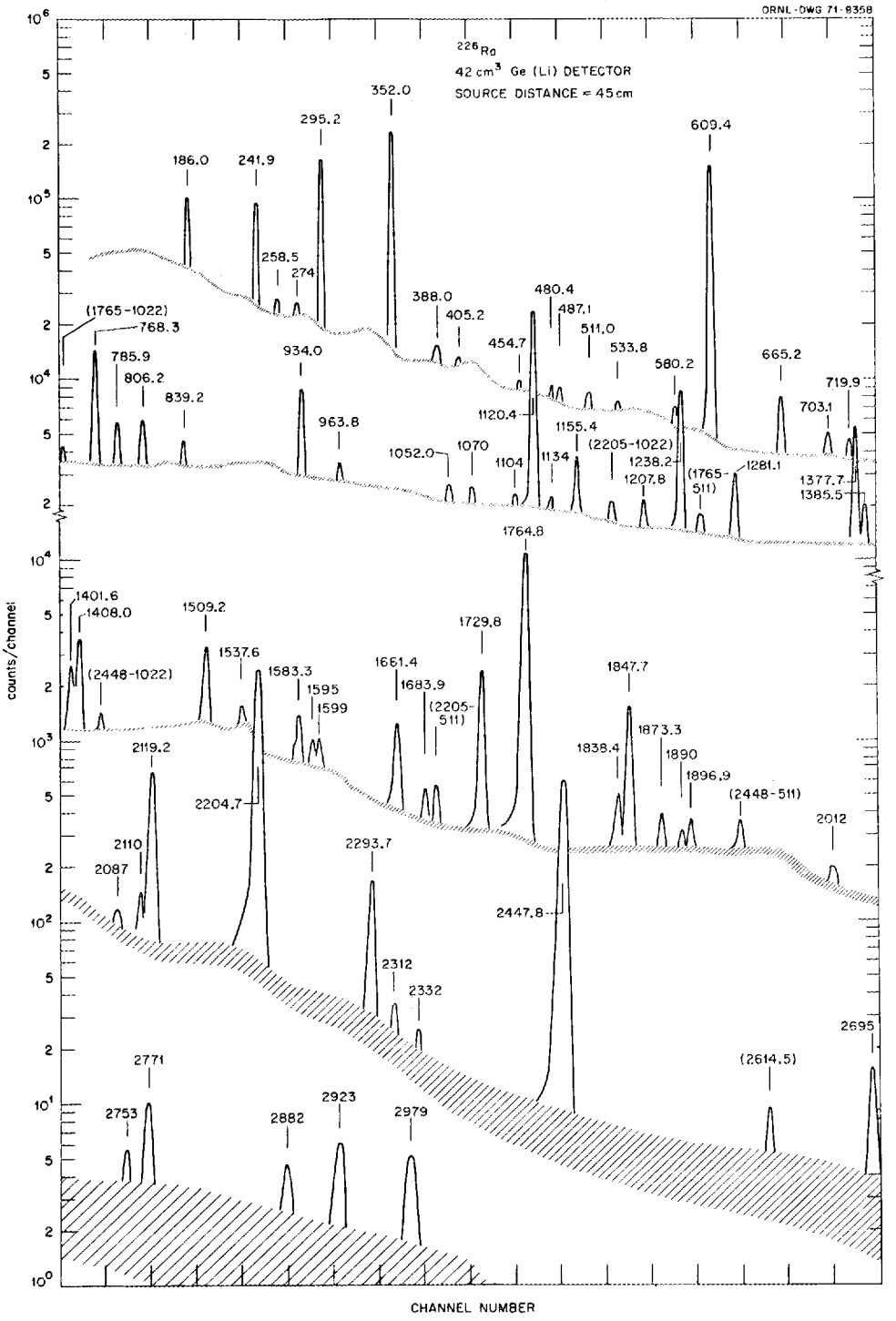

Fig. 1. Spectrum of gamma rays emitted by ^{226}Ra. The source strength is ~ 10 μcuries and the total counting time was ~ 15 hours.

