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Jakub Osko[1], Natalia Golnik[2]

Spectrometric measurements of radioisotope activity in the thyroid

[1]Institute of Atomic Energy, Otwock-Swierk
[2]Institute of Precision and Biomedical Engineering, Warsaw University of Technology
e-mail: kuba.osko@cyf.gov.pl

The results of measurements of iodine ^{131}I and technetium ^{99m}Tc uptake in human thyroid, performed with scintillation or semiconductor detectors can exhibit a considerable uncertainty due to the differences in the thyroid position in the patient's neck. Basic physical laws of radiation attenuation and scattering show that the final shape of the registered spectrum should depends on the thyroid position in the neck and on the thickness of the tissue between the thyroid and the detector. The use of the spectrometric measuring method is proposed in this work for determination of the iodine gathering effective depth. The performed studies showed that the measurements results can be used for improving the accuracy of the iodine ^{131}I activity in thyroid measurements and for selection of the group of patients for whom the anatomical position of the thyroid or the spatial distribution of the iodine gathering is much different than the standard one, assumed during the calibration of the counters. The results of the measurements were in agreement with Monte-Carlo calculations of the detector response. The method was used in routine monitoring of occupationally exposed persons, using the thyroid counter. A group of six persons with measurable internal contamination was selected and the measurements were performed on consecutive days, so the results could be registered at decreasing iodine activities in the thyroid. Larger series of measurements were performed at Brodno Regional Hospital in Warsaw, for a group of 95 patients after diagnostic administration of iodine ^{131}I.

Key words: thyroid, radioisotope activity, spectrometric measurements.

Introduction

The results of iodine ^{131}I and technetium ^{99m}Tc activity measurements in the human thyroid, performed with scintillation or semiconductor detectors, can show a considerable uncertainty due to the differences in the thyroid position in the patient's neck.

The energy spectrum of the radiation emitted from the thyroid contains peaks due to unscattered radiation (the emission spectrum) and a broad energy band from the radiation scattered in the human neck. The spectrum registered by the detector is additionally influenced by radiation scattering in the detector. Usually, when radionuclide activity in the thyroid is measured, the counter registers either all the events induced in the detector or, more often, only the events associated with the main peak in the emission spectrum of the radionuclide under consideration (within the energy 'window' of the detector). Basic physical laws of radiation attenuation and scattering show that the final shape of the registered spectrum should depends on the thyroid position in the neck and the thickness of the tissue between the thyroid and the detector. It could be also expected that the differences in the registered spectrum are big enough to be quantified, so that the radionuclide activity can be determined more accurately if the energy spectrum of the radiation emitted from the thyroid is measured. The proper analysis of the spectrum might provide data for more personalized calculations of the radionuclide uptake in the thyroid, taking into account the position of each patient's thyroid. The method of detector calibration and data analysis were described in detail in our earlier papers [1–2, 4–5]. This paper summarizes our experimental results as compared with the results of the Monte-Carlo calculations.

Method

The iodine ^{131}I spectrum registered by a NaI(Tl) detector is showed in Figure 1. Two areas were selected for further consideration. The first one was the area of the main energy peak (364 keV, marked as P), corrected for the background determined as an average value of counts in eight channels — four channels preceding the main peak and four channels immediately after the peak. The second area was the Compton scattering band of 110–140 keV, marked in Figure 1 as C. The ratio P/C of the counts in the 364 keV peak to the counts in the Compton scattering band is denoted here as S. The criterion for

