Bioinformatics, Proteomics and Immaging Analysis

OMMEGA Publishers
Answering Intelligence
www.ommegaonline.org

Mini Review Open Access

Recent Advances of Radiation Detector Systems in Nuclear Medicine Imaging

Eugene Stephane Mananga[1,2,3*]

[1]Physics Department, The Graduate Center, The City University of New York, 365 Fifth Avenue, New York, NY, USA
[2]Department of Engineering, Physics, and Technology, BCC, The City University of New York 2155 University Avenue, CPH 118, Bronx, New York , USA
[3]Department of Applied Physics, New York University, 6 Metrotech Center, Brooklyn, New York, USA

***Corresponding author:** Eugene Stephane Mananga, Physics Department, The Graduate Center, The City University of New York, 365 Fifth Avenue, New York, NY, USA; E-mail: emananga@gradcenter.cuny.edu

Abstract

A common radiation detector system is an instrument that can identify the presence of radiation in the environment, on the surface and within people. In this paper I argue that the most important design criterion in a radiation detector system is its energy resolution. In the first part of the paper I explore the form of radiation detector systems encountered in nuclear medicine imaging and in the second part of the paper I reconnoiter the recent advances of radiation detector systems in nuclear medicine imaging.

Received Date: November 16, 2016
Accepted Date: November 20, 2016
Published Date: November 25, 2016

Citation: Mananga, E.S. Recent Advances of Radiation Detector Systems in Nuclear Medicine Imaging (2016) Bioinfo Proteom Img Anal 2(2): 169- 171.

Radiation detector systems in nuclear medicine imaging

A radiation detector system in nuclear medicine imaging is definitely a timely topic or area of research where not many papers are available in the literature of nuclear medicine imaging. Arguably, no single device can detect all kinds of radiation and no one device is useful in all situations. Understanding of the principles of radiation detection and the characteristics of the commonly encountered detection devices is essential in nuclear medicine imaging. All radiation detector systems share the characteristic that the radiation incident on the transducer produces ionization effects that are not directly observable. The ideal radiation detector system achieves high quantum detection efficiency by effectively absorbing the radiation of interest. As a US National Institute of Health (NIH-T32) Research Fellow at Massachusetts General Hospital and Harvard Medical School, I had the opportunity to be a member of the Center for Advanced Medical Imaging Sciences now called the Gordon Center for Medical Imaging[1]. During my training, I worked in physics and instrumentation in nuclear medicine[2]. In this article, I am reviewing the types of detectors encountered in nuclear medicine and the recent advances of radiation detector systems in nuclear medicine imaging.

The detectors have been used in numerous medical applications such as isotope preparation, studies of biological samples, anatomical studies, whole-body counting, *in vivo* counting, and body-function studies[3]. The types of detectors encountered in nuclear medicine are gas-filled detectors, solid-state (semiconductor) detectors, and scintillation (organic and inorganic) detectors. The ideal detection system will have very good energy resolution, which implies that the detector resolves and discriminates efficiently different radiation energies[4]. The energy resolution is the capability of a detection system to accurately control the deposited energy of the photon[5]. Scintillation detectors are the most extensively used detectors in nuclear medicine and in this paper, we briefly review some of their aspects. Detectors are used in three types of devices: the Anger Camera or gamma camera (SPECT), positron emission tomography (PET), and in vivo probes. Since the development of the first gamma camera by Hal Anger in 1957, major improvements including software developments have been made in nuclear medicine[6]. Currently, single photon emission computed tomography (SPECT) systems can have as many as three large field of view camera heads that have the capability of acquiring data while in motion. Improvements in gamma camera technology lead to the improvement of the spatial resolution, sensitivity, and uniformity. Nearly a decade and half ago, Schmand[7] developed a hybride PET/SPECT instrument to function in both, the SPECT and PET modality. New hardware and software developments are continually being assessed to refine the performance of gamma camera systems[3].

DOI: 10.15436/2381-0793.16.1183

Scintillation detectors are widely used as gamma-ray detectors that form the basis for almost all PET scanners in use today. It is worth noting that in PET detectors based on scintillators detectors, the high-energy annihilation photons (511 keV) are absorbed by the scintillator and the burst of low-energy optical photons (few eV) are emitted by the scintillator. Each interaction of a 511 keV photon in the scintillator produces a single electric pulse[6]. *In vivo* counting systems are used to detect radioactivity that has been injected into patient. Quintessential single-element device *in vivo* probe measures a specific organ or anatomical region.

In early 2016, Sabet et al[3]. published an article that corroborates the feasibility of a new method for fabrication of high spatial resolution CsI:T1 scintillation detectors for SPECT.

