A method for lateral localization of a compact gamma source in radionuclide diagnostics

A K Berdnikova1, A I Bolozdynya1, V A Kantserov1, A K Kondakov1,2, I Pashkovich1 and I A Znamenskiy1,2

1 National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
2 Pirogov Russian National Research Medical University (RNRMU), Ostrovitianov str.1, Moscow, Russia, 117997

E-mail: akberdnikova@mephi.ru

Abstract. A method for lateral localization of a gamma source in a medium with a miniature single channel scintillation detector is developed and experimentally tested. Method is based on simultaneous registration of two (or more) gamma lines emitted from an area of increased uptake of a radiopharmaceutical in the patients body. The proposed method is tested with the most widely used medical radioisotope technetium-99m which has a 140 keV gamma emission line and a 18 keV characteristic x-ray line. The results of experimental studies show that the lateral coordinate of a point-like 99mTc source can be determined with an accuracy of ± 4 mm at the depth of soft tissues equivalent phantom up to 30 mm.

1. Introduction
Radionuclide diagnostic procedures are nowadays established as a golden standard of the early cancer diagnosis [1]. The principle of emission radionuclide diagnostics is based on the accumulation of a dedicated radiopharmaceutical in areas of interest of a patient’s body and following visual reconstruction of these areas. Certain radionuclide procedures can be performed directly during a surgical operation in order to localize more precisely an affected formation which has to be removed, or, in some cases, to specify a stage of a malignancy process [2]. Such type of medical procedures is called radioguided surgery, and requires a dedicated gamma detecting instrumentation. Typically miniature gamma probes based on a scintillation crystal or on a semiconductor detector are used to detect the radiation emitted by radiotracer during radioguided surgery.

However, commercially available gamma probes allow only to determine a projection of an area of radiotracer uptake on a surface of a patient’s body, and do not provide any information about a depth of its placement within the soft tissues. The goal of this work is to develop and experimentally confirm a method for lateral localization of a gamma source in a medium with a miniature single channel scintillation detector.

2. Lateral localization of a compact gamma source
The proposed method of lateral localization of an area of an increased radiotracer uptake is based on the difference of the linear attenuation coefficient for gamma lines of different energies. The relative difference in intensities of gamma lines which were emitted from the same depth of the material allows one to determine a thickness of the layer of the absorber. In this paper it is proposed to implement this possibility in medical radionuclide diagnostics, due to the fact that the most widely
used medical radionuclide $^{99m}$Tc aside from a gamma line with an energy of 140 keV has a characteristic x-ray line of 18 keV.

According to the Beer-Lambert law in a narrow beam geometry the radiation intensity after passing a layer of absorber depends on an initial intensity, radiation energy and medium properties:

$$I = I_0 e^{-\mu x},$$

where: $I$ – the intensity of gamma rays after passing through the slab of material,
$I_0$ – the initial intensity,
$\mu$ – linear attenuation coefficient of the material,
$x$ – thickness of the layer of the material.

In a wide beam geometry a contribution of scattered radiation is also considered by a so-called buildup factor $B$. Buildup factor depends on the geometry of an experiment, properties of the material and energy of gamma-radiation. In that case the ratio of intensities of two gamma lines of different energies is:

$$\frac{I_1}{I_2} = \frac{I_{01} e^{-\mu_1 x B_{21}}}{I_{02} e^{-\mu_2 x B_{21}}} = \frac{I_0}{I_2} e^{-\frac{(\mu_1 - \mu_2)}{x B_{21}}},$$

where $B_{21}$ is the total buildup factor. In most cases a buildup factor cannot be calculated analytically, and can only be evaluated experimentally.

A set of experimental tests was previously carried out in order to confirm a proposed method with a cadmium telluride semiconductor detector and a laboratory point-like $^{137}$Cs gamma source (662 keV, 32 keV) [3]. Due to the high energy resolution of a semiconductor detector it is possible to measure an energy spectrum of $^{137}$Cs with a low discrimination threshold and to resolve a low energy gamma line in order to calculate a total absorption peaks ratio. The next step of the study is to confirm a proposed method with a usage of a single channel scintillation detector and an actual medical gamma source $^{99m}$Tc.