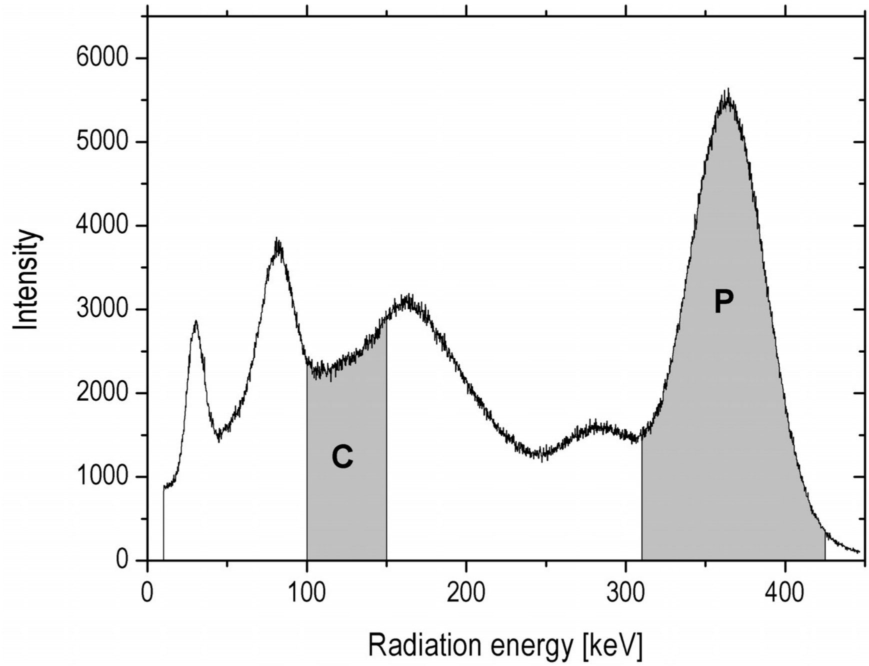

Figure 1. Iodine ^{131}I spectrum with marked areas under main energy peak of 364 keV *P* and the selected Compton scattering band *C*

the choice of the particular energy range within the Compton scattering band was to maximize the dependence of the ratio *S* on the effective depth of the thyroid in the human neck [1].

The next step of the method involves determination of the relationship between the detection efficiency, ε, (the number of counts registered in the main peak per 1{N}Bq of source activity) and the parameter *S*. The relationship ε(*S*) has to be determined for each particular geometry of measurements, i.e. for each configuration of the patient-detector-collimator setup. In this work, ε(*S*) was determined experimentally for the standard distance of 12 cm between the detector and the human neck. The radiation spectrum was measured for different positions of the radiation source in the neck phantom, using a special phantom described in the next section. The results of the measurements were compared with Monte-Carlo calculations of the detector response. The same code, can be used for further calculations of ε(*S*), e.g. when the distance between the detector and the human neck is not the same as that used for calibration.

The radionuclide activity, A, in the thyroid is then calculated using a well-known relationship (1), in which the fixed value ε is substituted for by the ε(S) relationship:

$$A = \frac{R_p}{\varepsilon(S)\, t\, k_\gamma} \tag{1}$$

where R_p is the number of counts registered in the main peak, t is the time of the measurements (after subtracting the dead time) and $k_{\gamma?}$ is the efficiency of the main emission line.

Calibration of the detector and determination of ε(*S*)

In most human neck phantoms, the thyroid depth is fixed, so a special water phantom (Figure 2) was designed for this work. The phantom is a cylinder-shaped Lucite (PMMA) vessel (128 mm in diameter and 165 mm high), with a cover, and two small (13 cm^3) cylinder vessels inside, simulating thyroid lobes [4, 5]. During the measurements, the bigger vessel was filled with distilled water, and the small ones were filled with reference solutions of radioisotopes. The construction of the phantom made it possible to move the small vessels in two directions (horizontally and vertically). The whole phantom could be rotated on its base, with a certain angle of fixed rotation. There was also the possibility to use vessels of various volumes.

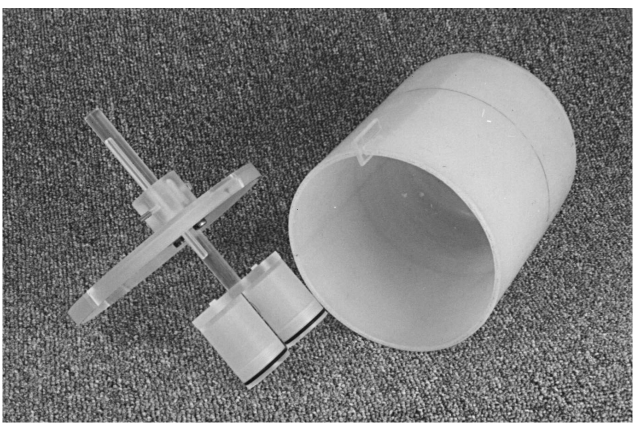

Figure 2. Thyroid water phantom with a variable position of the vessels with radioactive solution

Monte Carlo simulation of a NaI(Tl) detector response for ^{131}I source in the human thyroid

A mathematical model was created in order to describe the NaI(Tl) detector response for various positions of the radioactive iodine source in the human neck phantom.

