CALCULATIONS OF THE CORRECTIONS FOR THE TRUE SUMMATION OF CASCADE $\gamma$ RAYS ON THE BASIS OF STATISTICAL SIMULATION USING EVALUATED NUCLEAR DATA

A. N. Berlizov,1 V. N. Danilenko,2 S. L. Solov’eva,2 and A. S. Kazimirov3

A method of calculating the corrections to the true summation of the $\gamma$ radiation for arbitrary radionuclides for measuring point and volume sources using scintillation and ultrapure germanium detectors is described. The calculations are based on the Monte Carlo method using ENSDF evaluated data on the structure of atomic nuclei. An experimental check made using IAEA test spectra confirms that the calculations of the correction factors are reliable. The method is integrated into the $\gamma$ spectrometric packages LSRM-2000 and AkWin, where the corrections for the true summation are used for developing a library.

The increase or decrease in the number of counts recorded in the total-absorption peaks as a result of summing the impulses at the exit of a detector can strongly influence the accuracy of the results of $\gamma$ spectrometry. Taking account of this effect is now one of the mandatory requirements for modern $\gamma$-spectrometric software.

The effect appears in measurements of radiation from cascade sources and is due to the summation of impulses while simultaneously detecting two or more $\gamma$ rays in the sensitive volume of a detector. This distorts the measured $\gamma$-ray spectrum, specifically, it changes the areas of the total-absorption peaks, deforms the continuous Compton distribution, and results in the appearance of spurious peaks in the energy, which are absent in the true emission spectrum of the source.

In contrast to the random summation, where the probability of detecting impulses simultaneously is proportional to the squared counting rate at the entrance into the spectrometric channel, the intensity of true summation is determined by the measurement geometry, the characteristics of the detector, and the special features of the radionuclide cascade scheme. The difficulty of introducing corrections for the true summation is due, first and foremost, to the fact that it is necessary to know the $\gamma$-ray detection efficiency along the total-absorption peak and the total efficiency which depends on the relative arrangement and configuration of the source and detector, as well as of the environment in which scattering and backward reflection of $\gamma$ rays occur. The problem is exacerbated during measurement of radiation from a volume source, which effectively absorbs and scatters its own radiation.

An accurate calculation requires taking into account the possible anisotropy of the angular distribution of the emitted cascade photons. In addition, the coincidence of $\gamma$ radiation with annihilation (511 keV) photons must be taken into account when measuring a source of $\beta^+$ radiation. A coincidence of the $\gamma$ radiation from the source and the characteristic and

---

1 Institute of Nuclear Research, National Academy of Sciences of Ukraine.
2 Laboratory of Spectrometry and Radiometry OOO.
3 Atom kompleks pribor, Scientific-Industrial Association.

bremssstrahlung from electrons and β particles excited by it in the source, detector, and shielding materials could be true. For detectors which are sensitive to x-rays (low-energy or wide-band detectors), the true summation of pulses from γ and x-rays, arising as a result of internal conversion and K capture, could be substantial. For detectors sensitive to electrons, coincidence of γ radiation with conversion electrons and continuous β radiation can be expected to have an effect.

As a result of all this, no analytical or semiempirical method proposed today for introducing corrections for true summation has adequate accuracy and universality [1–5]. An alternative method is a calculation using the Monte Carlo method.

Simulation by the Monte Carlo method recommends itself well and is widely used for calculating the effectiveness and response functions of detectors of ionizing radiation and detecting systems with a complex configuration. The use of this approach for calculating corrections to the true summation in the case where radiation from volume sources is measured was first proposed in [6]. Subsequently, Monte Carlo simulation was used to calculate corrections when measuring radiation using well-type detectors [7, 8]. Comparing the computational results with experiment showed that a small error (10–15%) could be obtained in estimates of the correcting factors and that this method could be promising.

In [9], the corrections were calculated using a modified version of the MCNP code [10] in combination with ENSDF evaluated nuclear data [11], which contain the most complete information about the decay scheme of radionuclides. Such a combination solves the problems indicated above. The error in the estimates obtained for the correcting factors is actually determined by the error in describing the measurement geometry and present knowledge of the properties of the decay of a radionuclide. Tests showed good agreement between the corrections for true summation, obtained by experimental and theoretical methods. In addition, it was shown that the corrections for anti-Compton spectrometers, where the influence of the true summation effect is much larger, can be calculated. In the present paper, the TS program for performing a Monte Carlo calculation of the corrections for the true summation on the basis of statistical simulation using the evaluated ENSDF nuclear data is described.

**Computational Procedure.** The TS program makes it possible to calculate corrections for the true summation of cascade γ rays for arbitrary γ-emitting radionuclides and point and volume sources using scintillation and ultrapure germanium detectors. The ENSDF data are supplemented by information on the probability of radiative and nonradiative transitions occurring when vacancies in deep atomic shells are filled. Together with the probability of electron capture for different atomic shells and the theoretical coefficients for internal conversion, they are used to estimate the yield of the characteristic radiation. On the basis of all data taken together, the TS program is used to simulate the radioactive decay of a prescribed radionuclide using alternately analog and nonanalog regimes. In the analog regime, the intranuclear and intraatomic cascades, accompanied by the emission of correlated γ and x-ray radiations, are simulated. The results make it possible to determine the area S₀ of the peaks reflecting the influence of true summation effects. In the nonanalog regime, the particles emitted in the decay process move independently of one another, and the computational results reflect the area S₀ of the observed peaks. The ratio of the areas of the peaks CF = S₀/Sₐ is the desired correction factor.

The computational scheme implemented takes into account, together with γ–γ coincidences, the correlation between γ radiation and annihilation and characteristic radiation in the K and L series, which arises as a result of internal conversion and K capture. In addition, the anisotropy of the angular correlations of cascade γ rays and the temporal dynamics of decay, due to the finite lifetime of the excited states of the daughter nucleus, are taken into account. The angular correlation functions for γ radiation are calculated on the basis of the spin of the nuclear states, the multiplicity, and the mixing parameters of the corresponding γ transitions. The Monte Carlo method is used to simulate the movement of particles in the user-prescribed measurement geometry.

The input parameters of the program are the charge, mass, and isomeric index of the radionuclide, the number of tests, the geometric dimensions and elemental composition of the structural materials of the detector and the source (see Fig. 1). The radiation sources lie on the symmetry axis of the detector. The distribution of the activity in the source material is assumed to be uniform. A calculation can be performed for a point source at an arbitrary distance from the cover of the detector. Arbitrary mixtures of chemical elements, compounds, and other materials are prescribed as the material for the structural components of the detector and source. It is possible to create and take into account the users’ own materials. The coefficients of attenuation of γ radiation are calculated on the basis of the attenuation coefficients of the chemical elements. The computational results contain correction factors and the detection efficiency for each γ-ray line of the source and the standard errors of the quantities used.