NUCLEAR INSTRUMENTS AND METHODS 69 (1969) 330–334; © NORTH-HOLLAND PUBLISHING CO.

EXPERIMENTAL PEAK/TOTAL RATIOS FOR A FEW NaI(Tl) CRYSTAL SIZES

U. C. MISHRA and S. SADASIVAN

Air Monitoring Section, Bhabha Atomic Research Centre, Trombay, Bombay, India

Received 7 January 1969

The ratios of full energy peak/total counts (peak/total ratios) for five different sizes of NaI(Tl) crystals have been experimentally determined for point sources. Brief description of the experimental set up and estimation method is given. The results have been compared with theoretical and/or experimental values reported by others, where available. The usefulness of the data has been discussed. The sources of error and their implications have also been included.

1. Introduction

The two important parameters in the use of NaI(Tl) crystals as detectors for gamma-ray spectrometry work are the total or absolute efficiency and the photopeak efficiency. The total efficiency for different crystal sizes and energies have been calculated by several authors[1–4]. The values are found to agree with the experimental values. However, the quantity required more often for spectrometric measurement of isotopes from complex gamma spectra is the full energy peak (commonly called as photopeak) efficiency. This can be obtained if peak/total ratios are available because as explained earlier, either total efficiency will be available or can easily be calculated. It is difficult to calculate full energy peak efficiency or peak/total ratio since it involves detailed computer calculations using Monte Carlo methods[5,6]) and even these theoretical values do not agree with experimental results in most cases. The theoretical values are usually higher than experimental results[7]). Also it is found that theoretical values calculated by Weitkamp[5]) and Miller et al.[6]) for a crystal size of 4″ dia. × 4″ thick are not in agreement, the values reported by Weitkamp being higher, especially at higher energies[8]).

The more reliable approach is, therefore, to measure either the full energy peak or peak/total ratios for different crystal sizes. Several authors[9–13]) have measured peak/total ratios for a few crystal sizes for the energy range usually required by the experimenter. The peak/total ratio measurement has an advantage over full energy peak efficiency measurement in that it is relatively invariant to source-crystal distance[10]).

This paper presents peak/total ratio measurements for five different crystal sizes ranging from 5″ × 4″ to 2″ × 2″ used in this laboratory, for the energy range 0.145 MeV to 2.75 MeV. A brief discussion of our results as well as those of other authors is also given.

2. Experimental set-up and measurement technique

The relevant data about the five different crystal sizes used are given[14]) in table 1. All the crystals are from Harshaw Chemical Company and five of the crystals mentioned are Harshaw Integral line assemblies. The pulses from the photomultiplier are fed to a 256-channel pulse height analyzer[15]) through a cathode follower and a non-overloading linear amplifier respectively. The sources are mounted on a special holder fabricated for the present experiments so that the source height above the crystal can be measured accurately, and the source can be moved up and down along the crystal axis. The sources are as close to point sources as possible and are sandwiched between two 1 mm thick polythene discs to minimize back-scattering. The crystal photomultiplier probe is kept in the centre of a big room 4′ above ground, to reduce contribution from back-scattered radiations.

TABLE 1

Details of the crystals used for peak/total ratio studies.

Crystal dimensions dia. × height	Photo-multiplier	Crystal can and reflector	Resolution for ^{137}Cs (662 keV) (%)
2″ × 2″	Dumont 6292	Al, Al_2O_3	8.8
2.5″ × 2.5″	Dumont 6363	Al, Al_2O_3	7.3*
3″ × 1″	Dumont 6363	Al, Al_2O_3	9.1
3″ × 3″	Dumont 6363	Fe, Al_2O_3	8.3*
3″ × 3″	RCA 8054	Fe, Al_2O_3	8.0*
3″ × 3″	Dumont 6363	Cu, Al_2O_3	9.6
3″ × 3″	Dumont 6363	Al, Al_2O_3	8.6*
5″ × 4″	Dumont 6364	Fe, Al_2O_3	10.3*

* Integral line (Harshaw).

The isotopes used and their details are given in table 2.