The calculations were performed using the Monte Carlo ‘Penelope’ code and the ‘Penmain’ programme in the code [6]. The radiation source, which is a point source in the ‘Penmain’, was modelled as a sphere source, and the emission spectrum of ^{131}I was added as a source term for calculations.

The modelled detector was a ∅40 × 25 mm scintillation detector placed in a ∅46 × 32 mm and 1 mm thick wall aluminium cover. The space between the crystal and the wall was filled with Al_2O_3. The detector was shielded with a cone-shaped lead collimator. A sphere-shaped iodine ^{131}I source was placed in a tissue or water-modelled cylinder. In this way, the results of activity measurements of the iodine source in the water thyroid phantom and in the human neck could be compared.

The ‘Penelope’ code did not account for the detector resolution. In order to simulate the energy spectrum, the number of counts in each energy channel was considered as Gaussian-shaped, with σ values corresponding to the energy resolution of the particular detector used. All Gaussian functions were summed up in each channel.

Measurements

Two radionuclides, iodine ^{131}I with activities of up to about 1{N}MBq and technetium ^{99m}Tc with activities of up to 432 kBq, were investigated. The radionuclides were placed in the thyroid water phantom, and the gamma energy spectra were registered for different simulated depths of the thyroid gland in the neck, varying from 24 to 52 mm, while the distance between the detector and the phantom surface was 12 cm.

Calibration measurements, needed for the $\varepsilon(S)$ determination, were performed at the Institute of Atomic Energy in Swierk, using a thyroid counter with a NaI(Tl) scintillation detector (Tesla) mounted in a SS-33W52 counter (manufactured by POLON, Bydgoszcz, Poland) [5]. Additionally, a HpGe counter PRGC-4019 of the whole body counter placed in a shielded cabin was used to prove the independence of S of the source activity.

The method was used in routine monitoring of occupationally exposed persons, using the thyroid counter mentioned above. A group of six persons with measurable internal contamination was selected and the measurements were performed on consecutive days, so the ratio *P/C* could be registered at decreasing iodine activities in the thyroid.

Larger series of measurements were performed at Brodno Regional Hospital in Warsaw, for a group of 95 patients after diagnostic administration of iodine ^{131}I. During hospital tests, the activity of iodine ^{131}I in the thyroid gland was measured about 24 hours after swallowing radioiodine diagnostic pills. In all cases, routine measurements were performed by the hospital staff, and then repeated by the IAE researchers using specially calibrated counter. The time of each IAE measurement was 10 minutes.

Results

The dependence of the *S* value on the source depth in a phantom is illustrated in Figure 3, where the results obtained in one series of measurements with ^{131}I source are shown and compared with the calculated values.

The limited energy resolution of the detector resulted in the spread of *S* values, up to 5%, when the results of measurements performed for different radionuclide activities were compared. This problem was fully overcome by the measurements with the HpGe

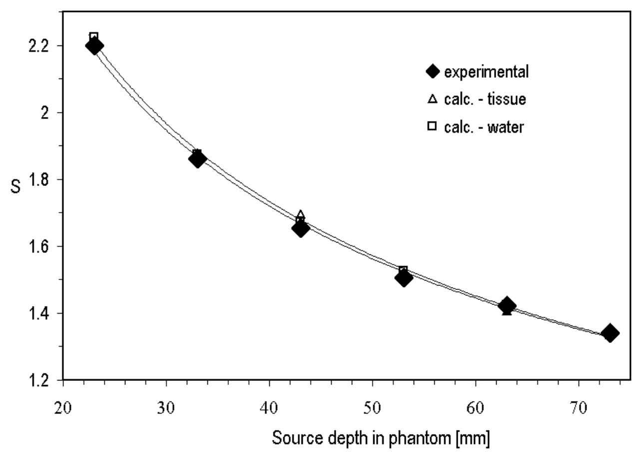

Figure 3. The measured values of parameter *S* versus the radiation source depth in a water phantom as compared with those calculated

