Introduction

The history of nuclear medicine is rich with contributions from gifted scientists across different disciplines in physics, chemistry, engineering, and medicine. The multidisciplinary nature of nuclear medicine makes it difficult for medical historians to determine the birthdate of nuclear medicine. This can probably be best placed between the discovery of artificial radioactivity in 1934 and the production of radionuclides by Oak Ridge National Laboratory for medicine related use, in 1946.[1] Nuclear medicine imaging technologies are viewed in the context of anatomy, physiology and molecular level to diagnosis of disease, assessment of response to treatment and determination of drug’s distribution throughout the body.[2-4] The concept of emission and transmission tomography, later developed into a single photon emission computed tomography (SPECT), was introduced by David E. Kuhl and Roy Edwards in the late 1950s.[1]

Single photon emission computer tomography is a computerized tree-dimensional image processing for demonstration of acquisitioned image by gamma camera.[5] The function of the scintillation crystals in the nuclear medicine imaging systems is production visible light from hitting high energy $\gamma$-rays.[6] Many physical factors degrade SPECT images, qualitatively and/or quantitatively. Researching on quality improvement is proceeding on the gamma camera and SPECT system for assessment the quality and quantity of images.[7]

Growing interest in the development of new scintillator materials is pushed by increasing the number of medical, industrial and scientific application.[8] Detectors are the heart of a SPECT system and are responsible for collecting the high-energy photons emitted by the patient, estimating the photon energy and location of interaction, and generating count data for subsequent image reconstruction.[8] A scintillation crystal with high luminous efficiency, short decay time, low cost, high density, short radiation length, good spectral match to photodetectors and without afterglow is more favorable.[9-11]

The luminous efficiency can reduce the radiation absorbed dose to patients by decreasing radiopharmaceutical injection dosage as concerns about patient safety.
Short decay time is important for special resolution and photon detection. The afterglow is also a critical parameter and is often induced by some traps from crystal detects.\textsuperscript{16,12} Afterglow in halides is believed to be intrinsic and correlated to certain lattice defects. Bismuth germinate (BGO) and cadmium tungstate crystals are examples of low after glow scintillation materials. Despite the acknowledge advantages of the CsI: Tl in many scintillator applications, a characteristic property that undermines its use in high-speed radiographic and radionuclide imaging is the presence of a strong afterglow component in its scintillation decay. This causes pulse pileup in high count rate applications, reduced energy resolution in radionuclide imaging, and reconstruction artifacts in computed tomography applications.\textsuperscript{[23]} Materials with high atomic numbers and high density are important for detector efficiency. The materials shown in Table 1 have comparable effective densities. Both energy resolution and spatial resolution depend on the size of the signal generated with each detected event.\textsuperscript{[14,15]} Studies continue to get good crystals with different materials for obtaining of an image with the best quality.

\textbf{Scintillation Crystal Materials}

Research and development of new scintillator materials are mainly triggered by the growing needs of modern medical imaging and high energy physics.\textsuperscript{[16]} The first and most common crystal which was introduced in 1948 was thallium activated sodium iodide (NaI: Tl).\textsuperscript{[13]} NaI: Tl is a crystal with reasonable price, a proper luminance efficiency and an acceptable energy range, which it makes a common crystal for use in most nuclear medicine imaging equipment. Studies continue to get a good image quality for an accurate diagnosis.\textsuperscript{[18]} NaI: Tl properties include: The density of 3.47 g/cm\(^3\), a decay time of 230 ns and an energy resolution of 7.2 [Table 1].

Derenzo \textit{et al.} (1990) compared NaI: Tl and BGO [Table 1] and found that later is more sensitive mainly due to its higher density. BGO with a density of 7.13 g/cm\(^3\), proper absorption of \(\gamma\)-rays, decay time of 300 ns and an energy resolution of 12 was proposed as a proper candidate.\textsuperscript{[19,20]} Chewpraditkul \textit{et al.} (2009) compared voltage of 662 kilo electron volte in terms of energy resolution in lutetium-yttrium oxyorthosilicate, cesium activated yttrium aluminium garnet (YAG: Ce) and lutetium aluminium garnet activated by cerium (chemical formula Lu3Al5O12), (LuAG: Ce). YAG: Ce is a crystal’s material with high-speed oxidation and its effects on atomic number and density. YAG: Ce has a density 4.55 g/cm\(^3\), decay time of 70 ns and energy resolution 7.2.\textsuperscript{[16,21]} LuAG: Ce has energy resolution of 6.7 and 70 ns decay time is better than BGO.\textsuperscript{[22]} As well as LuAG: Ce has better detection rate than YAG: Ce because of higher density (6.76 g/cm\(^3\)) and atomic number (58.9).\textsuperscript{[16]}