3. Experimental setup

For the experimental study of the proposed method a point-like $^{99m}$Tc gamma source was used.

For registration of gamma radiation a miniature LaBr₃:Ce scintillation detector was used. Optical readout is carried out with a SensL MicroFC silicon photomultiplier (SiPM) with an active area of 3×3 mm², which is optically coupled to the scintillation crystal. SiPM and scintillator are packed together in a sealed aluminum housing with a wall thickness of ~ 200 µm. According to the results of experimental studies this detector provides an energy resolution of 4.9% at 662 keV gamma energy line [4].

The scheme of the experiment is presented in the figure 1. In order to imitate human soft tissues a polymethylmethacrylate phantom was used. A point-like $^{99m}$Tc gamma source was placed between the plates at the increasing distances from the detector, which was fixed on the top of the phantom. Signals from the SiPM were digitized and recorded with a Lecroy oscilloscope, which has an integrated amplitude to digital converter.

Experimental pulse height spectra, obtained at the depths of 5 and 15 mm of the source placement in PMMA phantom, are shown in the figure 2. In the presented spectra one can see peaks of the photoelectric absorption of 18 keV characteristic x-ray line and 140 keV gamma emission line of $^{99m}$Tc. Due to the detector shielding with a lead collimator (wall thickness of 3 mm, aperture diameter 4 mm), a contribution of Compton events in the spectra is reduced. Area of the total absorption peaks defines the intensity of radiation of the corresponding energy after passing the bulk of PMMA. In the figure 2 spectra of $^{99m}$Tc are normalized to the heights of 140 keV total absorption peaks and one can
see the difference in relative intensity of 18 keV x-ray line at the surface of the phantom at the different depths of source placement.

**Figure 1.** Scheme of an experimental setup.

![Experimental setup diagram](image)

**Figure 2.** Energy spectra of $^{99m}$Tc at different depths of source placement in PMMA obtained with a LaBr$_3$:Ce scintillation detector.

4. **Experimental results**

The ratio of 18 keV total absorption peak area to 140 keV peak area was measured for $^{99m}$Tc pulse height spectra obtained at the distances from 0 to 40 mm between the source in the phantom and the detector, with a 5 mm step. The experimental plot of the dependence between the ratio of 18 keV to 140 keV peaks areas ($I_1/I_2$) and the material layer thickness ($x$) is presented in the figure 3. Experimental data is approximated with an exponential function.

The resulting dependence shows that the lateral coordinate of the source placement can be reconstructed for the depth of soft tissues equivalent phantom up to 25-30 mm.

In order to evaluate the minimal time needed to perform measurements with an adequate error a dependence of lateral localization error from data acquisition time was calculated. Given that the average lymph node activity is $\sim$ 40 kBq and sensitivity of the detector to 140 keV gamma radiation is
known to be 650 cps/MBq (at the depth of 30 mm) [5], according to the equation (2) data acquisition
time which provides ± 4 mm accuracy of lateral localization was calculated to be ~ 60 s.

Figure 3. Ratio of 18 keV line intensity to 140 line intensity vs depth of the source placement in PMMA.

5. Conclusion
In this work a method for determination of the depth of the radiotracer uptake spot in the human soft
tissues is developed and experimentally tested. Experiments with a point-like $^{99m}$Tc gamma source
placed inside a PMMA soft tissues equivalent phantom and a single channel LaBr$_3$:Ce scintillation
detector were carried out to measure the dependence between the 18 keV and 140 keV lines intensities
and the PMMA layer thickness. Experimental results showed that the dependence can be fitted with an
exponential equation, which can be used for the detecting system calibration. Data acquisition time
required to obtain provides ± 4 mm accuracy of lateral localization was calculated to be ~ 70 s for the
depth up to 30 mm of the source placement in a soft tissues equivalent phantom.

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