

PEAK/TOTAL-RATIOS FOR NaI(Tl)-CRYSTALS

H. LEUTZ and G. SCHULZ

II *Physikalisches Institut der Universität Heidelberg*

and

L. VAN GELDEREN

Harshaw-van der Hoorn, Utrecht

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The fraction of γ -quanta totally absorbed in NaI(Tl)-crystals was determined for eight scintillation assemblies having dimensions from 1" dia. \times 1" hgt through 8" dia \times 8" hgt. The γ -energies varied from 122 keV to 2.62 MeV and the γ -sources

were placed at distances of 10 cm and 50 cm from crystal face. For the crystals up to 5" dia \times 5" hgt we also used collimated γ -beams. The measured ratios are about 10% to 30% lower than the ratios calculated by Miller et al.

1. Introduction

Many scientists working with detector arrangements in nuclear physics and related fields are dealing with intensity determinations of γ -quanta emitted either from radioactive isotopes or from reactions induced by accelerator beams. If there is only one γ -energy present, the problem is reduced to the evaluation of the geometric counting efficiency and the absorption probability of the detector. The intensity determination, however, becomes difficult in all cases where the emitted spectra are rather complex and where considerable background intensities are present. Since in the energy region, where Compton interaction dominates, all γ -lines are connected with a continuous Compton distribution, the overlap of these Compton spectra makes detailed intensity determinations impossible.

Only the total energy absorption peaks can more or less accurate be separated from these complex spectra. With the use of an anti-Compton-spectrometer, one may decrease the Compton background with respect to the total absorption peaks considerably. Therefore it is

important to know the relation of such peak intensities to the total γ -intensities shared between these total absorption peaks and the corresponding Compton distributions. Further on we call this relation the peak/total-ratio. This ratio was calculated for several dimensions of NaI(Tl)-crystals by Miller et al.¹⁾. Experimental determinations of the peak/total-ratio were reported by Kreger and Brown²⁾ for two special shaped NaI(Tl)-crystals and for a 4" dia. \times 4" hgt cylindrical NaI(Tl)-crystal. Heath³⁾ and Weitkamp⁴⁾ measured the peak/total-ratio for a 3" dia. \times 3" hgt and for a 4" dia. \times 6" hgt. NaI(Tl)-crystal, respectively. Since, in several cases, the calculated peak/total-ratios do not agree with the experimentally obtained ones, we measured the peak/total-ratios of eight NaI(Tl)-crystals with different sizes.

2. Technique of measurement and apparatus

The interesting data of the crystals used are compiled in table 1; all scintillation assemblies were Harshaw units. The anode pulses of the photomultipliers were

TABLE 1
Interesting data of the crystals used for the determination of peak/total-ratios.
All scintillation assemblies are Harshaw units.

Crystal dimensions dia. \times height	Mounting procedure	Photomultiplier	Resolution for ¹³⁷ Cs (662 keV) (%)
1" \times 1"	Integral line	1 \times RCA 6199	7.8
2" \times 2"	Integral line	1 \times RCA 6342A	7.6
3" \times 3"	Integral line	1 \times RCA 8054	7.5
4" \times 4"	Integral line	1 \times RCA 8055	7.1
5" \times 5"	Integral line	1 \times RCA 8055	8.3
8" \times 4"	Matched window line	4 \times RCA 8054	8.5
9" \times 6.5"	Matched window line	4 \times RCA 8054	8.7
8" \times 8"	Matched window line	4 \times RCA 8054	10.0

directly fed to a preamplifier and then coupled to the internal amplifier of a Victoreen 400 channel pulse height analyzer. Linearity between the energies of incident γ -quanta and the corresponding channel numbers of the registered pulse height distributions was found to be in order. Distortions due to electronic noise and overload effects were reduced to a sufficiently low level as to not to interfere with our measurements.

The most serious problem in these measurements arose from the undesired intensity contributions of γ -quanta emitted from the source and Compton-scattered in the surroundings of the source-detector arrangement. To avoid wrong shapes of the Compton distributions, induced by such scattering effects, attention had to be paid to the geometric arrangement of source and detector and to the surroundings of the entire arrangement.

