Calibrator of radioactive preparation doses for nuclear medicine based on CsI(Tl) crystals

Yu.A.Borodenko, V.V.Belogub, B.V.Grinyov, A.V.Gektin, A.V.Didenko, E.M.Selegenev, V.A.Tarasov, S.Kh.Cherevatova*, Yu.A.Deryachenko*

Institute for Scintillation Materials, STC "Institute for Single Crystals", National Academy of Science of Ukraine, 60 Lenin Ave., 61001 Kharkiv, Ukraine
*Institute of Child and Adolescents Health, Academy of Medical Sciences of Ukraine, 52 50-richchya VLKCM Ave., 61153 Kharkiv, Ukraine

Received January 10, 2010

A dose calibrator for nuclear medicine was developed and manufactured. In contrast to the existing analogs which use ionization chamber as a detecting device, the dose calibrator is based on the system scintillator-photodiode. This allows to considerably decrease the dimensions and weight of the device and to provide its operation in spectrometric regime. The latter makes it possible to determine not only the activity of physiological solution, but also the type of radionuclide. The dose calibrator was pretested at the Institute of Child and Adolescent Health of Ukraine (Kharkiv) and showed positive results.

Разработан и изготовлен калибратор доз для ядерной медицины. Отличительной особенностью калибратора доз является то, что в отличие от известных аналогов, работа которых основана на использовании в качестве детектирующего устройства ионизационной камеры, в данном калибраторе доз в качестве детектирующего устройства используется система сцинтиллятор-фотодиод. Это выгодно отличает данный прибор от аналогов, так как, помимо значительного уменьшения габаритов и веса измерительного блока, он работает в спектрометрическом режиме, что позволяет кроме активности физраствора определять еще и тип радинонуклида. Калибратор доз прошел предварительные испытания в Институте охраны здоровья детей и подростков АМН Украины г.Харьков и показал положительные результаты.

1. Introduction

Modern medicine uses various kinds of tomographs, gamma-ray chambers and other devices for diagnostics and therapy of different diseases of human viscera at their early stages. For this purpose, a special physiological solution containing short-lived radioisotopes is introduced in the circulatory system. The use of the above-mentioned devices allows to study the intensity of blood circulation in different viscera, for identification of deviations from the normal state. The activity of the introduced radionuclide is measured by means of special facilities — dose calibrators.

The detecting device of all known dose calibrators [1–3] is an ionization chamber, normally filled with inert gas under pressure. Located along the axis of well-type chamber is a cavity for a glass to place the analyzed sample contained in a syringe or vial.

The work of calibrators of these types is based on the absorption of gamma-quanta by inert gas inside the ionization chamber followed by ionization of the gas, which results in the creation of a short current pulse registered by a control and indication unit. Since the atomic number of inert gas is low, the efficiency of gamma-quanta registration is not high and does not exceed

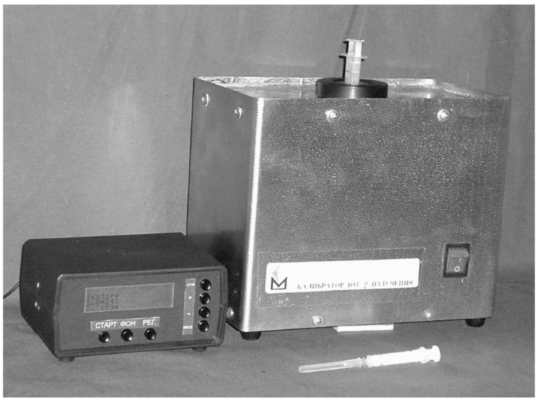

Fig. 1. External appearance of the dose calibrator.

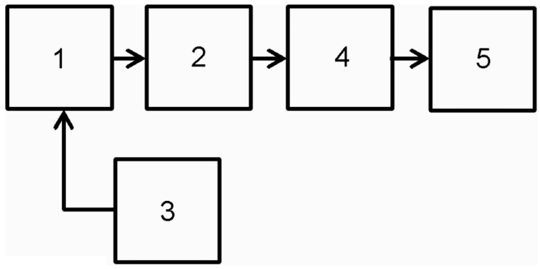

Fig. 2. Structural diagram for the detection assembly: *1* — SC-PD detector; *2* — charge-sensitive amplifier; 3 — voltage transformer; *4* — shaper; *5* — power amplifier.

