METROLOGY, QUALITY, STANDARDIZATION AND SERTIFICATION

METROLOGICAL SUPPORT OF GAMMA-RAY MEASUREMENTS IN UKRAINE

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Abstract. The specific of metrological support for different types of dosemeters are considered. Gamma-ray sensors are commonly used for measuring radiation doses as also the fluid levels in the industry. Typically, the ^{60}Co or ^{137}Cs isotopes as the radiation source are applied. For instance, in the USA, such detectors are beginning to be used as part of the Container Security Initiative [1]. Problems of their metrological assurance are becoming more general. They require the development of metrological support. There are conducted researches of calibration, metrological verification, and determination of the sensitivity of gamma-ray dosemeters, based on the joint application of installations equipped with ionizing radiation sources and of X-ray installations.

The implementation of the Program of Integration of Ukraine into the European Union requires harmonization of Ukrainian and International standards, in the field of metrological assurance of means for measuring the characteristics of ionizing radiation including. Recently, several regulatory, methodological documents and issues have been published. They concern the dosimetric measurement of gamma-ray characteristics in the field of radiation safety, diagnostics, and therapy.

Key words: Dosemeters, Reference equipment, Ionizing radiation, Calibration, Metrological assurance, Spectrum.

1. Introduction

Despite the intensive development of nuclear instrument making, there is a slow replacement and modernization of the reference equipment for metrological assurance of measuring equipment (hereinafter – ME) for ionizing radiation in Ukraine. The main challenge consists of the characteristics of the standards provided by metrology laboratories. They relate to the conditions and methods of creating the reference radiation sources for metrological verification/calibration of the MEs. Most standards do not meet the requirements of international standards. Particularly difficult is the reference setting for gamma radiation dosimetry. It needs to ensure the safety in operation with ionizing radiation sources (further IRSs), especially high-activity gamma radiation sources.

2. Goal of the Work

This work aims to study the ways of improving the reference base of Ukraine in the field of dosimetric measurements based on the analysis of the state of metrological assurance for measuring the characteristics of gamma – radiation sources.

3. Radiation Sources and Reference Base in the Field of Radiation Measurements

According to a series of standards ISO 4037 [2], the requirements for the characteristics of standard X-ray and gamma radiation as well as for the methods of their creation are established. For the latter it is necessary to use the IRS's with radionuclides, which are listed below in table 1.

Table 1

Radionuclides

No	Radionuclide	Radiation energy, keV	Half-life, days
1	^{60}Co	1173,3 1332,5	1925,5
2	^{137}Cs	661,6	11050
3	^{241}Am	59,54	157788

It is important for the application of radioactive material with sufficient activity per unit mass in radiation sources. Also, the power of the rudder (dose rate) in the air caused by the action of radioactive impurities should not exceed 1% of the power of the rudder in the air. It is also important that the contribution of external scattered radiation to the radiation from the source does not exceed 5% of the total power of the rudder in the air; this can be achieved through the use of non-collimated geometry settings (due to operation in the rooms of large sizes) and / or collimated geometry. The latter should be housed in rooms with a minimum size of 4m × 4m × 3m.

A schematic example of the installation of collimated geometry is presented in Fig. 1. Installations of this type are particularly suitable for the use of IRSs with ^{60}Co and ^{137}Cs radionuclides since they are inherent in a scattered emission contribution of less than 5%.

The installations must meet two basic requirements: the contribution of the external scattered radiation to the radiation from the source in the capsule should not exceed 5% of the total power of the rudder in the air; the power of the rudder in the air must be inversely proportional to the square of the distance from the source center to the center of the detector (within 5%).

The metrological base in Ukraine in this area is built on the reference calibration installations of the UPGD-1 (-2, -3) and UPD – Intertype, which are currently considered to be the main ones for calibration of gamma-ray dosemeters. Their main characteristics are demonstrated in Table 2.

