Excitation Functions for the Proton Irradiation on $^{45}\text{Sc}$ Target

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Abstract:
In the nuclear medicine for the positron emission tomography, the injected positron emitter leads to two 511 keV $\gamma$-rays. One of the most promising radionuclides is $^{45}\text{Sc}$. In this study, the main purpose was to investigate the excitation functions for the reactions $^{45}\text{Sc} (p, x)$. TALYS 1.6 nuclear reaction simulation code was used for the excitation functions. These calculated excitation functions have been discussed and compared with each other and with Experimental Nuclear Reaction Data Library (EXFOR).

1. Introduction

Production cross sections for charged particle especially protons induced of nuclear reactions on metals are important for development of improved nuclear reaction theory and have a big role in many applications practical (nuclear wear measurement, medical radioisotope production, radiobiology etc.). All over the world the cyclotrons and accelerators number are continuous increasing to production of radioisotopes for both diagnostic and therapeutic purposes because medical applications of nuclear radiations are of considerable interest for the humankind nowadays [1]. Variations of cross sections represented by the excitation functions with incident energy for appointed reactions used in field of radioisotope production for example for a particular reaction type determine required particle energies and optimal energy ranges calculate the radioisotope production yield which can be expected and calculate the production yields for radionuclides impurities, for determine the need for isotopically enriched target materials especially for medical radioisotope production [2]. The present study was carried out using a Monte Carlo nuclear reaction simulation code TALYS 1.6. For some interactions of proton with Scandium -45. Using Monte Carlo methods other several work have been done in this field [3-8].

2. Materials and Method

Theoretically and by used the model calculations TALYS 1.6 code, the production cross-sections of the residual radionuclides are obtained from the $^{45}\text{Sc} (p, x)$ processes with proton energies up to 100 MeV, these calculation for nuclear reaction cross-sections, are usually employed in cases where there is a shortage of experimental data or there are other controversies. Moreover, it ensure the internal consistency of the data, and also allows us to predict and extrapolate the experimental data. TALYS is a computer code system for the simulation, analysis and prediction of nuclear reactions. The basic objective behind its construction is the simulation of nuclear reactions that involve neutrons, photons, protons, deuterons, tritons, $^3\text{He}$-and alpha particles. TALYS integrates the optical model, direct, preequilibrium, fission and statistical nuclear reaction models in one calculation scheme and gives a prediction for all the open reaction channels [9]. In using a Monte Carlo method for nuclear data evaluation a series of
correlations can be extracted from the previous results. At this point, it is worth mentioning that for each calculated quantity, thousands of values are obtained. These quantities can be differential nuclear data such as total and partial cross sections, isomer and residual production cross sections, continuum and discrete c-ray production cross sections, angular distributions, energy spectra, angular distributions, recoil cross sections, as well as double differential spectra. To achieve this, a suite of nuclear reaction models has been implemented into a single code system [10, 11].

2. Results and discussion

$^{45}$Ti with a half-life of 3.08 h is a positron-emitting radioisotope with a positron branching of 85% and a decay of 15% by electron capture with E (β + max), i.e., 1.04 MeV de cays to $^{45}$Sc [12]. $^{44}$Sc 3.97 h half-life is one of radioisotope used in positron emission tomography (PET) application for studying bone disease. $^{44}$Sc is a positron emitter with β + branching 94.3%. K Potassium having a half-life of 12.36 hours; is used as a radioactive tracer in studies of potassium distribution in bodily fluids, and in localization of brain tumors. And $^{45}$Ti with half-life of 60 years were obtained via the Sc (p, 2n) nuclear reaction [13, 14]. These isotopes were obtained in our study by interaction of proton with $^{45}$Sc.