15 % for energies of ≈0.1 MeV. With the growth of gamma-radiation energy, the registration efficiency diminishes, that is why for raising the efficiency of gamma-quanta registration by gas counters one has to increase their volume and, correspondingly, the total dimensions of the measuring chamber and the lead shield. This causes a significant increase of the weight and price of gas counters with dose calibrators.

At present, technical progress in the area of scintillation crystals [4] and photosensitive elements preconditioned the development of dose calibrators based on other detection systems, in particular, those of scintillator — photodiode type [5–7].

2. Experimental

The detecting element of the developed calibrator of ionizing radiation doses is the system scintillator-photodiode. It is designed in the form of scintillator — PIN-photodiode assembly based on CsI(Tl) crystal (i.e. CsI(Tl)-based spectrometric gamma-radiation detector). This allowed to decrease the dimensions of the device which in its turn made it possible to reduce the calibrator weight and cost. Since the density of CsI(Tl)) crystal is much higher than the one of inert gas, for ~ 5 mm thick crystal the registration efficiency of gamma-quanta with a radiation energy of e.g. ~ 0.14 MeV (technetium — 99_m isotope) reaches ~ 90 %. Moreover, unlike gas counters, spectrometric detectors permit to directly identify the type of isotope in physiological solution from the radiation energy, which in the case of gas counters is to be made indirectly. High spectroscopic characteristics and direct identification of the isotope type increase the accuracy of activity measurements in comparison with the analogs.

Presented in Fig. 1 is the external appearance of the calibrator. It consists of the measuring chamber and the unit for registration and display of the measurement results.

The main component of the dose calibrator is the detecting unit which is a part of the measuring chamber. The scheme of the detecting unit is presented in Fig. 2.

Detector *1* consists of 4×4×5 mm CsJ(Tl) scintillator joined with silicon p-i-n photodiode with 4×4 mm photosensitive area by means of optical cement. The measuring chamber is designed in the form of rectangular casing made of stainless steel sheet containing a measuring glass where standard ∅10 and ∅14 mm vials or 1 ml, 2 ml, 5 ml, and 10 ml medical single-use syringes can be placed. The measuring glass is made of stainless steel and has ~ 10 mm thick walls. With the walls of such a thickness, the glass plays the role of passive attenuator of gamma-radiation, which is required due to high sensitivity of the detection block. The working range of gamma-radiation energies registered by the unit lies within the limits of 0.025÷3.0 MeV, thereat the sensitivity of the assembly ranges between the natural radiation background and ~ 10^9 Bq.

Table 1 presents the main technical characteristics of the dose calibrator.

3. Results and discussion

Per se, the developed calibrator is a spectrometer with one "window". With the help of the control unit, the width of this "window" can be set for the whole of the energy range of 0.025÷3.0 MeV. This regime is useful when a preparation may contain the impurity of another isotope. For example, during the making of physiological solution containing technecium-99_m isotope, the im-

Table 1. Main technical characteristics of the dose calibrator

No.	Characteristic	Value
1.	Detection unit type	scintillator + p-i-n photodiode
2.	Scintillator type and dimensions, mm	CsI(Tl) 4×4×5
3.	Range of registered energies, MeV	0.025÷3.0
4.	Energy resolution, %: – for ^{241}Am line – for ^{137}Cs line – for ^{60}Co line	 20 5 4
5.	Sensitivity range, Bq	from background level up to ≈10^9
6.	Time of measurement, sec	1÷10
7.	Dimensions of standard vessels for measurement of isotope activity: – vials, mm – syringes, ml	 ∅10, ∅14 1, 2, 5, 10
8	Calibrator control	– by detecting unit – by computer
9.	Overall dimensions, mm – detecting unit – measuring chamber	 150×110×70 250×200×150

purity of molybdenum isotope may appear. However, such a regime leads to a significant increase in the noise level which complicates the work of the dose calibrator at low energies. In the other regime of the calibrator work, the control unit is used to narrow the width of the "window", and to shift it smoothly by hand within the whole of the energy range for adjusting the dose calibrator to the radiation energy of a particular isotope. This information is fed into the main memory, and then the dose calibrator is automatically tuned for discrete energies of isotopes which are most often used in medical practice.

