Nuclear model calculations of Chromium-51 production via ^{51}V (p,n)^{51}Cr reaction

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Introduction

Radioisotopes produced by charged-particle nuclear reactions find important applications in medicine, industry and agriculture [1, 2]. Chromium is an element with an excellent corrosion resistance (e. g. against high temperature gaseous corrosion), which explains the wide use of the element in the form of protective coatings and as alloying element. Chromium-51 ($T_{1/2}$ = 27.7 d) is a radionuclide with large application in biological studies mainly in blood cells labeling [3]. The present article, which is a part of our previous work [7], is describes calculations on the excitation function of ^{51}V(p,n)^{51}Cr, reaction by using nuclear model codes TALYS [4] and ALICE/ASH [5]. The theoretical stopping power and the target thickness are simulated by using SRIM (Stopping and Range of Ions in Matter) code [6]. In order to assign the suitable model to structure of nuclei, the present theoretical results and experimental data are compared with each other.

Calculation of excitation functions

The excitation functions of p + ^{51}V, d + ^{51}V, a + ^{48}Ti and n + ^{52}Cr reactions were calculated by using TALYS-1.6 and ALICE/ASH codes. An optimum energy range was determined and employed to avoid the formation of the radionuclide impurities and decrease the abundance of the stable impurities as far as possible. To further achieve the aim, the feasibility of ^{51}Cr production via various nuclear reactions per low/medium energy accelerators was investigated.

Calculation of the required thickness of target

According to the SRIM code, the required thickness of target was calculated. The physical thickness of the target layer is chosen in such a way that for a given beam/target angle geometry (90°) the incident beam exits of target layer with predicted energy [7].

Calculation of theoretical yield

To enhance the production yield, beam current and time of bombardment may be increased. The production yield can be calculated via following relation:

Reaction	Energy range (MeV)	Theoretical yield (MBq/μAh)
^{51}V(p,n)^{51}Cr	11 – 3	9.10
^{51}V(d,2n)^{51}Cr	22 – 7	18.46
^{48}Ti(a,n)^{51}Cr	19 – 7	0.74
^{52}Cr(n,2n)^{51}Cr	30 – 14	-------

Table 1: ^{51}Cr theoretical production yield via different nuclear reactions by TALYS-1.6 code.

$$Y=N_A a_{is} a_{ch} I/M\int\{\delta(E)/S_p(E)\}(1-e^{\lambda t})dE \quad (1)$$

where N_A, a_{is}, a_{ch}, I, M, $\delta(E)$, $S_P(E)$, k and t are the Avogadro number, isotopic abundance of the target nuclei, chemical abundance of the target element, the proton beam current, molar mass of the target material, the reaction cross section at energy E, the stopping power of the target material, decay constant of the radioactive product, and time of irradiation, respectively [7]. The production yields of ^{51}Cr via different reactions were calculated using Eq. (1) (Table 1).

Results and discussion

The excitation function of proton induced reaction on ^{51}V (^{51}V (p,n)^{51}Cr) was calculated by TALYS-1.6 and ALICE/ASH codes. The evaluation of the acquired data showed that the best range of energy for production of ^{51}Cr is 18 – 3 MeV. TALYS-1.6 predicts the maximum cross section to be about 723 mb at 11 MeV (Fig.1). There is an isotopic impurity in this energy range. ^{50}Cr ($T_{1/2}$ = 1.8 e17 year) has long half-life compared to ^{51}Cr (T1/2 = 27.7 d) and can be decreased by choosing proper energy range. To avoid the isotopic impurity and to attain full benefit energy range without decreasing the production yield considerably, 3 –

11 MeV energy range could be selected. According to the calculation of SRIM code, the required target thickness should be 351.42 µm. Figure 2 shows a comparison between the calculated cross section of ^{51}V (p,n)^{51}Cr reaction from ALICE/ASH and TALYS-1.6 codes, and the experimental data reported [7]. The results are closely consistent with each other. The theoretical thick target yield of ^{51}V(p,n)^{51}Cr at 11 – 3 MeV is calculated using TALYS-1.6 and ALICE/ASH GDH cross sections to be 9.10 and 8.67 MBq/µAh, respectively.

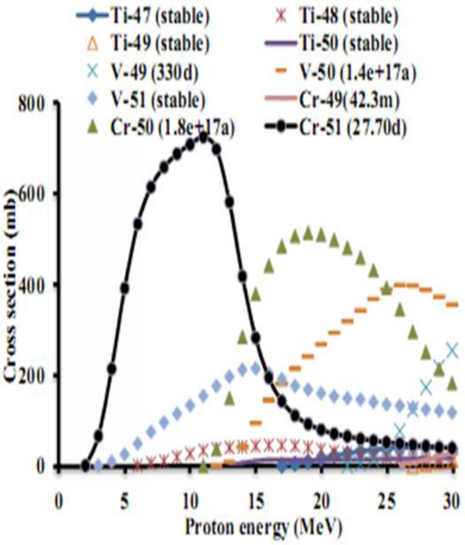

Fig. 1 Excitation function of ^{51}V(p,x) by TALYS-1.6 code

Conclusions

Cross section data for the production of the medically important radionuclide ^{51}Cr via proton, deuteron, neutron and alpha induced reactions were estimated. The nuclear model codes were used for consistency checks of the experimental data. The TALYS code based on the exciton model reproduces experimental cross sections more satisfactory than the ALICE/ASH code based on hybrid and GDH models. However, the GDH model with the adjusted level density parameter a gives consistent result compared to default. ^{52}Cr (n, 2n) ^{51Cr} and ^{51}V (d, 2n) ^{51}Cr reactions are not suitable to produce non-carrier-added ^{50}Cr due to the isotopic impurities inevitable. The production of ^{51}Cr can be achieved by both ^{51}V (p,n)^{51}Cr and ^{48}Ti(a,n)^{51}Cr ideal reactions in low energy accelerators. The theorical yield for ^{48}Ti (a,n)^{51}Cr reaction lower than for ^{51}V(p,n)^{51}Cr.

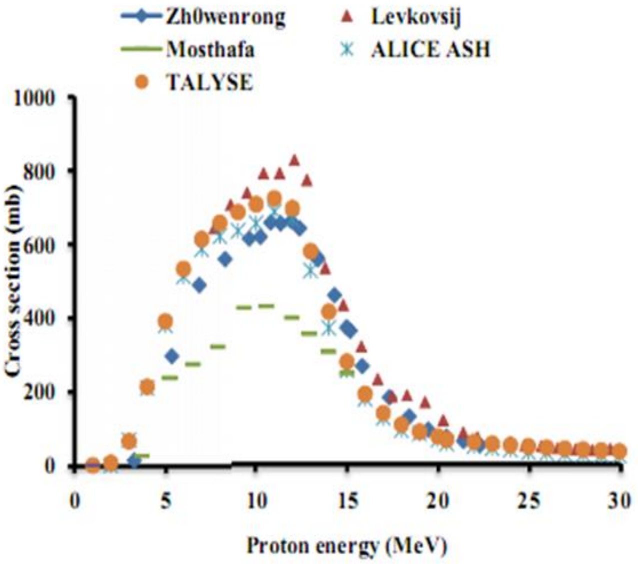

Fig. 2 Comparison of the theoretical cross sections of ^{51}V (p,n)^{51}Cr reaction with experimental data

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