To cover a rather wide range of current experimental arrangements we measured the peak/total-ratios in three different geometries shown in fig. 1. In a first series of measurements we located the sources at a distance of 50 cm from crystal face (fig. 1a), thus providing an almost parallel beam of γ -quanta at least for the smaller crystals. In this geometry the ratio of γ -quanta Compton-scattered in the surroundings to γ -quanta directly striking the crystals is very disadvantageous. Therefore we shielded the sources by a lead box as shown in the drawing. To provide a better detection efficiency we located the γ -sources in the

TABLE 2
Isotopes and γ -energies used for the determination of peak/total-ratios.

Isotope	γ -energy (keV)
^{57}Co	122
^{139}Ce	166
^{203}Hg	279
^{113}Sn	392
^{22}Na	511, 1274
^{137}Cs	662
^{54}Mn	835
^{60}Co	1173, 1333
^{88}Y	900, 1841
$^{208}\text{Tl} (\text{ThC}''')$	2620

second series of measurements at a distance of 10 cm from crystal face (fig. 1b). In this arrangement the best conditions resulted from totally unshielded sources. Arrangements with collimated γ -beams are often applied for smaller crystals. Therefore we used this geometry in a third series of measurements (fig. 1c). Since the contribution of γ -quanta Compton-scattered in the surroundings of the arrangement varies approximately with the squared inverse of the distance from the detector, we located all crystals at distances of at least 150 cm from floor, ceiling and walls of the laboratory. All γ -sources used for these investigations consisted in thin layers of radioactive materials canned in about 0.5 mm lucite to prevent scattering effects in the very near source region.

3. Measurements and results

Besides the 8" dia. \times 8" hgt, 8" dia. \times 4" hgt and 9" dia. \times 6.5" hgt Na(Tl)-crystals the other five scintillators, respectively 1" dia. \times 1" hgt through 5" dia. \times 5" hgt, were measured at twelve different γ -energies using the isotopes listed in table 2. From all spectra collected the background radiation was subtracted. As an example for our peak/total determination we depicted in fig. 2a the spectrum obtained by the detection of 662-keV γ -quanta from ^{137}Cs with a 4" dia. \times 4" hgt crystal. This spectrum consists of the total absorption peak, the Compton continuum and the peak due to back-scattered radiation. The ranges of these three intensities are indicated by dashed lines. The backscatter-peak is mainly caused by the phototube connected with the crystal, provided that any material behind the source is avoided. Therefore this peak does not contribute to the γ -intensity directly absorbed in the crystal. The absolute intensity of backscattered radiation is mainly proportional to the mass of glass of the photomultiplier envelope and to the γ -intensity transmitted

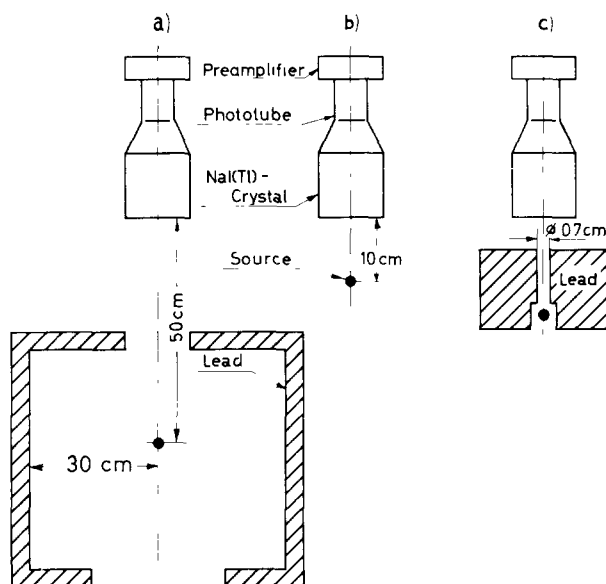


Fig. 1. Arrangements of source and detector for the three series of measurements. Distance (a) 50 cm and (b) 10 cm between source and crystal face (c) Collimated beam.

through the crystal. The ratio of backscattered to directly absorbed radiation is therefore more important for thin crystals because it is favoured by the high ratio of transmitted to incident radiation for these crystals. As in fig. 2a also in all other measured pulse height distributions the backscatter-peaks could clearly be recognized and deducted from the Compton continua.