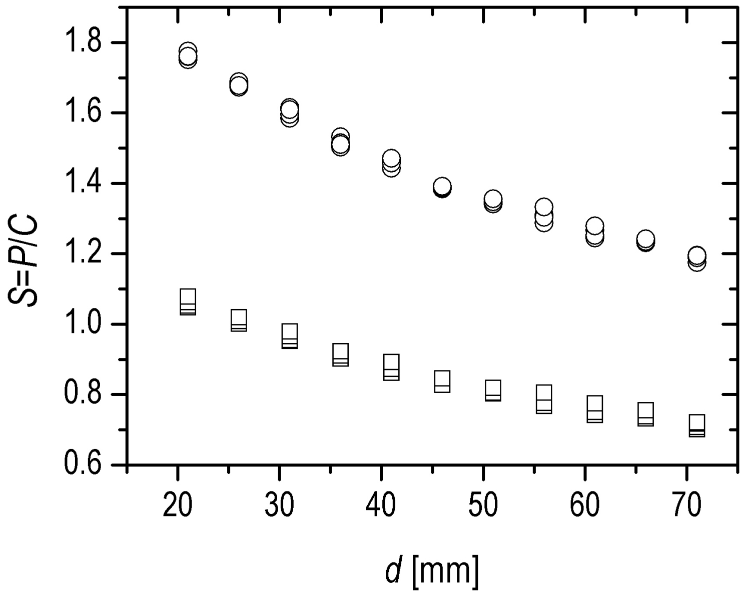

Figure 4. $S_1(d)$ – upper curve and $S_2(d)$ – lower curve, determined using the HpGe detector. Points of different shapes indicate the measurements for the activities of 960, 885, 686 and 380 kBq [1]

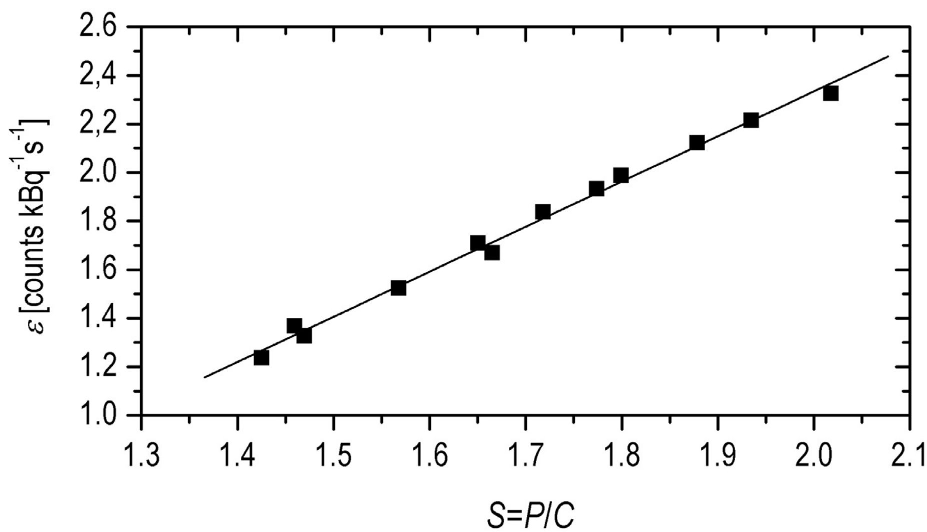

Figure 5. Relationship $\varepsilon(S)$ for ^{131}I. The distances between the detector and the phantom were 12 cm [2]

detector. These measurements were performed for two energy bands of scattered radiation — the same as those with NaI(Tl) (110–140 keV) and 100–150 keV. The results are shown in Figure 4. No dependence of the ratio S on the activity of the radiation source was observed [1].

The influence of other parameters such as vertical and horizontal shifts of the source from the detector axis are described elsewhere [1, 3].

The detection efficiency, ε, was determined for each depth of the source according to Eq. (1). Combining the dependencies ε(d) and $S(d)$ made it possible to derive the relationships ε(S), shown in Figure 5 for the iodine source and in Figure 6 for the technetium source.

The method of spectrometric measurements was used in a series of measurements performed for a group of occupationally exposed persons and for a group of patients after diagnostic administration of iodine ^{131}I.