The calibration of the 42-cm^3 detector had been carried out previous to the Van de Graaff run in a manner discussed above. Sources of well-known strength (IAEA, 1971) were used to obtain calibration points from 59 to 1836 keV for source-detector distance of 45 cm. The overall uncertainty of the activities are quoted from $\pm$ 0.6% to $\pm$ 1.3%. The calibration points for E_γ between 279 and 1836 keV follow very well an analytic representation of the efficiency of the form

$$\text{eff} = k\ E_\gamma^{-x}. \qquad (1)$$

The isotope ^{182}Ta was studied to obtain the low-energy shape of the efficiency curve and the simple expression (1) becomes incorrect for E_γ below ~230 keV. The isotopes ^{66}Ga (produced by 10 MeV proton bombardment of ^{66}Zn) and ^{56}Co were studied to obtain the higher energy shape of the efficiency curve, and the curve deviates from equation (1) for E_γ above ~3.5 MeV. For the range $250 \leq E_\gamma \leq 3500$ keV equation (1) using x = 1.02, the resulting efficiency curve fits all of the IAEA sources and most of the strong lines in the other sources to $\pm$ 3%.

Two methods were used to extract peak areas in the 42-cm^3 detector spectrum of ^{226}Ra. The first method involves displaying the spectrum on a large-screen oscilloscope and "drawing-in" the underlying Compton distribution using a light pen. The basic system has been described previously.[2] The second method utilizes a computer code to estimate and subtract the Compton distribution and then to extract the peak area from the remaining data. The code does not "fit" a Gaussian (or other analytic description) to the data; however, certain requirements are imposed on the data which are related to the basic Gaussian shape. Table 1 presents a comparison between the two methods for some typical peaks. For the

Table 1. Comparison of Peak Extraction Techniques

E_γ	Light-Pen Area	Computer Code Area	% Difference
186	242000	266000	10.
242	302000	306000	1.3
295	625000	628000	0.5
352	992000	990000	0.2
511	10800	11100	3.0
609	686000	684000	0.3
719	5850	5520	5.7
768	58600	58900	0.6
806	13200	12960	1.8
934	30300	30800	1.6
1120	121900	121400	0.4
1238	43200	43100	0.2
1281	10450	10710	3.2
1661	6160	5844	5.2
1765	80400	78900	1.8
1935	861	900	4.8
2204	20280	19520	3.7
2448	5600	5400	3.5

most part the largest variations are associated with relatively small peaks. The very good precision (generally $\leq 1\%$) for the large peaks is very comforting.

Energy calibration used the very well-known energies of the three strong gamma rays associated with the ^{214}Pb decay and assigning E_γ = 609.4 keV to the first-excited state in ^{214}Po. Despite the small nonlinearity in the total detection system, the gamma-ray energies were determined to within a precision limited by the varying resolution of the detection system. Generally, the energy uncertainties in the present results are smaller than previously reported for $E_\gamma < 1.5$ MeV, larger for $E_\gamma > 1.5$ MeV.

The resulting energies and intensities are tabulated in Table 2. The intensity results are compared with previous results[1] in Table 3.

Computing transition probabilities among the levels in ^{214}Bi from the decay of ^{214}Pb, using the present data and tabulated conversion coefficients, indicates that the ground state β decay of ^{214}Pb is about 6% of the total β decay, in agreement with the measured value.[3] The same computation for ^{214}Bi $\rightarrow$ ^{214}Po yields ~17% transition probability to the ground state of ^{214}Po, a value somewhat smaller than 20% previously reported.[3] The rather large value for the 186-keV gamma ray is somewhat puzzling, since the α branching of ^{226}Ra is reported[3] as 5.6%, and the e/γ ratio is ~0.6, the intensity per 100 decays ought to be ~3.5.