The analyzer has a built in live-timer so that at high counting rates dead time corrections are not necessary. All the sources used were of about 1 μCi activity to ensure good counting statistics. The readings were taken for 1, 5, 10, 20 and sometimes for 30 cm distances from the top of the crystal. However, the values reported here are for 10 cm distance only because for the other distances the values are so close to 10 cm values that they fall within the confidence level with which the values are being reported. The reproducibility of all the results is very good and the absolute values of the ratios are accurate to $\pm 5\%$.

TABLE 2

Data about isotopes used for the measurement of peak/total ratios.

Isotope	Gamma energy used for ratio determination	Other gamma energies (MeV)	Beta energies (MeV)*
^{141}Ce	0.145	—	0.44(70%), 0.58(30%)
^{203}Hg	0.279	—	0.21(100%)
^{51}Cr	0.323	—	—
^{85}Sr	0.513	—	—
^{137}Cs	0.662	—	0.52(92%), 1.17(8%)
^{54}Mn	0.835	—	—
^{65}Zn	1.11	0.511 (annihilation)	β^+ 0.325(1.5%)
^{22}Na	1.28	0.511 (annihilation)	β^+ 0.54(89%), 1.83(0.06%)
^{24}Na	2.75	1.37	1.39(100%)

* Emission percentages are given in parentheses.

Fig. 1 gives a typical gamma spectrum of ^{22}Na for a 5″ × 4″ NaI(Tl) crystal. The regions of the spectrum chosen for estimation of the peak counts and total counts are shaded differently. The total counts also include the area under the peak. Since the linearity of the system is extremely good, for estimating the total counts, the channel counts are extrapolated to zero bias channel. The method used for estimating full energy peak counts and total counts is similar to those used by Christaller[7]) and Leutz et al.[9]).

3. Results and discussion

Table 3 gives the results of measurements for various crystals for 10 cm distance. Fig. 2 shows

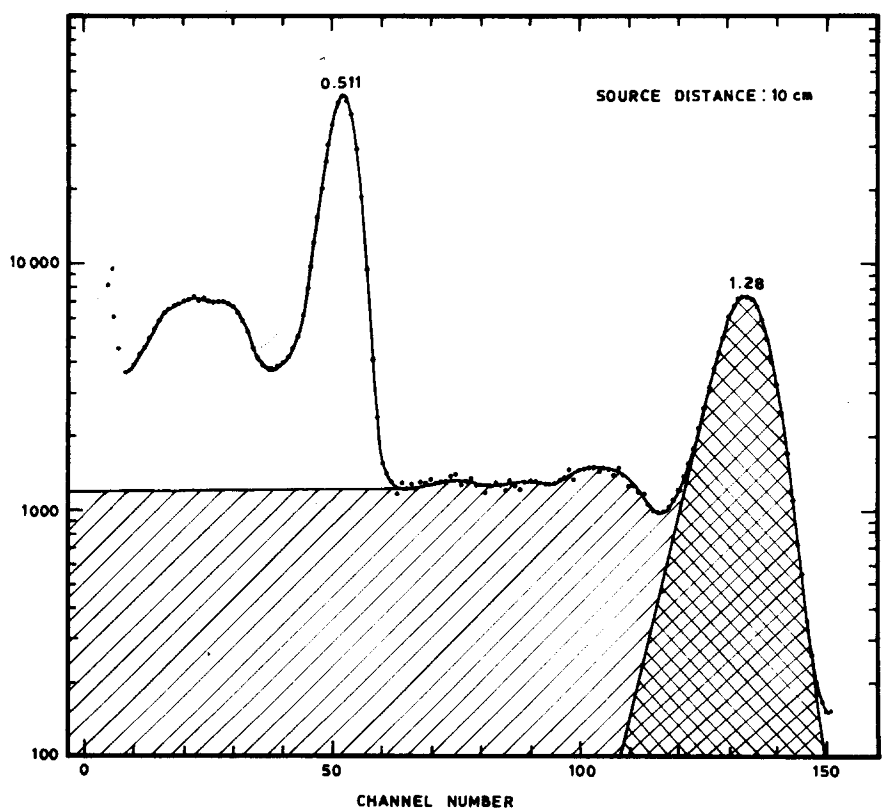

Fig. 1. Gamma spectrum of ^{22}Na with a 5″ dia. × 4″ thick NaI(Tl) crystal showing peak and total regions.