In fig. 2b the absorption spectrum of the 900-keV and 1841-keV γ -lines from ^{88}Y is displayed as an example for the treatment of spectra containing two γ -lines. To get the peak/total-ratios for both energies, we separated the two Compton continua by extrapolating the Compton distribution of the 1841-keV quanta to an energy which equals zero. The backscatterpeaks from 900-keV and 1841-keV quanta have approximately the same energy and can not be separated from each other but can be clearly deducted from the total Compton continuum. In this case also a pair escape peak at 1330-keV and a peak at 511-keV due to annihilation quanta can be distinguished, since ^{88}Y also emits positrons with an intensity of about 0.5%. The intensity of the pair escape peak was added to the total intensity while the 511-keV peak was deducted from the spectrum. In those instances where applicable, we corrected in this way for contributions of such side

effects calculating the peak/total-ratios. This procedure is very important for the evaluation of the $^{208}\text{Tl}(\text{ThC}''')$ -spectrum.

Finally, the peak/total-ratios for the three geometries mentioned above, are given as a function of the energy for all crystals in fig. 3. Although it is difficult to calculate, we estimate that the errors in our measurements are not greater than about $\pm 5\%$ due to the deviations of the individual experimental points from the fitted curves.

4. Discussion

As can be seen from figs. 3a, 3b and 3c the peak/total-ratios vary for the various source-detector arrangements. The highest ratios resulted from the arrangement with a collimated γ -beam (fig. 1c and fig. 3c). This is obvious, because in this geometry the path for onefold Compton-scattered quanta is longer and hence the probability for further collisions in the crystal leading finally to total absorptions of the quantum-energies is greater than in the other geometries mentioned above.

Miller et al.¹⁾ have calculated peak/total-ratios applying the Monte Carlo method to evaluate the interaction probabilities of the incident γ -quanta. Assuming a parallel γ -beam they obtained for 2" dia. \times 2" hgt,

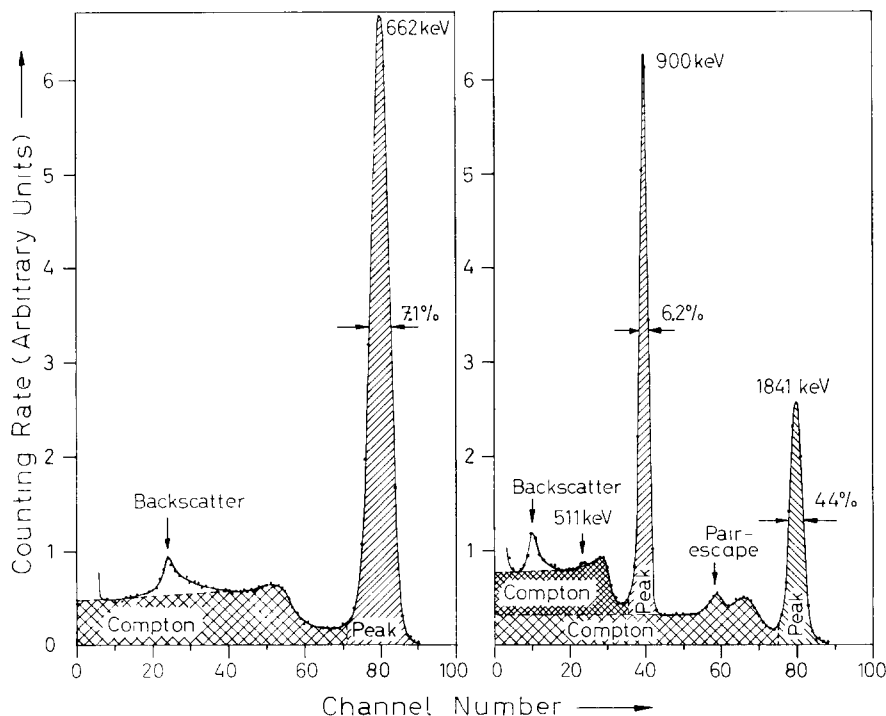


Fig. 2. a. Absorptionspectrum of 662-keV γ -quanta (^{137}Cs) and b. Absorptionspectrum of 900-keV- and 1841-keV γ -quanta (^{88}Y) in a 4" dia. \times 4" hgt NaI(Tl)-crystal at a distance of 10 cm between source and crystal face. Background is subtracted. The peak/total-ratios are defined as the corresponding peak/(peak + Compton).