Another crystal is cesium activated yttrium aluminium YAP: Ce has high density of 5.37 g/cm\(^3\) and decay time of 25 ns is a good time. Energy resolution (6.7) YAP crystal is better than YAG.\textsuperscript{[24]} Figure 1 shows a diagram of YAG energy resolution.

\textbf{Crystal, Mixed Rare-Earth Silicate}

These are two different types of new crystals with suitable characteristics in nuclear medicine; CRY018 and CRY019. CRY018 crystal has a density of 4.5 g/cm\(^3\), decay time of 45 ns and detection of 425 nm wavelength. CRY018 scintillation detectors are intended and preferred for use in electron microscopy, \(\beta\)- and X-ray counting, as well as for electron and X-ray imaging screens.\textsuperscript{[24]} CRY019 crystal has density of 7.4 g/cm\(^3\), 46 ns decay time and detection of 4.2 nm wavelength and preferably used for \(\gamma\)-ray detectors (positron emission tomography and SPECT system) and high spatial resolution imaging screens for X-ray, \(\gamma\)- and \(\beta\)-rays.\textsuperscript{[25]}

\begin{figure}[h]
\centering
\includegraphics[width=0.7\textwidth]{tcm_01755}
\caption{\(^{99}\)mTc spectrum from cesium activated yttrium aluminium garnet detector\textsuperscript{[16]}}
\end{figure}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
 & NaI: Tl & BGO & YAG: Ce & YAP: Ce & CRY018 & LuAG: Ce & CRY019 \\
\hline
Density (g/cm\(^3\)) & 3.67 & 7.13 & 4.35 & 5.37 & 7.4 & 6.76 & 4.50 & 5.78 & 5.08 \\
Light output (% NaI: Tl) & 100 & 15-20 & 40 & 60 & 40-75 & 20 & 80 & - & 160 \\
Decay time [ns] & 230 & 300 & 70 & 25 & 46 & 70 & 45 & 1 & 26 \\
Energy resolution (%at 661 keV) & 7.2 & 12 & 7.2 & 6.7 & 8.5 & 6.7 & 7 & 0.5 & 2.7 \\
\hline
\end{tabular}
\caption{Comparison of the characteristics of nuclear medicine used - detectors in different case of studies}
\end{table}

\textsuperscript{NaI:Tl: Thallium-activated sodium iodide; BGO: Bismuth germinate; YAG: Ce: Cesium activated yttrium aluminium garnet; LuAG: Ce: Lutetium aluminium garnet activated by cerium; CZT: Cadmium zinc telluride; \textit{LaBr}_3: Lanthanum bromide; ns: Nano second}
Development of Crystal

Mirela Angela et al. (2011) evaluated cerium-activated lanthanum bromide (LaBr₃) and LaCl₃ as new nuclear medicine detectors, in terms of energy resolution, processing speed of light (decay time), the high temperature stability, high γ-ray detection efficiency and crystal size. The LaBr₃ was used in in vivo for administration of I-131 in the thyroid to obtain acceptable results and consequently was enunciated as appropriate detector. The properties that make the LaBr₃:Ce scintillator detector attractive for different applications based on γ-ray spectrometry are very good energy resolution, very fast light output decay, enabling high count rate applications, high temperature stability, high gamma detection efficiency, operation at room temperature, promising technology for manufacturing crystal at larger sizes. LaBr₃ is a good crystal material and has an excellent energy resolution and short decay time (16 ns) and the best gamma radiation detection rate. The crystal shows excellent energy resolution values good radiation absorption properties and speed. LaBr₃ is a good a crystal material and has an excellent energy resolution and short decay time (16 ns) and the best gamma radiation detection rate. The crystal shows excellent energy resolution values good radiation absorption properties and speed. LaBr₃ is a good a crystal material and has an excellent energy resolution and short decay time (16 ns) and the best gamma radiation detection rate. The crystal shows excellent energy resolution values good radiation absorption properties and speed.

