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YIELDS CALCULATIONS FOR POSITRON EMISSION TOMOGRAPHY (PET) FOR NON-STANDARD RADIONUCLIDE

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ABSTRACT

The PET scans provide images that pinpoint the anatomic location of abnormal metabolic activity within the body. A radionuclide suitable for labeling a wide range of radiopharmaceuticals for positron emission tomography imaging is used also for local therapy of tumors. Among the possible methods for cyclotron production of radionuclide used in PET. We investigate the proton irradiation to produce the standard radionuclide (^{15}O, ^{11}C, ^{13}N, ^{18}F) and some non-standard Radionuclide (^{76}Br, ^{124}I, ^{60}Cu, ^{66}Ga, ^{86}Y and ^{89}Zr). The total integral yield based on the main published and approved experimental results of excitation functions were calculated.

KEYWORDS: Positron Emission Tomography, Medical Radioisotopes Production

INTRODUCTION

Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose and determine the severity of or treat a variety of diseases. Radioactivity plays an important role in medical science in terms of beneficial applications in both diagnosis and therapy. The former entails the introduction of a short-lived radionuclide attached to a suitable pharmaceutical into the patient and measurement of the accumulation and movement of activity from outside. This process is called “emission tomography” and involves the measurement of either a single low-energy γ-ray (i.e. Single Photon Emission Tomography (SPECT)), or coincidences between the two 511-keV photons formed in the annihilation of a positron (i.e. Positron Emission Tomography (PET)). A PET scan measures important body functions, such as blood flow, oxygen use, and sugar (glucose) metabolism, to help doctors evaluate how well organs and tissues are functioning.

Principles

Positron emission tomography (PET) is a gamma imaging technique that uses radiotracers that emit positrons. In PET the gamma rays used for imaging are produced when a positron meets an electron inside the patient’s body, an encounter that annihilates both electron and positron and produces two gamma rays travelling in opposite directions. By mapping gamma rays that arrive at the same time the PET system is able to produce an image with high spatial resolution. Certain radioisotopes decay by positron emission, and such radioisotopes can be used as tracers. If injected into the body, they can be readily followed because the emission of the annihilation pairs of coincident gamma rays at 180° allows their source to be located along a line figure 1[1]. When a positron is emitted by a nucleus, it almost instantly finds an electron and the pair annihilates, converting all the mass energy of the two particles into two gamma rays. The two gamma ray photons possess momentum, and the conservation of momentum requires that they travel if opposite directions.

A simultaneous detection of gamma ray photons in two detectors places the source on a line between those detectors.

Application

The basis of PET imaging is the labeling of small, biologically important molecules, such as sugars, amino acids, nucleic acids, receptor-binding ligands, or even water and molecular oxygen, with positron-emitting radionuclides. When these positron-emitting tracers undergo radioactive decay, their positions can be detected by the PET scanner. By imaging the temporal distribution of these labeled compounds, we can create “physiologic maps” of the functions or processes relevant to the labeled molecules [2, 3]. However, it is able to provide true 3D information. This information is typically presented as cross-sectional slices through the patient, but can be freely reformatted or manipulated as required. PET has incomparable abilities to determine the metabolic activity of tissues but needs the assistance of higher-resolution, anatomic information that it cannot provide. [4, [5]

- We can resume the steps of diagnosis and prognosis as follows:
- location and extent of disease
- General or tumour-specific probes
- Size, stage, grade of disease
- Proliferation and/or hypoxia
- Real time "Therapy Evaluation"
- Customizing treatment could increase efficacy, decrease toxicity, and improve economics

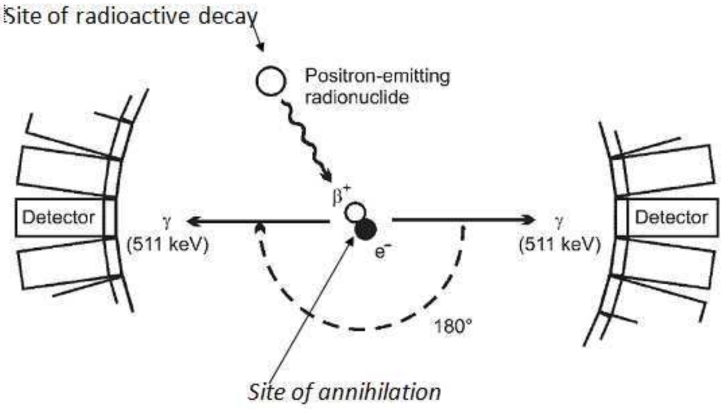

Figure 1: Annihilation Pairs of Coincident Gamma Rays at 180° Allows their Source to be Located Along a Line[1]

METHODS

The feasibility of the production of PET radionuclides via various nuclear reactions was investigated. PET Radionuclides production by the reactions of proton standard PET Radionuclide are shows in table 1, we calculate the excitation functions of the non-standard PET Radionuclides table 2 using the available data in the international libraries, according to SRIM code[6], the thick target integral yields were deduced using the calculated evaluated cross sections. A Matlab sub programs was used to solve the following yield equation[7,8]:

$$Y = NP\sigma(E).10^{-30}(1-e^{-\lambda t}) \quad (1)$$

Whereas, $\sigma(E)$ (mb) is the average cross section at a specific energy (E); N is the number of target atoms/cm2, λ is the decay constant of the produced isotopes, P is the number of incident protons/sec for (1 μA) and t is the irradiation time (t= 1 h). The integral target yield is calculated by summing up the differential yields.