By their design, installations of the UPGD type meet the requirements [2]. With their help, it is possible to carry out a metrological check or calibration of almost dosimetric devices, if the requirements of item 4.1 [2] are fulfilled. Consider the spectrum (Fig. 2) obtained from the calibration of the CsI gamma detector at the UPGD-2 installation. It is quite similar to the ^{137}Cs spectrum from a point source: the effect of scattered radiation is negligible, and the peak/set ratio is satisfactory.

However, in these installations for the metrological verification or calibration of gamma-ray dosemeters, several (typically 3-4) IRSs with a maximum activity of up to 10^{11} Bk (5 Curie) are the subjects to inspection. It provides the gamma-ray dosemeters testing at a dose rate range of up to 50 mg / h (at 1meter distance to the source). Whereas in many devices the measurement range is much higher, up to 10 Gy / h. Individual dosimeters for current and emergency monitoring applied to radiation-hazardous objects also have a measuring range of up to 10 Sv (10 Gy). For calibration over the entire measurement range, they must be irradiated on the UPGD installation for 160 hours.

Table 2

Main characteristics of UPGD and UPD-Inter reference installations

No	Main characteristics	UPGD	UPD – Inter
1	Source of ionizing radiation	^{60}Co, ^{137}Cs, ^{241}Am	^{137}Cs
2	Measuring range, Gy / h	$< 5\times10^{-2}$ 1)	< 3 1)
3	Range of working distances, m	0,5 – 5,0 1)	0,2 – 1,5 1)
Note 1. The approximate data are given.			

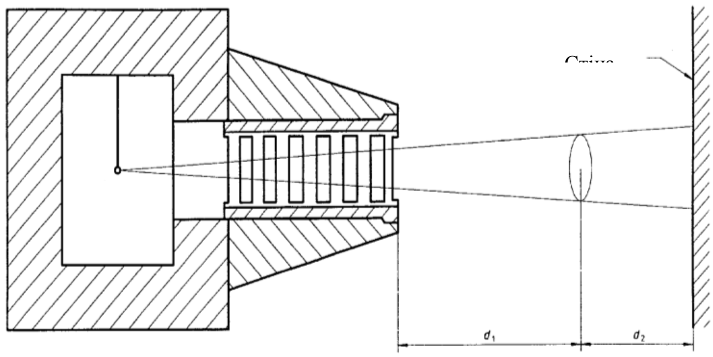

***Fig. 1**. Example of installation of collimation geometry*

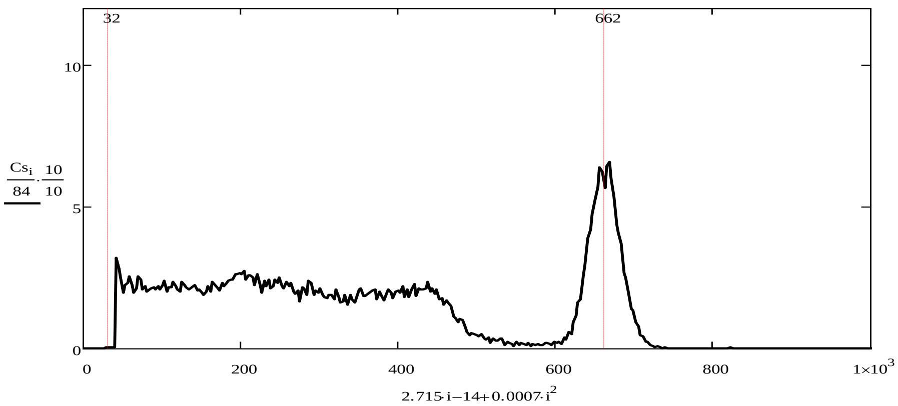

Fig. 2. Spectrum response of the gamma – CsI detector from the ^{137}Cs IRS in a thin capsule of steel at the UPGD-2 installation

The sources used in UPGD installations are stored in wall safes. When checking the dosemeters, they are taken out of the safe and installed in the collimator of the installation manually or through a mechanical hand-held device; similarly, they are returned to the safe. This operation is repeated several times during the calibration of one wideband dosemeter. It increases the dose of staff exposure.

