Metrological problems of measurements of environmental objects in terms of spectrometry and radiometry of alpha, beta, gamma-emitting radionuclides

T P Berlyand., N G Tonkikh

All-Russian Scientific Research Institute of Physicotechnical and Radio Engineering Measurements, 141570, Russia, Moscow Region, Mendeleevovo

The corresponding author’s email: tonkih@vniiftri.ru

Abstract. This article deals with methods for measuring the characteristics of ionizing radiation in solving problems of radiation monitoring of the environment, industrial premises, sanitary protection zones, human pollution control using measurement techniques certified in the prescribed manner. The types of measuring instruments involved in the measurement of various quantities are listed. The main objects of measurements used in radiation monitoring of the environment, control of surface contamination and human contamination are named. The metrological characteristics (measured quantities) of measuring instruments are compared with the metrological characteristics of real measurement objects. A number of necessary established metrological characteristics for radiometric and spectrometric measuring instruments for the successful use of a measuring instrument in solving one or another problem of radiation measurements is indicated. An example from a real work is considered, in which the method of mathematical modeling when calculating additional metrological characteristics showed a significant discrepancy with the real data obtained during the experiment.

Spectrometers and radiometers of alpha, beta and gamma radiation are one of the main measuring instruments (hereinafter - MI) when solving problems of radiation monitoring of the environment, industrial premises, sanitary protection zones (hereinafter - SPZ), and control of human pollution.

Radiometers for photon (gamma and X-ray), alpha and beta radiation are divided into:
- low-background activity radiometers, including liquid scintillation radiometers;
- radiometers of surface contamination;
- radiometers for certification of radioactive waste (hereinafter - RW).

Spectrometers are classified into:
- low-background liquid-scintillation spectrometers;
- spectrometers for determining the radionuclide composition, including radioactive waste passports;
- human measurement spectrometers (hereinafter referred to as HMS).

In radiation monitoring, depending on the field of application, the following monitoring objects are distinguished. For radiation monitoring of the environment:
- soil samples from the territories of sanitary protection zones, production sites, etc.;
- water samples from natural and technological reservoirs, artesian wells, etc.;
- agricultural and food products;
- precipitation;
- air sampling.

When controlling contamination of surfaces:
pollution of the uniforms of employees of RO enterprises;
- superficial pollution of equipment and production areas.
- control of human pollution (surface and internal).

The radiation situation in radiation-hazardous enterprises is determined by a set of parameters characterizing the level of their exposure to personnel and the public under controlled conditions for handling sources of ionizing radiation and in the event of a radiation accident. Radiation monitoring, depending on the nature of the work, generally includes the following measurements:
- the rate of ambient/directional dose equivalent;
- the density of the flux of ionizing particles;
- superficial contamination by radionuclides;
- the volumetric activity of radioactive gases, radioactive aerosols (vapours) in the air;
- specific (volumetric) activity of radionuclides in liquids, solids and various environmental compartments;
- radionuclide deposition density to the soil;
- energy distribution of ionizing radiation (spectrometric measurements).

Currently, most of the alpha-photonic (gamma- and X-ray) spectrometers are being tested to confirm the declared metrological characteristics as a measuring tool (hereinafter - MT) the energy emitted by alpha-nuclides, X-ray and gamma radiation particles and photons to determine the radionuclide composition of the counting samples. Furthermore, the main metrological characteristic - the range of activity measurement is given most often without specifying the parameters of the counting reference (such as density or thickness of the active layer, geometric dimensions). The same situation applies to radiometers - among the metrological characteristics, the range of energies recorded and the range of values measured (activity, density of flow, etc.) are decisive also without specifying the parameters of the measuring object and the mutual location of the detector and the measuring object. It follows from [1] that spectrometers can determine the radionuclide composition of the counting sample. The radiometers in turn determine the activity of a specific nuclide, but not the total activity of the radionuclides.