In 2012, Dr. Majewski[8] gave a remarkable comprehensive lecture at Fermilab on medical applications of radiation detectors. His presentation illustrates how the advances in detector systems can play a major role in the development and future of nuclear medicine, experimental nuclear and high energy physics. Seco et al[9]. published an important review article on the characteristics of radiation detectors for dosimetry and imaging. The article focused on describing the range of technologies used for detecting ionizing radiation in the medical field. It is worth noting that the advances in imaging and therapy will both be driven by advances in detector technology which will pave the way for new types of measurement and improvements in imaging to ensure the safety of staff and patients.

Recent advances of radiation detector systems in nuclear medicine imaging

Recent advances of radiation detector systems in nuclear medicine imaging include laser-induced optical barriers (LIOB) [6], high-band gap semiconductor crystal or cadmium zinc telluride (CZT) that can be operated at room temperature[10,11], a new scintillation light detection concepts for PET called lutetium-yttrium-oxyorthosilicate (LYSO) which is a scintillation crystals coupled to two specially designed, planar and extremely thin (200 micron) position-sensitive avalanche photodiodes (PSAPD), and advanced Time-of-Flight (TOF) PET photon detectors.

Laser-Induced Optical Barriers[2,3]

Currently, the Gordon Center for Medical Imaging is developing advances radiation detector systems for nuclear medicine, intraoperative imaging probes, and computed tomography applications to stringently investigate some of the fundamental obstacles on high-performance imaging systems[2]. Recent work of the Gordon Center includes but not limited to the design of novel and cost-effective platforms to fabricate radiation detectors using laser processed scintillators[3]. Through the use of laser-induced optical barriers technology, the Gordon Center is investigating new designs of scintillator detectors for PET, SPECT, and CT imaging modalities that were not possible before. The laser-induced optical barriers method consists of focusing a pulsed laser beam inside the scintillator bulk. An optimized pulse with respect to the wavelength, pulse energy, duration, refractive index of the crystal, etc. can locally alter the crystal structure thus creating an optical barrier that has different index of refraction with respect to its immediate surrounding media[1]. These optical barriers can be used as a surrogate to mechanically pixelate arrays and can bestow high spatial resolution while sustaining the sensitivity in a high-throughput and cost-effective mode. The following graph (Figure 1) shows the stages of radiation detection.

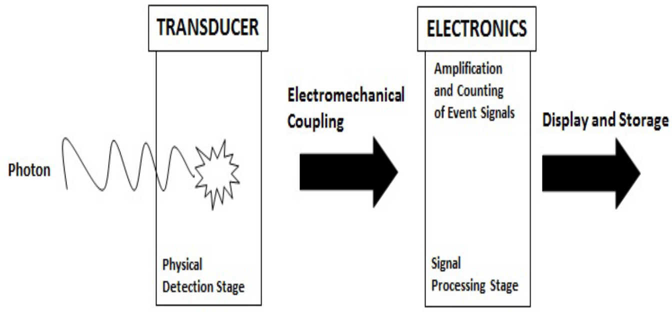

Figure 1: Basic components of a scintillation detector.

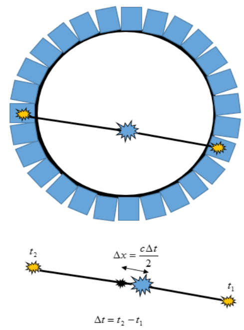

Figure 2: Time-of-Flight Principle.

High-Band Gap Semiconductor Crystal, Cadmium Zinc Telluride[10,11]

Most of the PET systems being developed utilize scintillation detector technology to convert the two 511 keV annihilation photons emitted from the subject into electronic signals for determining spatial, energy, and temporal information. The detectors are commonly displayed in the shape of a cylinder surrounding the subject. At Stanford University, Levin's group[10,11] employed a promising semiconductor detector material called cadmium zinc telluride (CZT) to study a high resolution, box-shaped PET detector system. The CZT has the advantage of a highly efficient, direct conversion of annihilation photons into an electrical signal, without requiring the intermediate steps of creating, collecting, and converting light as is the case for scintillation detectors5. But, unlike scintillation detectors, CZT detectors can localize the three-dimensional coordinates of individual photon interactions in the system. With the use of advanced algorithms, this feature empowers accurately the first interaction coordinate for more uniform spatial and better image contrast resolutions throughout the sensitive volume. CZT detectors delineate a significant sudden rise for PET technology that will advance the ability to detect, visualize and quantify subtle molecular signals associated with disease. Furthermore, CZT has numerous properties that make it attractive as a photon detector in PET applications. Overall, the system-level metrics show that this detector is adept of providing excellent performance and shows great promise for development into a full small animal PET imaging system[10,11]. Several agencies including the IAEA and the U.S. Department of Defense have studied spectroscopic-grade CZT for use in the detection of special nuclear materials in the field of nuclear nonproliferation[5].