Six occupationally exposed persons were selected from a group of routinely controlled persons, who had been working at a radioisotope production centre. Monitoring measurements were carried out during the period from January 2006 to August 2007. During this period, each person was subjected 18 to 25 times to measurements of iodine activity in the thyroid. The activities measured were generally

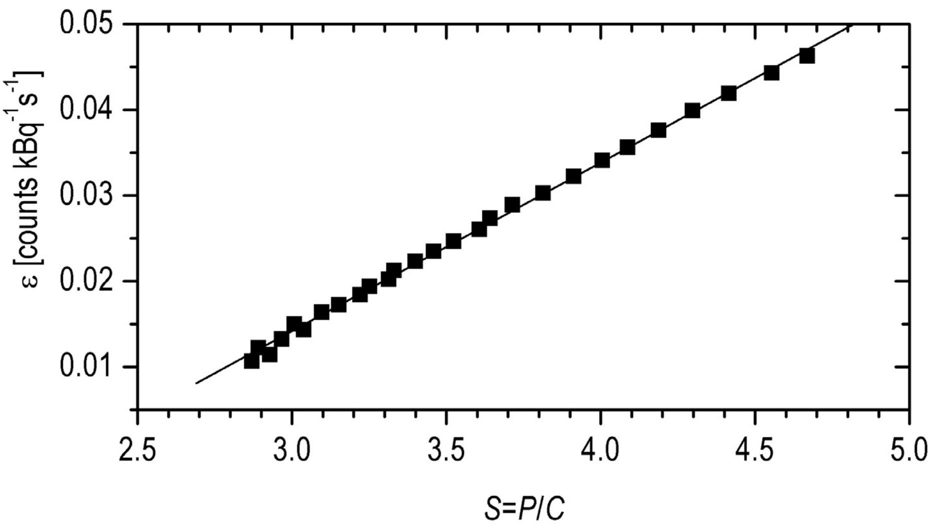

Figure 6. The relationship ε(S) for ^{99m}Tc determined for the distance between the detector and the phantom L=12 cm [2]

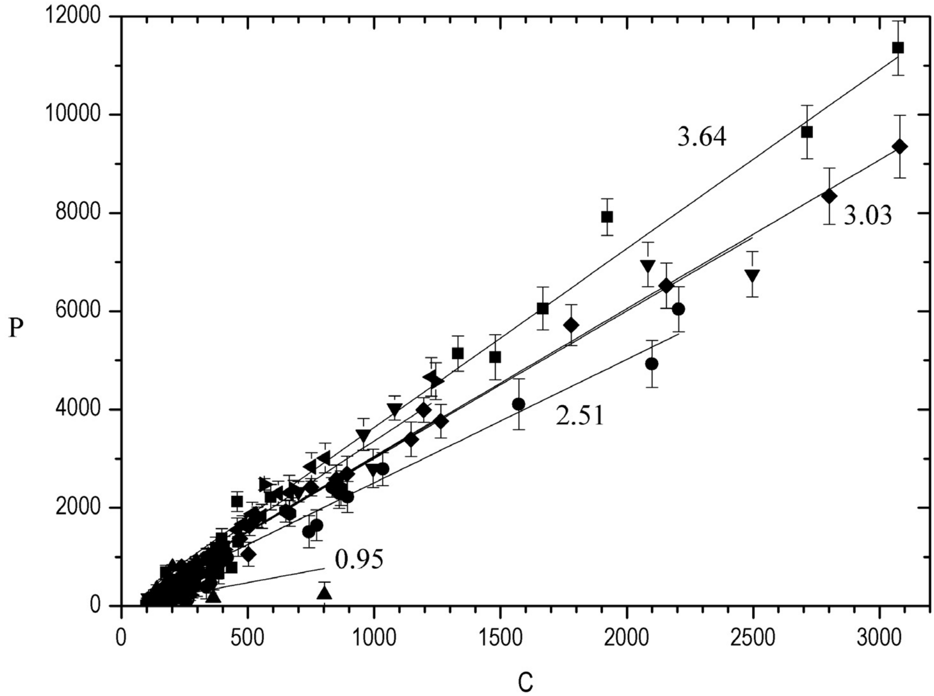

Figure 7. Count numbers in the main peak, *P*, versus count numbers in the selected part, *C*, of the Compton scattering band, measured for a group of six occupationally exposed persons, at different activities of ^{131}I. Lines are fitted to the data obtained for each person