Presented in Fig. 3, 4 and 5 are the amplitude spectra obtained from the detecting unit of the dose calibrator for different radionuclides.

As seen from Fig. 3–5, the detecting unit of the dose calibrator possesses a good energy resolution. High energy resolution and sensitivity were achieved due to thorough elaboration of the construction of SC-PD detector. This work was conducted in several directions: choice and preparation of the scintillation crystal, application of light-reflecting and spectrum-shifting coatings, choice of photodiode with optimum electrical parameters, development of the detector assembly and mounting technologies [8].

Besides this, developed specially for this detection unit was a low-noise charge-sensitive amplifier with the input characteristics optimally corresponding to the photodiode output parameters, i.e. dark current and p-n transition capacity [9]. The optimum working point with respect to the minimal noise level was established by choosing the value of the voltage shift on photodiode.

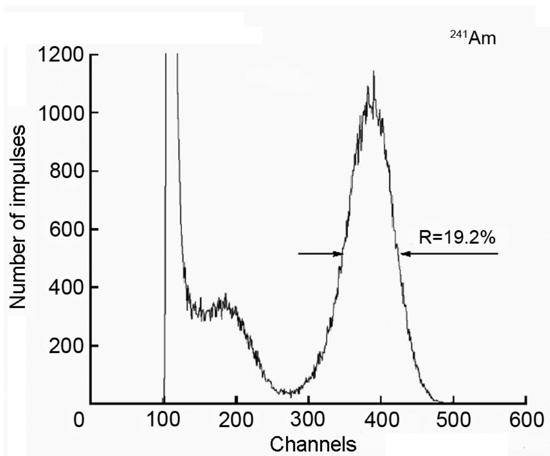

Fig. 3. Amplitude spectrum of CsI(Tl) + PD assembly at registration of 59.6 keV γ-quanta with from ^{241}Am source.

Preparation of CsI(Tl) scintillation crystal for manufacture of the assembly was mainly reduced to thermo-mechanical treatment which removed internal stresses and made the stoichiometric composition in the

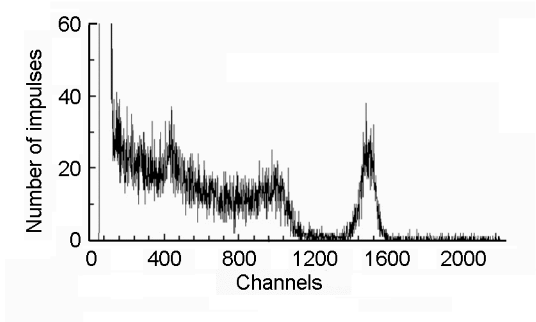

Fig. 4. Amplitude spectrum of CsI(Tl) + PD assembly at registration of 662 keV γ-quanta from ^{137}Cs source.

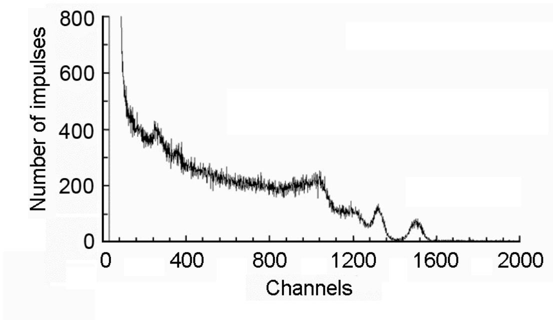

Fig. 5. Amplitude spectrum of CsI(Tl) + PD assembly at registration of 1.17 MeV and 1.33 MeV γ-quanta from ^{60}Cs source.

Table 2. Results of dose calibrator testing

Calculated activity, mBq	400	38	38	280	250	275	46	200
Calibrator-measured activity, mBq	368	41	40	265	235	270	51	192
Vessel capacity, ml	14	1	1	10	10	12	2	12
Time of measurement, sec	1	1	5	1	1	1	5	5

crystal volume homogeneous. On the one hand, this led to the increase of the crystal transparency in the region of its own radiation spectrum and, on the other hand, to a certain rise of the technical light output. The performed measurements demonstrate that the technical light output may increase up to ~ 10 %.