LaBr₃ is one of the most excellent detectors in nuclear medicine, this detector has high energy resolution that good proportionality characteristic and also CZT is a detector with good density, high energy resolution and lowest decay time in comparison with other detectors. Thus, until now, collected data from studies demonstrated that CZT can be the best detector. Research and studies continue about advantages and disadvantages of detectors, and also the best application of them in diagnostic imaging in the future.

Conclusion

Single photon emission computed tomography detector has more important effect to get a good image. Utilization of a suitable detector is necessary in obtaining high-quality images for better diagnosis. Many crystals have been evaluated in preclinical studies, and some of them have advantage in comparison with others due to chemical structure characteristics. For example, BGO is a crystal with the highest density and YAP:Ce has high density, and decay time of 25 ns is a good time, expressed a suitable detector than YAG:Ce. CRY018 and CRY019 crystals have high density and suitable decay time, but they haven’t good energy resolution. Moreover, LaBr₃ is one of the most excellent detectors in nuclear medicine, this detector has high energy resolution that good proportionality characteristic and also CZT is a detector with good density, high energy resolution and lowest decay time in comparison with other detectors. Thus, until now, collected data from studies demonstrated that CZT can be the best detector. Research and studies continue about advantages and disadvantages of detectors, and also the best application of them in diagnostic imaging in the future.
References

1. Imaginis.com-History of nuclear medicine. Available from: http://www.imaginis.com/nuclear medicine/history of nuclear medicine. [Last updated on 2008 Jun 10].

2. Kulver J, Aker S, Achilefu S. Multimodality molecular imaging with combined optical and SPECT/PET modalities. J Nucl Med 2008;49:169-72.

3. Garcia EV, Faber TL, Esteves FP. Cardiac dedicated ultrafast SPECT cameras: New designs and clinical implications. J Nucl Med 2011;52:210-7.

4. Rahmim A, Zaidi H. PET versus SPECT: Strengths, limitations and challenges. Nucl Med Commun 2009;29:190-207.

5. Hofstadter R. Alkali halide scintillation counters. Phys Rev C 1948;74:100-1.

6. Liu B, Shi C. Development of medical scintillator. J Chin Sci Bull 2002;47:1057-63.

7. Ibrahim ES, Nadia LH, Mohie ED, Rizk AM. Evaluation of varying acquisition parameters on the image contrast in spect studies. Int J Res Rev Appl Sci 2012;13:2.

8. Chemwedzikul W, Moszynski M. Energy and timing resolutions of Ce$^{3+}$- Doped Lu$_2$Al$_2$O$_{12}$, La$_2$SiO$_5$ and LaBr$_3$, single crystal scintillators. J Res Dev Bank Plc 2012;35:133-42.

9. Holly TA, Abbott BG, Al-Mallah M, Calnon DA, Cohen MC, DiFilippo FP, et al. Single photon-emission computed tomography. J Nucl Cardiol 2010;17:941-73.

10. Moses WW. Scintillator requirements for medical imaging. In: Vitaly M, editor. Proceedings of International Conference on Inorganic Scintillators and their Application. Moscow: Moscow State University; 1999. p. 11.

11. Melcher CL. Perspectives on the future development of new scintillators. Nucl Instrum Meth A 2005;537:1: 6-14.

12. Wu Y, Ren G, Meng F, Chen X, Ding D, Li H, et al. Ultralow-concentration Sm codoping in CsI:Tl crystals and its effect on afterglow. Radiat Meas 2007;42:541-44.

13. Ovetchkina EE, Gaysinskiy V, Miller SR, Brecher C, Lempicki A, Nagarkar VV. Multiple doping of CsI: Tl crystals and its effect on afterglow. Radiat Meas 2007;42:297-300.

14. Ovechkina EE, Gaysinskiy V, Miller SR, Brecher C, Lempicki A, Nagarkar VV. Multiple doping of CsI: Tl crystals and its effect on afterglow. Radiat Meas 2007;42:541-44.

15. Moses WW. Scintillator requirements for medical imaging. In: Vitaly M, editor. Proceedings of International Conference on Inorganic Scintillators and their Application. Moscow: Moscow State University; 1999. p. 11.