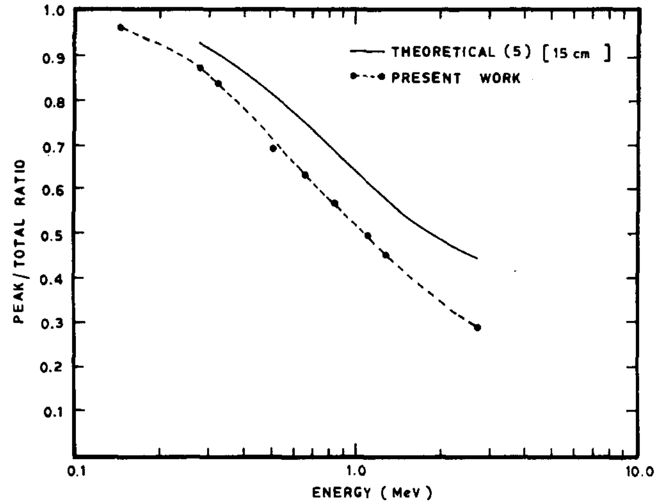

Fig. 2. Peak/total ratios for a 5″ dia. × 4″ thick NaI(Tl) crystal. Source distance: 10 cm.

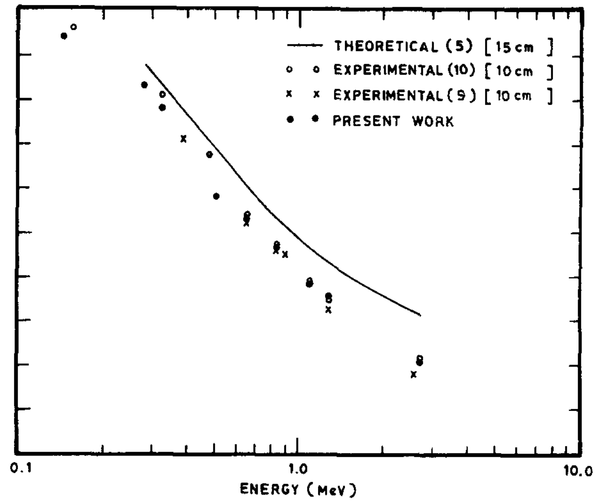

Fig. 3. Peak/total ratios for a 3″ dia. × 3″ thick NaI(Tl) crystal. Source distance: 10 cm.

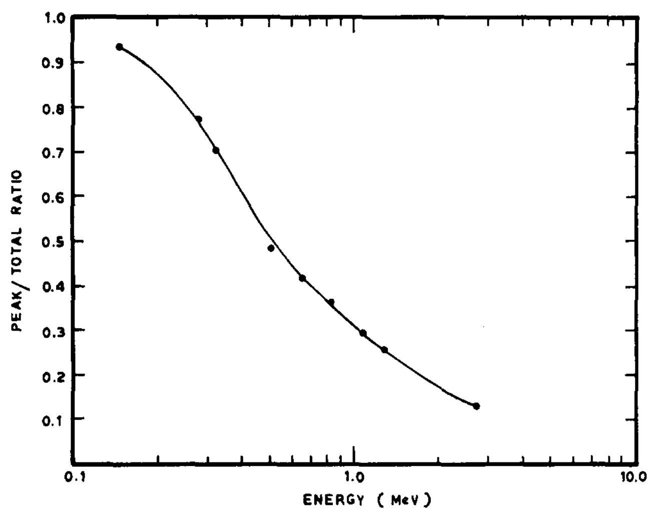

Fig. 4. Peak/total ratios for a 3″ dia. × 1″ thick NaI(Tl) crystal. Source distance: 10 cm.