RESULTS AND DISCUSSIONS

^{60}Cu Production by Proton Particles

^{60}Ni (p,n)^{60} Cu reaction is beneficial energy range of proton energy producing ^{60} Cu from a ^{60}Ni target is from 7 to 12 MeV ,the maximum cross-section obtained according to A. V. Muminov et al [9] is obtained, the production yield of ^{60}Cu using SRIM code and equation(1) in the chosen energy range is 209.2 GBq/C as shown in figure 2. This reaction appears to be suitable for the purpose of copper-60 production by a low-energy cyclotron.

^{86}Y Production by Proton Particles

The ^{86}Sr (p, n)^{86}Y reaction is an important proton incident particle for producing ^{86}Y from enriched ^{86}Sr targets. Several authors M. A. Avila-Rodriguez and, J. A. Nye et al [10-11] studied the energy range of proton energy producing ^{86}Y from 2 to 11 MeV, the cross-section is obtained. The theoretical thick-target yield using SRIM using eq.(1) is found to be equal to 7.398 GB q/C as shown in figure 3. This reaction appears to be good for the purpose of ^{86}Y production to use in PET[12].

^{89}*Zr* Production by Proton Particles

^{89}Y (p, n)^{89}Zr reaction is beneficial energy range of proton energy producing ^{89}Zr from ^{89}Y target is 7 to 30 MeV ,the cross-section obtained according to V. N. Levkovskij [13], H. M. Omara et al[14], G. F. Steyn et al[15], B. Satheesh et al[16] and Zhao Wenrong et al[17] is obtained the production yield of ^{89}Zr using SRIM code was obtained using eq.(1) in the chosen energy range and found to be 3.0986 GBq/C as shown in figure 4. This reaction appears to be suitable for the purpose of ^{89}Zr production by a low-energy cyclotron and cheap target to use in PET[18].

^{124}I Production by Proton Particles

Six cross section data sets were found in the literature for producing ^{124}I from ^{124}Te by using the p, n reaction, one data set by Acerbi et al[19] ,Kondo et al[20], Van Den Bosch et al[21], Scholten et al[22], Zweit et al[23]and Qaim et al[24]in the range 6 to 31 MeV. The obtained production yield of ^{124}I in the chosen energy range is 13.56GBq/C. The yield of this reaction is shown in figure 5 and This reaction appears to be good for the purpose of Iodine-124 production [25].

^{76}Br *Production* by Proton Particles

The ^{76}Se (p, n) reaction is an important proton incident particle for producing ^{76}Br. Data of four authors by V. N. Levkovskij [13] , Z. Kovacs et al[26] , H. E. Hassan et al[27]] and R. J. Nickles [28] ,, were founded in the literature in the energy range from 6.5 to 29.5 MeV . It's found that this reaction produce ^{76}Br with the maximum cross-section of 654mb occurred in 16.5MeV. The theoretical thick-target yield obtained using SRIM and equation (1) was found to be equal to 15.3662 GBq/C as shown in figure 6. This reaction appears to be very good for the purpose of ^{76}Br production and to use in PET[29] .

CONCLUSIONS

The production of non-standard Radionuclide to be used in PET can be obtained using different isotopes. Table (1) shows some isotopes known as standard PET radionuclides. Table 2 shows some of non- standard PET radionuclides with there nuclear characteristics. Different nuclear reactions can produce **^{60}Cu** but for low proton energies, the reaction ^{60}Ni(p, n) gives the largest yield (209.2 GBq/C) **and** this yield is very suitable for the use in PET.

The ^{86}Sr (p, n) reaction play an important role in ^{86}Y production, for low proton energy the yield of is about 7.398 GBq/C and very appropriate to be use in PET[30].

The **^{89}Y (p, n)** reaction appears to be suitable for the purpose of ^{89}Zr production by a low-energy cyclotron it's a cheap target and very useful to be use in PET[18].

The **^{124}Te(p, n)** reaction produce ^{124}I in the chosen energy range and give a yield of 13.56GBq/C , This reaction appears to be good for the purpose of Iodine-124 production and can be use in PET. It can be **p**referably used as a substitute for iodine 131 and iodine-*125* [25, 31].