very low, close to the detection threshold. For this reason, only a small number of results, when the measured activity was higher than 1.12 Bq, were taken into account in this work. The measured relationship between the area under the 364 keV energy peak, *P*, and the Compton scattering band, *C*, is presented in Figure 7. The dependence is linear, therefore, the value of the parameter *S* remains constant for each person. All the investigated patients were healthy, and their thyroid glands were similar to the standard. Also the measured values *S*, except one, corresponded to the physiological depth of the thyroid. The values of the source depth in the phantom resulting in the same values of *S* as those measured are indicated in the figure. The last value was measured only at a very low count ratio. That is why, dividing the small value *P* by an even smaller value *C* resulted in very big uncertainty in the ratio *S*. It can be concluded that there is a lower limit for the practical use of the described method. The measurement uncertainties for activities below about 1.2 kBq were definitely too high, and this value is now considered to be the lower limit for *P/C* measurements, if they are performed with the equipment used in this work.

Measurements at higher activities were performed for a group of 95 patients who received diagnostic activities of ^{131}I. The ratio of the counting rate in 364 keV to the counting that in the energy band between 100 and 150 keV was used for the determination of the apparent depth of the thyroid gland.

Figure 8 shows that in most cases, the obtained values were higher than the standard depth of the thyroid. This could be expected, because of the much larger sizes of the thyroid lobs and their displacements as compared with standard conditions. The associated uncertainties of routine measurements of the iodine uptake can be roughly estimated from the comparison of the ε values for certain apparent depths with those for standard conditions. In the majority of cases, the uncertainties were lower than 30%, so the standard method provided the accuracy required for diagnostic purposes. However, there was a group of patients (about 20% of the investigated group) with an apparent depth of the thyroid exceeding 50 mm. Such unrealistic values are caused by the

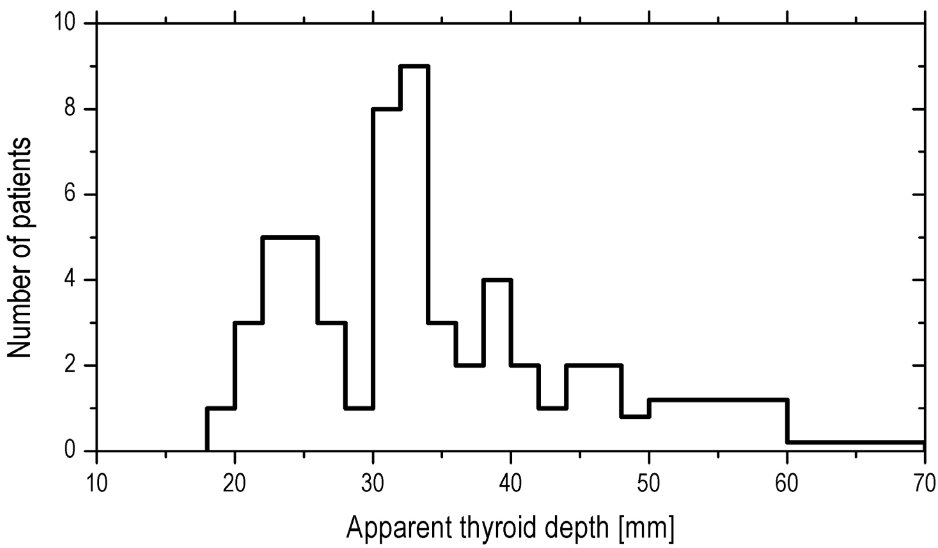

Figure 8. Distribution of apparent thyroid depths in a group of 95 patients with thyroid diseases

displacement of a large portion of iodine to lower parts of the body and by partial shielding of the thyroid by the sternum [1].

Conclusion

Our studies have shown that spectrometry methods can improve the accuracy of the measurements of iodine ^{131}I activity in the thyroid, performed in the routine monitoring of occupationally exposed persons.

The most important application are measurements of iodine uptake by patients with thyroid diseases. The *P/C* ratio can be used for selecting a group of patients for whom the anatomical position of the thyroid or the spatial distribution of the iodine accumulated is very much different from the standard distribution assumed during the calibration of the counters [1-3]. Standard measurements in this case give incorrect results.

A mathematical model using the Monte Carlo method was developed. It describes the NaI(Tl) detector response depending on the position of the radioactive source in the human thyroid. The results were in agreement with the experimentally determined relationship between the shape of the gamma spectrum and the depth of the radioactive source. The quantitative spectrum calculation of the *P/C* ratio could be done as a test before implementing new elements in the measurement equipment or in order to check a new measurement geometry.

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