Table 2. Gamma Rays Observed in the Decay of ^{226}Ra

Gamma-Ray Energy (keV)	Energy Uncertainty	Intensity (per 100 decays)	Remarks[a]
186.0	0.2	4.70 ± 0.75	
241.9		8.32 ± 0.32	E-standard
258.5	0.1	0.56 ± 0.15	
274		0.50 ± 0.15	Unresolved
295.2		20.7 ± 0.9	E-standard
352.0		39.2 ± 1.2	E-standard
388		0.81 ± 0.09	Unresolved
405.2	0.2	0.14 ± 0.08	
454.7	0.2	0.30 ± 0.08	
480.4	0.2	0.31 ± 0.08	
487.1	0.1	0.43 ± 0.08	
511		0.62 ± 0.12	Unresolved
533.8	0.2	0.28 ± 0.08	
580.2	0.2	0.45 ± 0.08	
609.4		47.5 ± 1.9	E-standard
665.2	0.1	1.58 ± 0.11	High side
703.1	0.1	0.52 ± 0.06	
719.9	0.1	0.48 ± 0.06	
768.3	0.1	5.14 ± 0.25	
785.9	0.1	1.09 ± 0.05	
806.2	0.1	1.23 ± 0.05	
839.2	0.3	0.62 ± 0.09	Low side
934.0	0.1	3.25 ± 0.13	
963.8	0.2	0.35 ± 0.06	High side
1052.0	0.2	0.33 ± 0.06	
1070		0.27 ± 0.08	Unresolved
1104		0.20 ± 0.08	Unresolved
1120.4	0.1	15.1 ± 1.0	
1134		0.29 ± 0.09	Unresolved
1155.4	0.1	1.62 ± 0.09	
1207.8	0.1	0.50 ± 0.06	
1238.2	0.1	6.36 ± 0.24	
1281.1	0.1	1.54 ± 0.14	
1377.7	0.1	4.28 ± 0.25	
1385.5	0.1	.82 ± 0.11	
1401.6	0.2	1.43 ± 0.13	
1408.0	0.1	2.51 ± 0.13	
1509.2	0.1	2.23 ± 0.11	
1537.6	0.2	.66 ± 0.20	High side
1583.3	0.2	.62 ± 0.06	Low side
1595	0.5	.25 ± 0.06	
1599	0.5	.27 ± 0.06	

Table 2 Cont.

Gamma-Ray Energy (keV)	Energy Uncertainty	Intensity (per 100 decays)	Remarks[a]
1847.7	0.2	2.10 ± .18	
1873.3	0.3	.24 ± .05	
1890		.13 ± .06	Unresolved
1896.9	0.4	.17 ± .06	
2087		.10 ± .05	Unresolved
2110	2.	.08 ± .04	
2119.2	0.3	1.22 ± .10	
2204.7	0.3	5.15 ± .26	
2293.7	0.4	.31 ± .04	
2312	1.	.023± .008	
2332	2.	.015± .005	
2447.8	0.3	1.62 ± .08	
2695	2.	.025± .008	
2753	3.	<.01	Contaminant?
2771	2.	.018± .005	
2882	3.	<.01	
2923	3.	.010± .004	
2979	3.	.010± .004	

[a]"Unresolved" implies that the peak was wider than expected for a single gamma ray, and the peak area was extracted for the entire group.

"Low Side" and "High Side" imply that the peak exhibited a tail, either on the low side or the high side, which did not affect the energy determination, and was not included in peak-area extraction.

Table 3. Comparison of Intensities of Principle Gamma Rays from a ^{226}Ra Source

Energy	Wallace & Cooke	Lingeman *et al.*	Present Results
186	9.91 ± 0.31	9.1	9.9 ± 1.6
242	19.33 ± 0.30	18.2 ± 2.0	17.5 ± 0.7
295	47.84 ± 0.91	45.3 ± 4.7	43.6 ± 1.9
352	87.2 ± 1.9	84.8 ± 9.3	82.6 ± 2.5
609	100.	100.	100.
768	9.90 ± 0.21		10.8 ± 0.5
934	6.26 ± 0.18	7.25 ± 0.70	6.85 ± 0.27
1120	31.90 ± 0.73	35.1 ± 3.5	31.8 ± 2.1
1238	12.77 ± 0.12	14.2 ± 1.4	13.4 ± 0.5
1378	8.70 ± 0.48	10.0 ± 1.2	9.0 ± 0.5
1730	6.94 ± 0.20	7.5 ± 0.9	7.05 ± 0.63
1765	35.34 ± 0.10	39.0 ± 3.8	34.8 ± 1.0
2119	2.76 ± 0.13	3.05 ± 0.35	2.57 ± 0.21
2205	11.22 ± 0.47	12.4 ± 1.2	10.85 ± 0.55
2448	3.32 ± 0.06	3.85 ± 0.40	3.42 ± 0.17

3. CONCLUSIONS

^{226}Ra should be a reliable, long-lived source of generally well-separated gamma rays useful for detector efficiency calibration. The source should be studied more carefully to obtain high precision intensities and energies. If the opportunity arises (and my detectors are repaired) I shall redo the study with this objective in mind.

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