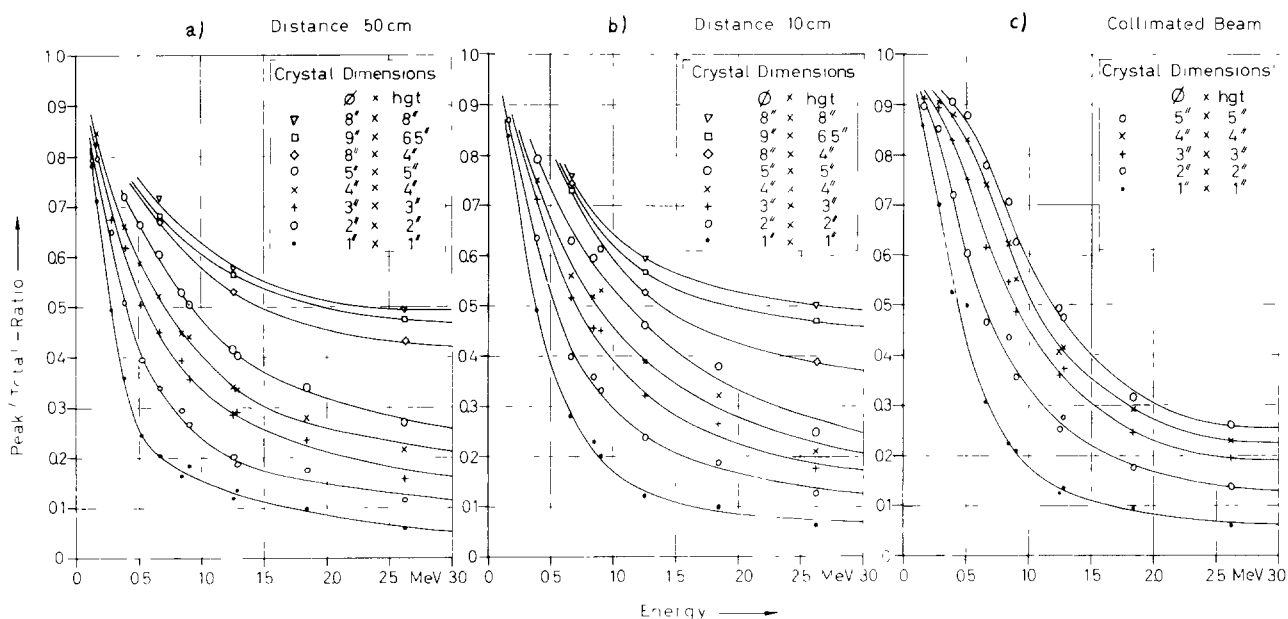


Fig. 3. Peak/total-ratios in the absorptionspectra of eight NaI(Tl)-crystals vs γ -energy a, b, c Measured with the arrangement shown in fig 1a, b, c respectively.

4" dia. \times 4" hgt, 8" dia. \times 4" hgt and 8" dia. \times 8" hgt crystals peak/total-ratios which are from 10% to 30% higher than our experimental data. The same holds for the arrangement with a collimated γ -beam at γ -energies above 1 MeV using a 4" dia. \times 4" hgt crystal. This difference can be partly induced by the scattering events in the Al_2O_3 reflector and in the containers of the crystals, because the calculations did not regard such effects. For practical applications, however, scattering events in reflector- and canning materials have to be taken in account.

Heath³⁾ measured the peak/total-ratios with a 3" dia. \times 3" hgt crystal at a source distance of 10 cm. His results are up to an energy of 2.5 MeV in good agreement with our data obtained with the corresponding arrangement. The peak/total-ratios of Kreger

and Brown²⁾ measured with a 4" dia. \times 4" hgt crystal using collimated and parallel γ -beams agree rather good with our results up to γ -energies of about 1 MeV. For higher γ -energies there are considerable differences amounting to about 40% at 1.8 MeV for the collimated beam arrangement.

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