When comparing the metrological characteristics of the various radiometers entered in the State register of measuring means [3], it may be noted that there are significant differences in the specification of metrological characteristics. Thus, for some MI, the geometry is given in the form of mass thickness limit values, without specifying the geometric dimensions of the counting reference for the remaining radiometers, the specified activity measurement range is normalized to the approved type in flat geometries, or not regulated at all.

The tasks of measuring the activity (specific, volumetric) of counting references other than those specified in the description or in the technical documentation (or not specified at all) of the MI are carried out using methods of measurement that have been validated in accordance with established procedure. The measurement methods shall describe the procedure for obtaining the transition coefficients of recorded pulses to the determined activity value (specific, volumetric) in the counting samples, with the obligatory indication of traceability to state standards of units of quantities.

For the range of measurements, the following characteristics shall be specified in the type approval tests and in the type description and other operational documents:
- energy range or specific radionuclide,
- energy dependence (unless a specific radionuclide is specified),
- geometry of measurements for the given range (geometrical dimensions of the measuring object and its active part, and location of the measuring object relative to the measuring element of the measuring means).

The question of how to evaluate the result of the measurements or to develop a measurement method without this basic information remains open. At present, the main methods used for testing the declared metrological characteristics of the activity measurement means (specific, volumetric) of objects, such as radioactive waste packaging, are computational. On the basis of All-Russian Scientific
Research Institute of Physicotechnical and Radio Engineering Measurements (VNIIFTRI) in 2019 work was carried out in the framework of tests of a spectrometer intended for measuring specific activity of radioactive waste in packages. The manufacturer of MI - Installations for certification of radioactive waste was provided with the calculation of the efficiency of gamma spectrum recording for the measuring object «barrel of volume 200 dm3» with uniformly distributed radionuclide, obtained by mathematical modelling methods. As part of tests to confirm the results of the manufacturer’s calculation, specialists of VNIIFTRI made a radionuclide volumetric source of metrological use based on multi-reference radionuclide Eu-152, simulating parameters of the real object of measurement [2]. The calculated and experimental dependence of the efficiency of gamma radiation recording to the energy range for the measuring object «barrel 200 dm³» is shown in Figure 1.

![Figure 1](image-url)

**Fig. 1** Results of the GEM-40 Gamma Radiation Recording Efficiency Determination for Geometry «200 dm³ barrel»

MI manufacturer by mathematical modelling methods and obtained experimentally by VNIIFTRI showed the vulnerability of the calculation method not only in absolute efficiency, but also in the behavior of the function in low energy. It is clear that mathematical modeling methods should be validated by experimental studies.

A reference base is being developed on the basis of VNIIFTRI to determine the energy dependence of the efficiency of the activity registration (specific, volumetric) of γ-emitting radionuclides in different measurement geometries. In the framework of this work, it is planned to develop and certify as reference sources of α-, β- and γ-radiation in the required measurement geometries, for example: counting references based on aerosol filters; «thick-layer» counting samples prepared from sample substance (for example, by evaporation or sunbathing, or by any other method providing a "thick" reference) based on radionuclides in accordance with regulatory documentation for testing, calibration, and verification of MI, experimental testing in the validation of object measurement techniques.

Thus, the problem of ensuring the unity of metrological characteristics of radiometers and spectrometers have been unresolved yet. The currently developed methods of mathematical modeling have shown a lack of convergence with experimental studies. A reference base is necessary to determine the energy dependence of the registration of the activity of radionuclides in various geometries.
References

[1] State standard 4.59-79 «System of product quality indicators. Measuring instruments of ionizing radiation. Nomenclature of indicators». Section 2, Table 2 (in Russian).

[2] Radionuclide sources of photon radiation of metrological purpose closed IMN-G. [Electronic resource] / Information on approved types of measuring instruments - Federal Information Fund for Ensuring the Uniformity of Measurements: http://www.fundmetrology.ru/10_tipy_si/11/7list.aspx (in Russian).

[3] Federal Information Fund for Ensuring the Uniformity of measurements of FSIS «Arshin». Access mode: http://www.fundmetrology.ru Federal Information Fund for Ensuring the Uniformity of measurements of FGIS «Arshin». Access mode: http://www.fundmetrology.ru (in Russian)