MEDICAL ISOTOPE PRODUCTION BY CHARGED PARTICLE IRRADIATION OF NATURAL THORIUM

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Introduction

Radioisotopes have an important role in the field of medicine, both for diagnostic and therapeutic purposes. Targeted alpha therapy is one of the important and effective methods for treating oncologic diseases[1]. Irradiation of thorium target by charged particles produce different radioisotopes, which can be used for medical applications. Nuclear reactions with the charged particles is also important under diverse contexts including astrophysical ones.

Nuclear reaction cross section data gives the best route for the production of radioisotopes. In the present study, we have made an attempt to evaluate the production cross section of various radioisotopes by irradiation of thorium-232 target with charged particles (protons, deuterons, tritons, helium-3 and alpha particles) in the energy range 0-800 MeV. $^{225}Ac, ^{223,224,225}Ra, ^{227}Th$ are the different radioisotope formed from thorium-232 target. These isotopes have alpha decay as the main decay modes with energy values and half-lives appropriate for medical applications. The availability of these radioisotopes are limited due to the prevailing methods of production. Investigation of alternative methods help us to identify production routes with increased cross sections. In that respect the present study will be helpful in identifying better production methods.

Theory

In the present work, nuclear reactions are studied based on nuclear models implemented in the computational code Talys 1.9. Koning et al.[2] calculated the direct reaction cross section using coupled channels for deformed nuclei, with weak coupling model for odd nuclei and distorted wave Born approximation (DWBA) for spherical nuclei. Different level density models are used in Talys - phenomenological level density and microscopic level density. For pre-equilibrium particle emission, exciton model is used. The residual production cross section of nucleus (Z,N) is

$$\sigma_{prod}(Z,N) = \sum_{i_n=0}^{\infty}\sum_{i_p=0}^{\infty}\sum_{i_d=0}^{\infty}\sum_{i_t=0}^{\infty}\sum_{i_h=0}^{\infty}\sum_{i_\alpha=0}^{\infty}\sigma^{ex}(i_n,i_p,i_d,i_t,i_h,i_\alpha)\delta_Z\delta_N \quad (1)$$

where $i_n, i_p, i_d, i_t, i_h, i_\alpha$ are the number of outgoing neutron, proton, deuteron, triton, helium-3 and alpha respectively. δ_N, δ_Z are Kronecker delta's defined by

$$\delta_N = \begin{cases} 1 & \text{if } i_n + i_d + 2i_t + i_h + 2i_\alpha = N_c - N \\ 0 & \text{otherwise} \end{cases}$$

$$\delta_Z = \begin{cases} 1 & \text{if } i_p + i_d + i_t + 2i_h + 2i_\alpha = Z_c - Z \\ 0 & \text{otherwise} \end{cases}$$

(Z_c, N_c) is the first compound nucleus from the projectile and target. σ^{ex} is the exclusive cross section [2].

Results and Discussion

We have calculated the reaction cross section of medical isotopes formed from ^{232}Th target by charged particle irradiation. Plot of the cross section against incident energy is the excitation function curve. The shape of the curve gives information on the reaction mechanism involved and appropriate energy range. Experimental production cross section data for the reaction

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$^{232}Th(p,x)^{225}Ac,^{232}Th(p,x)^{223,224,225}Ra$ and $^{232}Th(p,x)^{227}Th$ are also available in literature for certain proton energies [3]. We compared our results with these values for the proton energy range 0-200 MeV to get the optimum input values for Talys. Figure 1 shows a comparison between the calculated value and literature values of the production cross section of ^{225}Ac for the proton energy in the range 0-200 MeV.

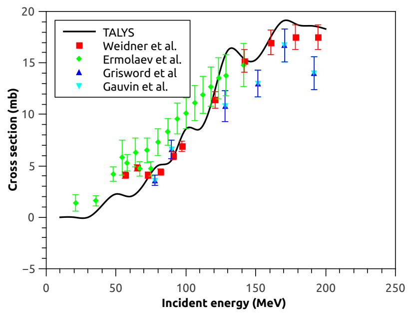

FIG. 1: Production cross section of ^{225}Ac from the nuclear reaction $^{232}Th(p,x)^{225}Ac$, in the energy range 0-200 MeV

Figure 2 shows the excitation function curve of ^{225}Ac using different charged particles like proton, deuteron, triton, helium-3 and alpha.

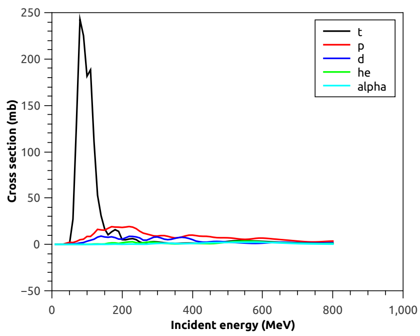

FIG. 2: Production cross section ^{225}Ac by irradiation of ^{232}Th, with different charged particles energy range 0-800 MeV

From figure 2, it is clear that the cross section for the reaction $^{232}Th(t,x)^{225}Ac$ is higher than for other reactions. We can say that triton is the most suitable projectile for the production of actinium from thorium target and the production cross section is higher in the energy range 50-100 MeV. This is the optimal energy range required for this nuclear reaction. Production cross section is less for the other reaction channels. We have also calculated the production cross section for $^{223,224,225}Ra$ and ^{227}Th from ^{232}Th on the interaction with different charged particles. Excitation function curve of $^{223,224,225}Ra$ and ^{227}Th are plotted with different charged particles.

Conclusion

In the case of actinium and radium nuclei, triton is the most suitable projectile than other charged particles. Optimal energy range for radium is 70-150 MeV. Proton and deuteron interaction produce ^{227}Th from natural thorium target. Production cross section of ^{227}Th is low when we use other charged particles. The shape of the excitation function curve depends on the competing channels in the nuclear reaction. Among competing channels, the production cross section varies and reach the maximum production for a particular energy. In the case of ^{225}Ac, the main competing channel is (t,x) for the energy range 50-150 MeV. For ^{227}Th, (d,x) and (p,x) are the dominant channels in the nuclear reaction.

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