Another problem with the metrological assurance of gamma-ray dosimetry consists of the absence (in metrological organizations) of required installations that provide a much wider range of transferred dose rates than UPGD installations. This is especially true for the calibration of wide-ranging gamma-ray dosemeters.

The UPD – Inter installation is one of the most widespread in Ukraine. It provides metrological checking/calibration of gamma-ray dosemeters over a wide range of dose rates. The installation consists of an irradiation chamber and a radiation head (collimator) with attenuators that provide a change in dose rate. The radiation head, which contains one ^{137}Cs source with an activity of ~20 TBq (550 Ci), is made of tungsten alloy and provides the formation of a radiation beam.

The side surface of the camera is made of steel and the end side is made of lead blocks. Overall dimensions – 758 x 618 x 1490 mm^3 with mass up to 1800 kg, which allows it to be used in stationary and mobile laboratories. The installation creates a radiation field of sufficient uniformity (Table 3), necessary to check most types of dosimetric devices. Unfortunately, the design of the UPD – Inter installation does not meet the requirements [2].

Fig. 3 demonstrates the experimental response of the spectrum for the gamma – detector CsI from a point source ^{137}Cs.

The spectrum clearly shows a peak of ^{137}Cs at an energy of 662 keV and an x-ray peak at an energy of 32 keV, with the contribution of scattered radiation is negligible. This spectrum can be considered standard. Figures 4-5 envisage the hardware spectra responses for the CsI gamma detector obtained in UPD – Inter installation with the ^{137}Cs IRS.

The spectrum of Fig. 4 is obtained from the UPD – Inter installation using different thickness attenuators. Here, the contribution of the scattered radiation (Compton distribution) is significant (the peak / Compton ratio is quite small). The spectrum of Fig. 5 is received without the attenuator's usage; here the scattering contribution is smaller, and there arises the scattering peak (~ 184 keV), which affects the result. As can be seen, these spectra are characterized by different shapes under different calibration conditions.

Unfortunately, while attenuating the gamma-ray beam the distance from the IRS to the effective center of the detection units becomes unknown, and the contribution of the scattered radiation becomes significant. This makes it difficult to determine the gamma-ray spectrum.

Table 3

The dependence of the size of the uniform field of the installation on the distance to the IRS

Distance to the IRS, m	0.2	0.4	1.0	1.2	1.65
Size of the field, m	0.085+ 0.068	0.155+ + 0.125	0.37+ 0.29	0.435+ 0.345	0.6+ 0.47