Early in the development of nuclear medicine, the biological significance of these radioisotopes was realized, and positron emitters were viewed with great promise. The availability of these biological radioisotopes has made a major impact on PET research. A vast array of biological radiotracers has been used to help understand kinetics and function. In β + decay process, proton transformed to neutron in the nucleus with emission a β + particle and a neutrino after few millimeters in the tissue facing with antiparticle. When that happens, the electron positron pair is annihilated each other and transformed into two opposite direction photons with energy 0.511 MeV. These photons can be detected by the coincidence technique used in (PET). In nuclear medicine (PET) Technique is important in the diagnosis treatment planning, and evaluation of the treatment response in cancer patients [15, 16]. Production cross sections of proton induced nuclear reactions are important for many medical applications and for development of nuclear reaction theory [17]. In this study the production cross-sections are shown in Figures 1-5 together with the available literature data and the evaluated data using Monte Carlo code TALYS 1.6 which is the nuclear reaction simulation code. The results are compared with the experimental data existing in the EXFOR [18]. In this study we have investigated only those reactions which produced $^{45}$Sc(p, n)$^{44}$Ti (Q = -2.84441 MeV), $^{45}$Sc(p, 2n)$^{43}$Ti (Q = -12.3763 MeV), $^{45}$Sc(p, x)$^{43}$K (Q = -20.9804 MeV), $^{45}$Sc(p, n)$^{44}$Sc (Q = -9.10195 MeV) and $^{45}$Sc(p, 3p)$^{42}$K (Q = -1.90737 MeV). Where the only stable isotope of natural Scandium can transmute to a Titanium-45 radioisotope through the $^{45}$Sc(p, n)$^{45}$Ti reaction, to a Titanium-44 radioisotope through the $^{45}$Sc(p, 2n)$^{44}$Ti reaction, to a Potassium -42 radioisotope through the $^{45}$Sc(p, x)$^{42}$K reaction, to a Scandium -44 radioisotope through the $^{45}$Sc(p, x)$^{44}$Sc reaction, and to a Potassium -43 radioisotope through the $^{45}$Sc(p, 3p)$^{43}$K reaction. The study has also its importance in the frame of our systematic investigation for amelioration the theoretical codes for proton induced reactions. [19]. The decay data of the product radioisotopes, calculated E-threshold energy and Q-value are shown in table 1.

Table 1. Decay data of the product radioisotopes [1, 10, 11] and the calculated E-threshold energy and Q-value.

<table>
<thead>
<tr>
<th>Reactor product</th>
<th>Half life (s)</th>
<th>Mode of decay</th>
<th>$E_\gamma$ (keV)</th>
<th>$I_\beta$ (%)</th>
<th>$E_{\text{thres.}}$ (MeV)</th>
<th>$Q$-value (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{45}$Ti</td>
<td>17.6 h</td>
<td>$\beta^+$ (77)</td>
<td>477.2</td>
<td>20.2</td>
<td>15.7087</td>
<td>-15.4308</td>
</tr>
<tr>
<td>$^{45}$Ti</td>
<td>271.8 d</td>
<td>EC(100)</td>
<td>122.06</td>
<td>85.6</td>
<td>11.8660</td>
<td>-11.6632</td>
</tr>
<tr>
<td>$^{45}$K</td>
<td>69.1 m</td>
<td>EC(100)</td>
<td>657.76</td>
<td>98.0</td>
<td>11.7417</td>
<td>-11.636</td>
</tr>
<tr>
<td>$^{45}$Sc</td>
<td>2.83 d</td>
<td>EC(100)</td>
<td>171.28</td>
<td>90.0</td>
<td>11.1379</td>
<td>-11.0386</td>
</tr>
<tr>
<td>$^{45}$K</td>
<td>4.18 d</td>
<td>$\beta^+$ (22)</td>
<td>602.7</td>
<td>60.5</td>
<td>10.5957</td>
<td>-10.5109</td>
</tr>
</tbody>
</table>

It can be seen that the present values for $^{45}$Sc(p, n)$^{45}$Ti reaction There is a good agreement between the data obtained in this work and with the experimental results of previous works, while one of experimental data is higher in peaked region as we shown in Figure 1. The other obtained results shown in Figures 2-5 are lower or upper than the experimental data at the peak this could be due to the older experimental technique in those measurements. It can be concluded from this work that it can be produced the isotopes used in medical applications like (PET) by the interaction of the proton with Scandium-45 [20] and the result of the theoretical model code TALYS 1.6 could produce the excitation functions quite well. The calculated curves make it possible to compare the execution radioisotope production.

References

Figure 1. Excitation functions for the proton reaction $^{45}$Sc$(p, n)^{44}$Ti.

Figure 2. Excitation functions for the proton reaction $^{45}$Sc$(p, 2n)^{44}$Ti.

Figure 3. Excitation functions for the proton reaction $^{45}$Sc$(p, x)^{42}$K.

Figure 4. Excitation functions for the proton reaction $^{45}$Sc$(p, x)^{44}$Sc.

Figure 5. Excitation functions for the proton reaction $^{45}$Sc$(p, 3p)^{43}$K.


[34] J. W. Meadows, R. M. Diamond, R. A. Sharp, (1956), Excitation functions and Yield Ratios for the Isomeric Pairs Br80,80m, and Co58,58m, and Sc44,44m Formed in (p, pn) Reactions, Physical Review, Vol.96, p.318, Netherlands, DOI:10.1016/0375-9474(70)90451-3