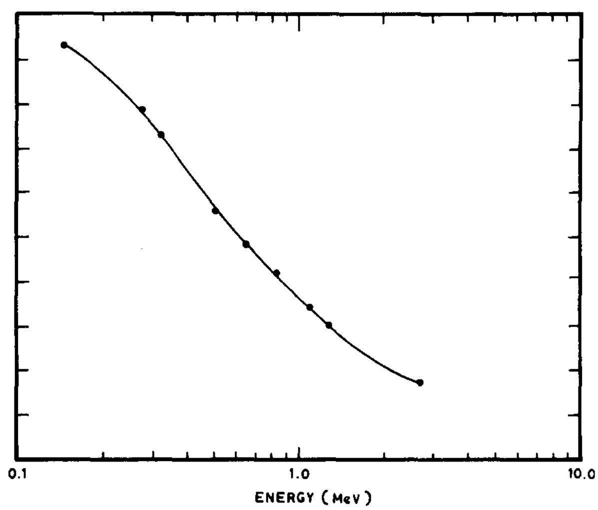

Fig. 5. Peak/total ratios for a 2.5″ dia. × 2.5″ thick NaI(Tl) crystal. Source distance: 10 cm.

peak/total ratios for 10 cm distance for a 5″ dia. × 4″ thick NaI(Tl) crystal. The theoretical values by Weitkamp[5]) are also plotted on the same graph. The theoretical values are higher over the entire energy range covered and the differences are more towards higher energies. Green and Finn[8]) have also found that their measured intrinsic peak efficiencies are lower than the calculated values of Weitkamp[5]) for a 5″ × 4″ crystal. Similarly, fig. 3 gives the theoretical and experimental ratios for a 3″ × 3″ NaI(Tl) crystal. The experimental results by different authors are also included. The present results are very close to Heath's[10]) values except at lower energies where the small differences may be due to the difference in the canning and reflector thicknesses of the two crystals. The present experimental results are higher than those of other authors. The theoretical values for this size are also higher than experimental values with larger difference at higher energies. Figs. 4 and 5 give experimental values for 3″ × 1″ and 2.5″ × 2.5″ NaI(Tl) crystals respectively. Since neither theoretical nor experimental values by other authors are available,

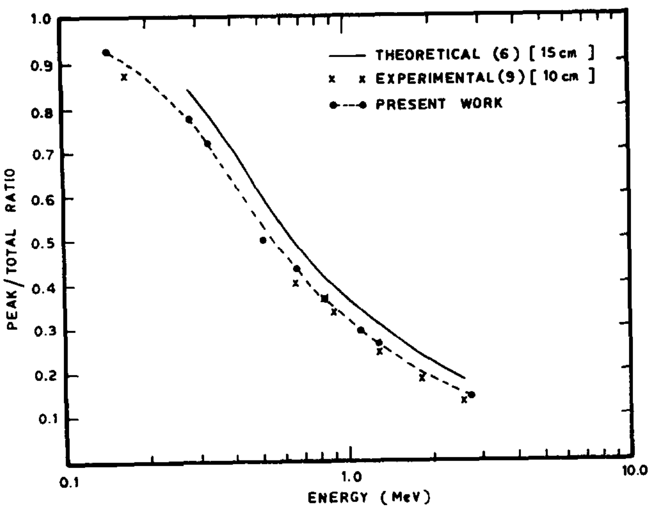

Fig. 6. Peak/total ratios for a 2″ dia. × 2″ thick NaI(Tl) crystal. Source distance: 10 cm.

TABLE 3

Experimental peak/total ratios for five different NaI(Tl) crystals. Source distance: 10 cm.

Energy (MeV)	Crystal size, dia. × height (inch)				
	5×4	3×3	3×1	2.5×2.5	2×2
0.145	0.96	0.94	0.939	0.93	0.929
0.279	0.87	0.832	0.775	0.79	0.775
0.323	0.836	0.78	0.703	0.731	0.723
0.513	0.69	0.58	0.485	0.56	0.50
0.662	0.632	0.53	0.417	0.482	0.433
0.835	0.566	0.465	0.365	0.42	0.365
1.11	0.495	0.381	0.291	0.341	0.291
1.28	0.454	0.356	0.256	0.301	0.262
2.75	0.29	0.206	0.129	0.172	0.142

they have not been compared. Fig. 6 gives theoretical values by Miller and Snow[6]) and experimental values by Leutz et al.[9]) and by the authors for a 2″ × 2″ NaI(Tl) crystal. The experimental values of Leutz et al.[9]) are lower than the present work. The difference between the theoretical values of Miller and Snow[6]) and the experimental values in this case does not seem to increase with energy. From the results for a 2″ × 2″ crystal as well as from the theoretical values for a 4″ × 4″ crystal calculated by Weitkamp[5]) and Miller and Snow[6]) and the experimental results of Leutz et al.[9]) and Christaller[7]), it appears that the theoretical results of Miller and Snow are closer to experimental values than Weitkamp's.