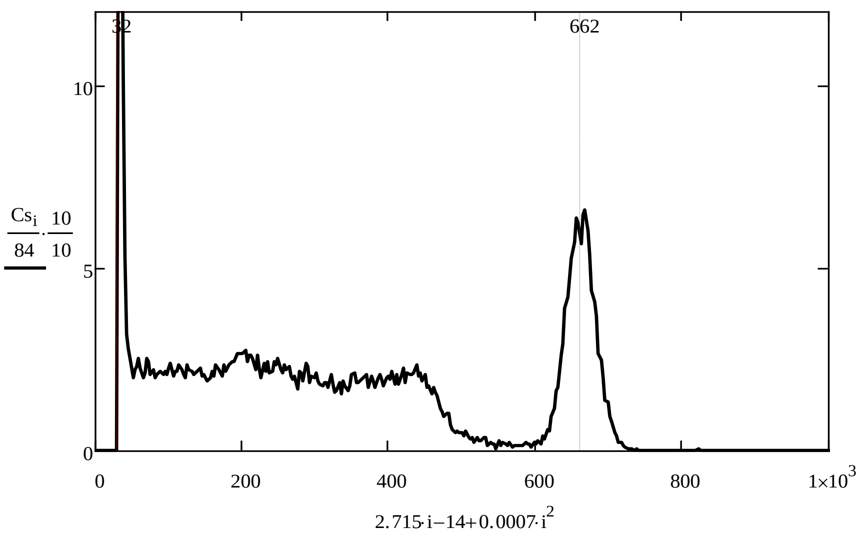

Fig. 3. Spectrum response of the gamma – CsI detector from the ^{137}Cs IRS

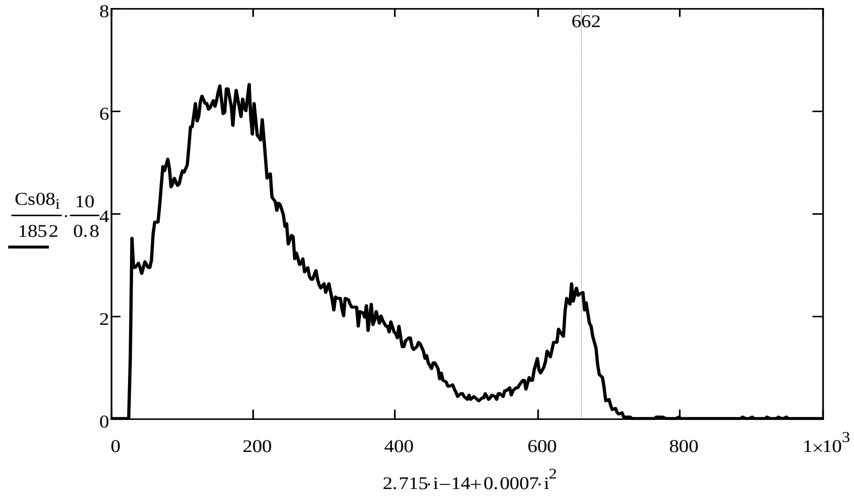

Fig. 4. Spectrum response of a gamma – CsI detector from a ^{137}Cs IRS at the UPD – Inter installation with several tungsten alloy attenuators

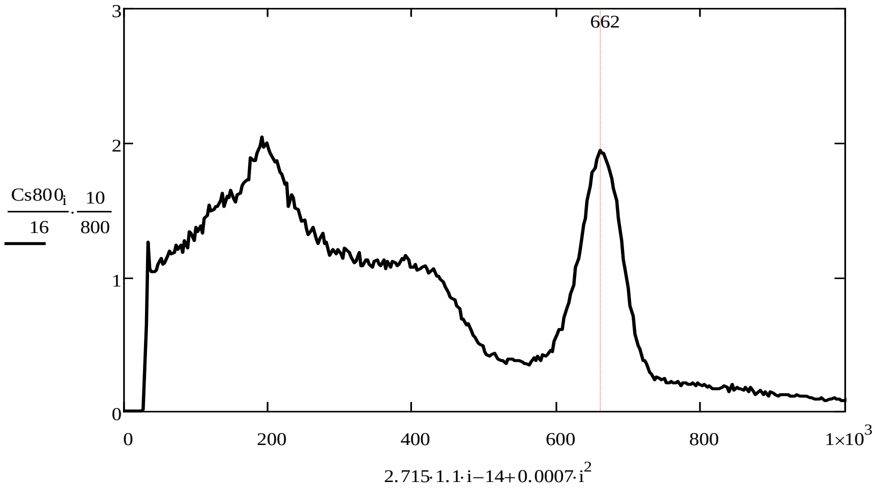

Fig. 5. Spectrum response of a gamma – CsI detector from a ^{137}Cs IRS at the UPD – Inter installation without attenuators

Transferring the unit size with reference ionization cameras for metrological checking/calibration of dosemeters with UPS – Inter installations is not always appropriate. It is allowed only on the condition that the calibration is carried out for energy-compensated measuring instruments. It should be emphasized that different energy dependence of the devices and different influences of the concomitant radiation in certain conditions can lead to considerable differences in the readings of dosemeters of different types. Therefore, the unit size transfer must be carried out by the group comparator method.