New Scintillation Light Detection Concepts for PET[12,13]

A new high performance scintillation detector technology for PET has been investigated in the group of Professor Levin at Stanford University[12]. The basic concept of the new scintillation detector consists to build position sensitive photon detector modules. These basic block detector modules are used to build high performance clinical or pre-clinical (small animal) PET systems. Reference[13] describes the new high performance scintillation detector technology employed in the breast-dedicated PET system. The module is in the form of many detector layers. Each layer comprises two planar arrays of 1 x 1 x 1 mm^3 lutetium-yttrium-oxyorthosilicate (LYSO) scintillation crystals coupled to two specially designed, planar and extremely thin (200 micron) Position-Sensitive Avalanche Photodiodes (PSAPD), each with a 8 x 8 mm^2 sensitive area. The PSAPD has both high light sensitivity and an intrinsic resolution that is finer than 1 mm which allows the system to generate large electronic signals and precise positioning of the light flashes resulting from the absorption of a 511 keV in any crystal. The PSAPD replaces the Photo Multiplier Tubes (PMT) used in standard PET designs.

Photo-Detectors for Time of Flight Positron Emission Tomography (ToF-PET)[14]

The time of flight positron emission tomography (ToF-PET) is considered to be among the most recent advances in photo-detector design. ToF-PET (see Figure 2) information yields better localization of the annihilation event along the line of response (LOR). This effect results to an enhancement in the signal to noise ratio of the reconstructed image. Apart from the demand of high luminosity and fast decay time of the scintillation crystal, proper design and selection of the photo-detector and methods for arrival time pick-off are a prerequisite for achieving excellent time resolution required for ToF-PET14.

In conclusion, as in any mini review of this type, many significant and model efforts have not been mentioned. To those whose excellent work has not been mentioned, I have a profound respect for the work that has already been done on radiation detector systems in nuclear medicine imaging. I would also like to encourage you to submit any findings to the Journal of Imaging Science (JIS). To those who are inspecting new incursion into the field of Nuclear Medicine and medical imaging, I invigorate you to join a body of scientists who like to push their intuition and themselves to the boundaries.

References

1. Eugene S. Mananga, Georges El Fakhri, Joshua Schaefferkoetter, et al. Myocardial Defect Detection Using PET-CT: Phantom Studies. (2014) Plos One 9(2): e88200.
2. Gordon Center - MGH - Harvard/research/PET-CT-SPECT-Instrumentation.
3. Sabet, H., Bläckberg, L., Uzun-Ozsahin, D., et al. Novel laser-processed CsI:Tl detector for SPECT. (2016) Medical Physics 43(5): 2630.
4. Ranger, N.T. Radiation Detectors in Nuclear Medicine. (1999) Imag Therapeutic Technol 19(2): 481-502
5. Wernick, M.N. Asrsvold, J.N. Emission Tomography: The Fundamental of PET and SPECT. (2004) Elsevier Academic Press pp: 596
6. M. Schmand, Higher Resolution PET by Means of a New Scintillator LSO, Ph.D. thesis, Max-Planck-Institute for Neurological Research.
7. Stan Majewski. Medical Applications of Radiation Detectors. (2012) Fermilab.
8. Joao Seco, Ben Clasie, Mike Partridge. Review on the characteristics of radiation detectors for dosimetry and imaging. (2014) Phys Med Biol 59: R303-R347.
9. Gu, Y., Matteson, J.L., Skelton, R. T., et al. Study of a high-resolution, 3D positioning cadmium zinc telluride detector for PET. (2011) Phys Med Biol 56(6): 1563–1584.
10. Peng, H., Levin, C.S. Design study of a high-resolution breast-dedicated PET system built from cadmium zinc telluride detectors. (2010) Phys Med Biol 55(9): 2761–2788.
11. Phelps, M.E. PET: Molecular Imaging and its biological applications (2004). Springer
12. Vandenbroucke, A.,. Foudray, A. M. K., Olcott, P.D., et al. Performance characterization of a new high resolution PET scintillation detector. (2010) Phys Med Biol 55(19) : 5895–5911.
13. Gu, Y., Pratx, G., Frances, W.Y. et al. Effects of multiple-interaction photon events in a high-resolution PET system that uses 3-D positioning detectors. (2010) Medical Phy 37
14. Spanoudaki, V.C.H., Levin, C.S. Photo-Detectors for Time of Flight Positron Emission Tomography (ToF-PET). (2010) Sensors 10(11): 10484-10505.

Ommega Online Publisher
Bioinformatics, Proteomics and Immaging Analysis
Short Title : Bioinfo Proteom Img Anal
E-mail: imagingscience@ommegaonline.com
website: www.ommegaonline.org