Table 1: Characteristics of Standard PET Radionuclides

Isotope	Half-life	Max. β^+ Energy(Kev)
^{11}C	20min	386
^{15}O	2min	735
^{18}F	110min	250
^{64}Cu	12.7h	278
^{68}Ga	1.1h	830

Table 2: Characteristics of Non-standard PET Radionuclides

Isotope	Half-life	Decay Modes%	Max. β^+ Energy(Mev)	The Best Reaction	Natural Abundance of Target Isotope
^{60}Cu	23.7 min	β^+ /93.0 EC/7.0	3.92	^{60}Ni(p,n)	26.1%
^{86}Y	14.74 h	β^+/34.0 EC/66.0	3.15	^{86}Sr(p,n)	9.9%
^{89}Zr	78.5 h	β^+/22.8 EC/77.2	0.40	^{89}Y(p,n)	100%
^{124}I	4.18 d	β^+/22.0 EC/78.0	2.15	^{124}Te(p,n)	4.8%
^{76}Br	16.2 h	β^+/58.2 EC/41.8	3.98	^{76}Se(p,n)	9.1%

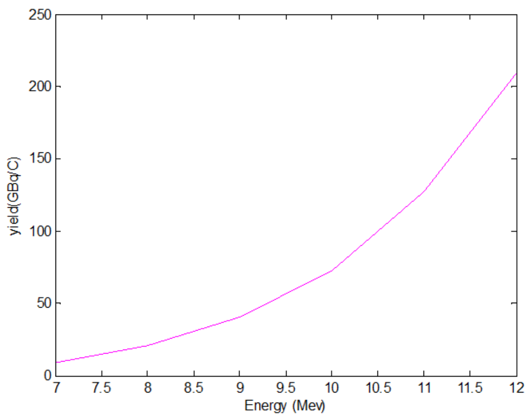

Figure 2: Yield of Reaction ^{60}Ni (p,n)^{60} Cu

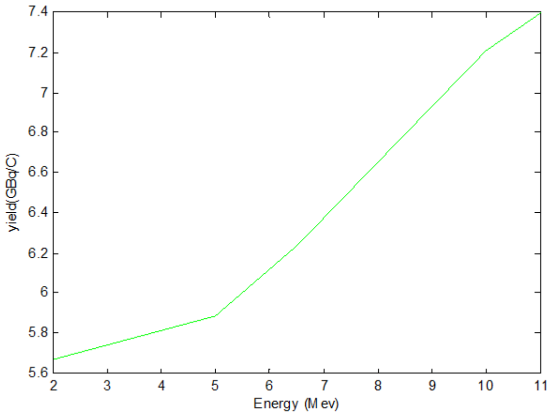

Figure 3: Yield of Reaction ^{86}Sr(p, n)^{86}Y

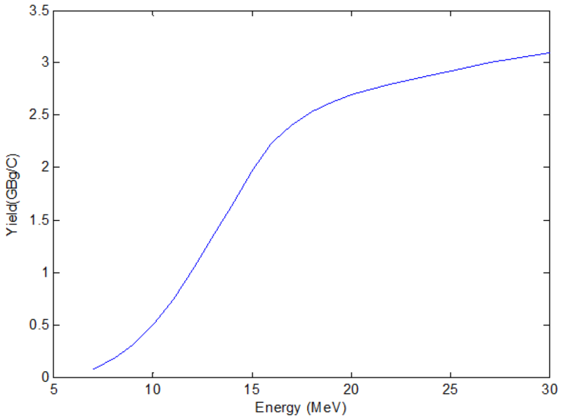

Figure 4: Yield of Reaction ^{89}Y (p,n)^{89}Zr

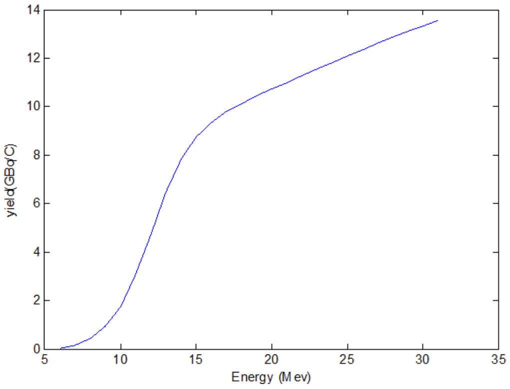

Figure 5: Yield of Reaction ^{124}Te (p, n) ^{124}I

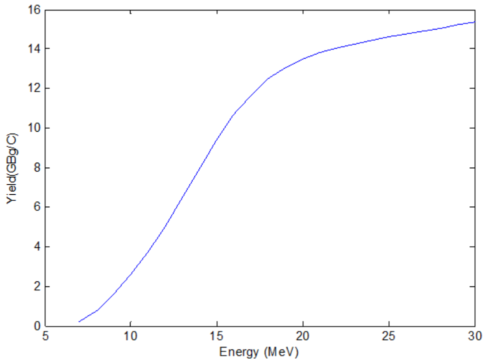

Figure 6: Yield of Reaction ^{76}Se(p, n)^{76}Br

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