Special attention has been paid to the choice of the geometrical shape of the crystal. Since the photodiode must possess minimal dark current ($R_T > 10^{10}$ Ohm) and low p-n transition capacitance (<50 pf at a shift tension of ~ 30 V), one must use a photodiode with a minimal photosensitive area. At the same time, to increase the efficiency of gamma-radiation registration it is necessary to increase the volume (i.e. dimensions) of the scintillation crystal. To solve this problem, there was made a chamfer on one end of the crystal, which cross-section was larger than the photosensitive area, at an angle established experimentally and making 40÷45° with the photodiode surface [10]. Besides this, the size of the scintillator output window precisely corresponded to that of the photodiode photosensitive area.

Thus, all the above-mentioned technological methods allow to achieve high sensitivity for the small-size detection unit.

The developed dose calibrator was pretested at the radiology laboratory of the Institute of Child and Adolescent Health of Ukraine in Kharkiv. During the tests controlled was the activity of technecium-99_m isotope which was obtained in a special generator of GT-2m type. Every portion of the obtained preparation with technecium-99_m isotope was controlled by the developed dose calibrator and compared with the calculated data from a special table drawn up for the generator. The results of the performed investigation are presented in Table 2.

As seen from Table 2, the measured values somewhat differ from the calculated ones. This is connected with the errors in establishing the exact volume of physiological solution, caused by small size of the vial and the presence of a meniscus on its walls. Overall, the dose calibrator readings coincide well with the calculated data. In our opinion, they are more reliable, since the calibrator registers each gammy-quantum absorbed by the scintillation crystal.

4. Conclusions

Thus, the developed dose calibrator not only measures the activity of this or that isotope, but also allows to identify the isotope type in the cases when the main isotope may have the impurity of another isotope. The fact that the dose calibrator can realize the function of spectrometer significantly widens its application field.

References

1. Prospect of firm PTW Freiburg GmbH, Germany, www.ptw.de/isotope_calibrators.html?&cId=3424
2. Prospect of firm NT Amplituda, Russia, www.amplituda.ru

3. Prospect of firm IBA Dosimetry. The ActIBAmeter, www.iba-dosimetry.com/sites/default/files/ActIBAmeter.p.
4. B.V.Grinev, B.G.Zaslavskii, A.M.Kudin et al., *J. Opt. Techn.*, **76**, 367 (2009).
5. WWW.detector.org.ua/detectors.html.
6. Hamamatsy WWW.hamamatsy.com.
7. Detection Technology http//www deetee.com.
8. A.M.Kudin, Yu.A.Borodenko, B.V.Grinyov, *Instr. and Exper. Techn.*, No.1, 39 (2010).
9. V.V.Nekrasov, V.V.Belogub, Yu.A.Borodenko et al., *Functonal Materials*, **12**, 159 (2005).
10. V.P.Semynozhenko, B.V.Grinyov, V.V.Nekrasov, Yu.A.Borodenko, *Nucl. Instrum. Meth. Phys. Res.*, **F537**, 383 (2005).

Калібратор доз радіоактивних препаратів для ядерної медицини на основі кристалів CsI(Tl)

Ю.А.Бороденко, В.В.Белогуб, Б.В.Гриньов, А.В.Гектін, А.В.Діденко, Е.М.Селегенев, В.А.Тарасов, С.Х.Череватова, Ю.А.Деряченко

Розроблено і виготовлено калібратор доз для ядерної медицини. Відмінною особливістю калібратора доз є те, що у відмінності від відомих аналогів, робота яких заснована на використанні іонізаційної камери як детектуючого пристрою, у даному калібраторі доз як детектуючий пристрій використовується система сцинтилятор-фотодіод. Це вигідно відрізняє даний прилад від аналогів, оскільки, крім значного зменшення габаритів і ваги вимірювального блоку, він працює у спектрометричному режимі, що дозволяє, крім активності фізіологічного розчину, визначати ще і тип радіонукліду. Калібратор доз пройшов попередні випробування в Інституті охорони здоров'я дітей і підлітків АМН України (м. Харків) та показав позитивні результати.