In making above measurements, due care has been taken to minimize all possible sources of error[16,17]). The most important ones are corrections for back-scattered gammas, X-rays, bremsstrahlung and betas. The method used for estimating total counts takes care of the back-scattered gammas, X-ray peaks and to a large extent bremsstrahlung contributions. The beta energies of all the isotopes, except ^{24}Na, used for these measurements are less than 0.6 MeV and these will be stopped by the canning and reflector of the various crystals. In the case of ^{24}Na, where the extrapolation was done from the Compton continuum of 2.75 MeV peak, bremsstrahlung and beta interference from the 1.39 MeV betas will be small. The ^{85}Sr source had some ^{89}Sr activity also which emits beta of 1.47 MeV. Complete bremsstrahlung and beta correction for this could not be made since the strength of ^{89}Sr in the source was not known and hence the ratio values for 0.513 MeV are consistently lower. The other likely sources of error are the deviation of the source size from point source, the positioning of the source with respect to the crystal, etc. As mentioned earlier, the overall error due to all the above factors is estimated to be less than $\pm 5\%$. Scattering at crystal canning and reflector will reduce the peak/total ratio values. However, as an experimenter is interested in the values for canned crystal assemblies for his use, these corrections have not been applied.

The authors tried to measure the differences in the peak/total ratios for the three available cannings viz., aluminium, electrolytic copper and stainless steel for 3″ × 3″ crystal (table 1). However, the results for the energy range considered are within the error limits mentioned and so one can use the above results for any type of canning material for standard integral line assemblies unless the canning and reflector thickness are very different.

It is proposed to extend these measurements for more crystal sizes so that one can draw curves for peak/total against crystal diameter for various thicknesses and energies and peak/total against crystal thickness for various diameters and energies, from which one can interpolate for any desired crystal size and energy.

The authors are thankful to Dr. K. G. Vohra for his keen interest and valuable suggestions in the course of this work. They also wish to thank Shri R. S. Mhatre for doing a precision job of designing and fabricating the source mounting system.

References

1) S. H. Vegors, Jr., L. L. Marsden and R. L. Heath, Report No. IDO-16370 (1958).
2) C. C. Grosjean and W. Bossaert, Table of absolute detection efficiencies of cylindrical scintillation gamma-ray detectors, University of Ghent, Belgium (1965).
3) E. A. Wolicki, R. Jastrow and F. Brooks, Report No. NRL-4833 (1956).
4) A. L. Stanford, Jr. and W. K. Rivers, Jr., Rev. Sci. Instr. **29** (1958) 406.
5) C. Weitkamp, Nucl. Instr. and Meth. **23** (1963) 13.
6) W. F. Miller and W. J. Snow, ANL-5902 (1958).
7) G. Christaller, Nucl. Instr. and Meth. **50** (1967) 173.
8) R. M. Green and R. J. Finn, Nucl. Instr. and Meth. **34** (1965) 72.
9) H. Leutz, G. Schulz and L. van Gelderen, Nucl. Instr. and Meth. **40** (1966) 257.
10) R. L. Heath, Scintillation spectrometry – Gamma-ray spectrum catalogue, Report No. IDO-16880-1 (1964).
11) K. L. Coop and H. A. Grench, Nucl. Instr. and Meth. **36** (1965) 339.
12) B. Chinaglia and R. Malvano, Nucl. Instr. and Meth. **45** (1966) 125.
13) F. C. Young, H. T. Heaton, G. W. Philips, P. D. Forsyth and J. B. Marion, Nucl. Instr. and Meth. **44** (1966) 109.
14) Harshaw Scintillation Phosphors (2d ed.), Harshaw Chemical Co., Cleveland, Ohio (1962).
15) S. Ragupathy, Instruction Manual – 256-channel pulse height analyzer model AEE/AM/PHA-256, Manual No. AEET/AM/M-3/(1966).
16) G. Bengtsson, Nucl. Instr. and Meth. **46** (1967) 356.
17) H. Leutz, G. Schulz and L. van Gelderen, Nucl. Instr. and Meth. **46** (1967) 357.