16. Melcher CL. Perspectives on the future development of new scintillators. Nucl Instrum Meth A 2005;537:1: 6-14.

17. Wu Y, Ren G, Meng F, Chen X, Ding D, Li H, et al. Ultralow-concentration Sm codoping in CsI:Tl crystals and its effect on afterglow. Radiat Meas 2007;42:541-44.

18. Ovetchkina EE, Gaysinskiy V, Miller SR, Brecher C, Lempicki A, Nagarkar VV. Multiple doping of CsI: Tl crystals and its effect on afterglow. Radiat Meas 2007;42:541-44.

19. Crystals.saint-gobain.com. BGO Bismuth germinate scintillation material. Available from: http://www.crystals.saint-gobain.com. [Last updated on 2014 Apr 03].

20. Yang H, Peng F, Zhang Q, Guo C, Shi C, Liu W, et al. A promising high-density scintillator of GdTiO$_3$ single crystal. Cryst Eng Comm 2014;16:2480-5.

21. Kusano Y, Suda K, Ishizawa N, Yamada T. Crystal growth and properties of (Lu, Y)$_2$Al$_2$O$_{12}$. J Cryst Growth 2004;260:59-165.

22. Lo B, Saldiazi G, Benatti P, Bolitti D, Cencelli VO, Cinti MN, et al. Optical physics of scintillation imagers by GANT4 simulations. Nucl Instrum Methods Phys Res Sect A 2009;607:259-60.

23. Moszynski M, Kapusta M, Zalipska J, Balcerzyk M, Wolski D, Szawloowski M, et al. Low energy γ-rays scintillation detection with large area avalanche photodiodes. IEEE Trans Nucl Sci 1999;46:880-5.

24. Crytur.cz. CRY018 - The new scintillation material. Available from: http://www.crytur.cz/content_pages/view/31. [Last updated on 2013 Nov 10].

25. Crytur.cz. CRY019 - The new scintillation material. Available from: http://www.crytur.cz/content_pages/view/32. [Last updated on 2013 Nov 10].

26. Saizu MA, Catalano MA. Lanthanum bromide scintillation detector for gamma spectrometry applied in internal radioactive contamination measurements. UPB Sci Bull Ser A 2011;73:4.

27. Pani R, Cinti MN, Pellegrini R, Bennati P, Betti M, Vittorini F, et al. LaBr$_3$ scintillation gamma camera prototype for X and gamma ray imaging. Nucl Instrum Methods Phys Res Sect A 2007;576:15-8.

28. Moszynski M, Plettner C, Nassalski A, Szczesniak T, Swiderski L, Synfivel-Kazuch A, et al. A comparative study of silicon drift detectors with photomultipliers, avalanche photodiodes and PIN photodiodes in gamma spectrometry with LaBr$_3$ crystals. IEEE Trans Nucl Sci 2009;56:1006-11.

29. Pani R, Cinti MN, De Notaristefani F, Pellegrini R, Bennati P, Betti M, et al. Imaging performances of LaCl$_3$:Ce scintillation crystals in SPECT. IEEE Nucl Sci Symp Conf Rec 2004;4:2283-7.

30. Danube-Willenspoon ME, Surfi S, Perkins A, Kyba CC, Wiener R, Werner ME, et al. The imaging performance of a LaBr$_3$-based PET scanner. Phys Med Biol 2010;55:45-64.

31. Iniewski K. CZT detector technology for medical imaging. J Nucl Cardiol 2014;9:11; C11001.

32. Iniewski K. CZT detector technology for medical imaging. J Nucl Cardiol 2014;9:C11001.

33. Gehealthcare.com. CZT Technology: Fundamentals and Applications. Available from: http://www3.gehealthcare.com. [Last updated on 2014 Dec 09].

34. Tepper GC, Kessick R, Szeles C. Investigation of the electronic properties of cadmium zinc telluride surfaces using pulsed laser microwave cavity perturbation. SPIE Proc. 2001;4571: 79-89.

35. Essays.se. The Alcyone CZT SPECT camera. Evaluation of performance using phantom measurement and Monte Carlo simulations. Available from: http://www.essays.se/about/Monte+Carlo+simulations/?Startrecord=21. [Last updated on 2014 Dec 18].