However, only the types of devices for which a specific installation is calibrated can be checked with its help. Hence, each installation has its advantages and disadvantages:

– with the help of UPGD-2 installations it is possible to carry out metrological verification/calibration of practically all types of dosemeters in a wide energy range, but not in the whole measuring range;

– using UPS – Inter installations it is possible to carry out metrological verification in a wider measurement range (due to a highly active radiation source), but the requirements for the characteristics of standard radiation are not fulfilled here.

4. Development of a Reference Base for Metrological Assurance in the Field of Radiation

The most obvious solution is to create reference installations that meet the requirements [2] with highly active sources of gamma radiation. However, the disadvantages of this solution are the next: at the considerable cost of sources, installations, and rooms for their placement there exist the problems with radiation safety.

That is why the issues have to regard the metrological verification of dosemeters at UPD – Inter installations; to concern the studies of dosemeters with different types of detectors (gas discharge meters, scintillators, ionization chambers, and others); to measure and analyze of energy spectra; to involve of different methods of calibrating installations and dosemeters with their help.

Preliminary investigations have been fulfilled of the features of an X-ray unit application in conjunction with installations equipped with IRS aiming the calibration, verification, and determination of gamma-ray dosemeters response over a wide range of dose rates. Similar work on calibration of dosemeters was previously carried out [7]. X-ray units have several advantages compared to high-power gamma-ray installations. They easier provide the radiation safety during transportation, installation, and operation; easier achieve reliable radiation protection of the exterior; at the lesser cost, the x-ray unit can block up to three orders of magnitude of dose rate.

Detection blocks of many dosemeters are characterized by a nonlinear calibration characteristic; for example, blocks based on gas meters. At high dose rates, the multiplicative component of error increases due to the presence of the time zone ("dead time") in the dosemeters characteristics. In many dosemeters, the upper limit of the measurement range is 10 Sv / h (10 Gy / h).

The linearization of the calibration characteristic is performed by the block processor introducing an adjustment for the period of operation by the formula: $X=K\times N\times(1-\tau\times N)^{-1}$. Here X is the measured radiation, for instance power of the rudder in the air, Gr · s^{-1}; K is the conversion factor (sensitivity) of the detection unit; N is the pulse rate, imp · s^{-1}; τ is the “dead time”, s.

Therefore, for the calibration of gamma-ray dosemeters, to determine the mentioned component of the error, IRSs are required, which ensure the reproduction of the dose rate at 6-8 Sv / h. Then only the sensitive detecting sub-range of the measuring mean is checked on the UPGD and UPD – Inter installations; in rough subrange of the measuring instrument its efficiency is checked only at the beginning of the mentioned subrange. At the same time, the response to the ^{137}Cs gamma radiation source at one point of the subrange beginning is determined first, and then the linearity of the calibration characteristic across the entire measurement range is investigated with the help of the X-ray installation.

5. Conclusions

As a result of the conducted researches the possibility of calibration, metrological verification as well as the determination of the sensitivity of gamma-ray dosemeters, based on the method of joint use of installation, completed with the sources of ionizing radiation, and X-ray installations, is proved. The essence of the method consists of the determination of the sensitivity to the gamma source – ^{137}Cs radiation at one point at the beginning of the range (UPGD or UPD – Inter installation), followed by the involvement of an X-ray installation for studying the linearity of the calibration characteristic over the entire measurement range. The main problems limiting the X-ray installations in metrological testing of dosemeters are related to the instability of the X-ray tube and the continuous spectrum of X-rays. If the first problem is solved with a reference dosemeters, then the second problem is much more complicated due to the nature of radiation formation.

6. Acknowledgments

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7. Conflict of Interests

Conflict of interest while writing, preparing, and publishing the article as well as mutual claims by the co-authors is absent.

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