Isotopes for New Modalities of Medical Imaging

C. Rangacharyulu[1], M. Fukuda[2], H. Kanda[2], N. Takahashi[2], S. Nishizaki[3], T. Fukuchi[4], H. Watabe[5], LTK Ly[6] and HTK Trang[6]

[1] University of Saskatchewan, Saskatoon, SK, Canada, S7N 5E2
[2] RCNP, Osaka University, Osaka, Japan
[3] Iwate University, Morioka, Japan
[4] RIKEN, Kobe, Japan
[5] Tohoku University, Sendai, Japan
[6] HCMUS, Ho Chi Minh City University of Sciences, Saigon, Vietnam

We embarked on a series of investigations of radioisotopes for medical imaging to enhance the image quality without an increase in the administered dose to the patient, to identify the isotopes and production mechanisms to render them economically viable options to developing countries and examine the imaging modalities as hybrids of SPECT/PET and photon correlations in beta minus decays. This program was initiated under the RI platform of Japan comprising of RCNP, RIKEN, and Tohoku universities.

In this regard, our first approach was to combine the positron emission tomography(PET) and single photon emission computed tomography (SPECT) to be carried out by a single isotope. While there are a few candidate isotopes, we performed our first measurements during the Spring 2017 beam time at the AVF cyclotron of RCNP. The results are published in JRNC [1].

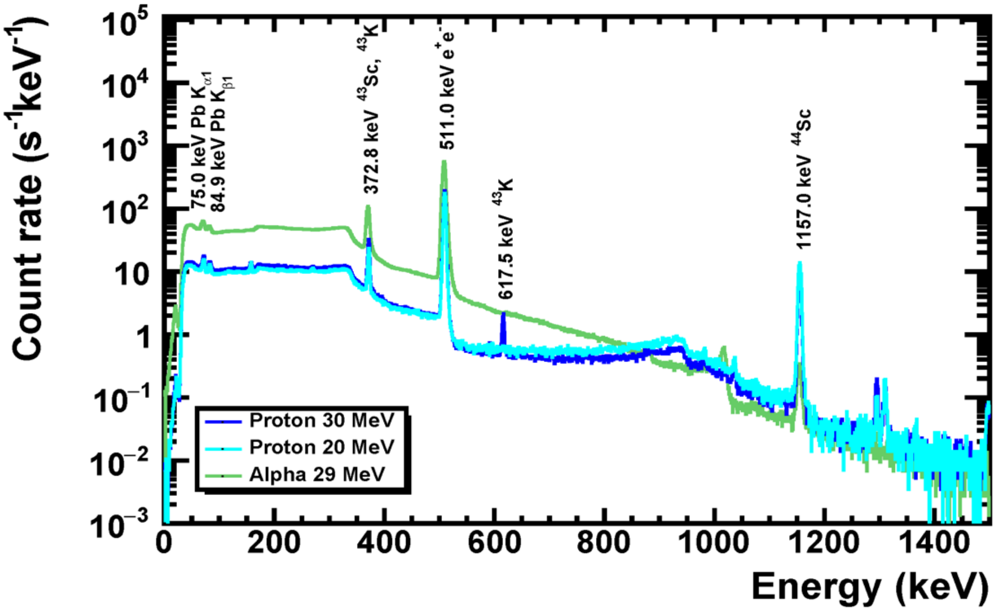

Figure 1: The gamma ray spectra of the natural Ca(p,x) and Ca(α,x) reactions for energies E_p= 20 and 30 MeV and E_α= 29 MeV.

This work identified the optimal irradiation protocols for the production of $^{43,44}Sc$ isotopes. The alpha production channel is the cleanest way to produce copious quantities of ^{43}Sc isotope.

More recently, we embarked on studying the possibility to employ gamma- gamma coincidence in the β^- decays as alternate to PET imaging to address the following weaknesses of PET:

i) The stopping point of positron does not coincide with the location of the decay nucleus. The positron wanders in the medium, which varies with its energy, which itself is not unique due to the nature of beta decays (3-body). The ranges of positrons of some PET imaging isotopes are listed at the end of this document. This causes two problems:
   a. The annihilation point does not coincide with the decay vertex of the isotope
   b. The random motion of positron causes blurring of the image.

ii) The annihilation photons are always collinear (180 degrees apart) and depth information is not available, unless one does TOF measurements. Even with TOF resolutions of the order of 100 pico seconds, one is still limited to vertex determination of a few centimeters.

In contrast, two photon correlations following the beta decays has these advantages:

i) The photons are emitted from the daughter nucleus, which is at the site of parent nucleus, being as heavy as the parent itself. The photon emission point is a direct measure of the location of the isotopes. This minimizes blurring too, since no random motion is to be considered.
ii) The two photon correlations, while being specific to each pair, they are mostly non-collinear. This feature offers an advantage, not available to PET, that we can reconstruct the vertex from the correlations. The parity conservation ensures a symmetry around 90 degrees, ensuring a good coverage over wide range of angles to determine a vertex to, likely, unprecedented precisions and enhanced contrast of the images.

Recently, we proposed to perform experiments with the gamma cascades of the β^- decays of ^{43}K isotope to be produced in $^{44}Ca(p,2p)$ reaction. These experiments are expected to run in Spring 2018. Currently, plans are underway to perform simulations and an imaging experiment in 2019.

References:

[1] C. Rangacharyulu, M. Fukuda, H. Kanda, S. Nishizaki and N. Takahashi, 2017 Assessment of $^{43,44}Sc$ isotope production in proton- and alpha induced reactions, J.Radioanal. Nucl. Chem. DOI 10.1007/s10967-017-5515-4

[2] Maurizio Conti and Lars Eriksson, 2016 Physics of pure and non-pure positron emitters for PET: a review and a discussion, *EJNMMI Physics*20163:8
https://doi.org/10.1186/s40658-016-0144-5

TABLE 1: The ranges of positrons in water for some isotopes of PET imaging interest is given below. The data are from Ref.2.

Isotope	Half-life	Branching (β^+) in %	E_{max} (MeV)	E_{mean} (MeV)	R_{max} (mm)	R_{mean} (mm)
^{11}C	20.4 min	99.8	0.960	0.386	4.2	1.2
^{13}N	10.0 min	99.8	1.199	0.492	5.5	1.8
^{15}O	2 min	99.9	1.732	0.735	8.4	3.0
^{18}F	110 min	96.9	0.634	0.250	2.4	0.6
^{64}Cu	12.7 h	17.5	0.653	0.278	2.5	0.7
^{89}Zr	78.4 h	22.7	0.902	0.396	3.8	1.3