Simulation of Proton beam using the MCNPX code; A prediction for the production of ^{123}I via ^{124}Xe(p,x)^{123}I reaction

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Introduction

The 13.2 h half-life radioisotope ^{123}I is widely used in clinical nuclear medicine diagnosis. Nowadays, the preferred process for ^{123}I production is bombardment of highly enriched ^{124}Xe gas with medium energy protons and taking advantage of the activation of the different radionuclides in the decay chain ^{123}Cs→^{123}Xe→^{123}I.

The Monte Carlo code MCNPX [1] was used to simulate proton irradiations, model particle fluence, particle energy distributions and proton flux in the target body. In the present work, ^{123}I production yield, using the MCNPX code on the basis of normalized particle distribution in the gaseous target in conjunction with calculated cross section has been estimated.

Materials and Methods

At first, the excitation function of ^{124}Xe(p,2n)^{123}Cs, ^{124}Xe(p,pn)^{123}Xe and ^{124}Xe (p,2p)^{123}I reactions were calculated by using TALYS-1.4 [2] nuclear code. The cross sections calculated by TALYS-1.4 code are shown in fig. 1 at different decay channels. As been in fig. 1, the optimum bombarding energy range is 28-18 MeV. According to the SRIM [3] code, the required thickness of the target was calculate (25 cm length), in this optimum energy range, for ^{124}Xe(p,x) reaction.

The MCNPX input file included detailed information of the geometry of gaseous target, and proton beam configuration. The source definition ("*SDEF*") card simulated a Gaussian profiled 28.63 MeV proton beam around the Z axis with a negative direction. ^{124}Xe gas target and Al chamber were represented by Z axis centered conical "macrobodies".

The formation rate R of a product nuclide is given by

$$R = \frac{\sigma . I . \rho . N_A . d}{M}, \qquad (1)$$

With, I, proton beam current, σ, reaction cross section, ρ, target material density, d, target cone thickness, N_A, Avogadro constant, and M, target material molar mass. For an energy-dependent cross section $\sigma(E)$ it is multiplied by the particle energy distribution $P(E)dE$ of the beam particle and it applies differentially. Integration and solving of the differential equation for an instable product nuclide results in:

$$\underset{tot}{\mathrm{A}}(t) = \sum_{n=1}^{j} [\frac{A_n . \rho . N_A . d}{M} \int_{E_{min}}^{E_{max}} P(E) \sigma_n(E)\, dE], \qquad (2)$$

Where,

$$A_n = \lambda_n N_n = N_1^0 \sum_{i=1}^{n} C_i\, e^{-\lambda_i t}, \qquad (3)$$

Where N_1^0 is the initial number of radioactive atoms, and

$$C_m = \frac{\prod_{i=1}^{n} \lambda_i}{\prod_{i=1, i \neq m}^{n} (\lambda_i - \lambda_m)}, \qquad (4)$$

With, $\mathrm{A}_{tot}(t)$, product nuclide radioactivity based on decay chains, t, time of bombardment, and the radionuclide decay constant λ. The product function $P(E)\sigma_n(E)$ was calculated from "*F4/E4*" tallies and calculated cross sections based on TALYS-1.4 code.

Results and Discussion

Fig. 2 shows the normalized energy distribution function for protons in the ^{124}Xe gas target body of conical shape as obtained with MCNPX. The proton beam energy degraded from 28.63 MeV to 28 MeV within the two Titanium windows and from 28 MeV to 18 MeV with the ^{124}Xe target. For short irradiations (for instance 1 h) the optimal growth time is 6.6 h, resulting in large increase of ^{123}I activity. The thick target yield at growth time, calculated for ^{123}I from the equation (2). The results of estimates were compared with experimental data for the same proton energy range (Table. 1).

Conclusion

^{123}I production yield estimate was obtained through proton energy distribution in the target. Good agreement between the experimental and simulated production yield was observed. We demonstrated that MCNPX provide a useful tool for the simulation of proton irradiations and target design for the purpose of radionuclide production.

Acknowledgment

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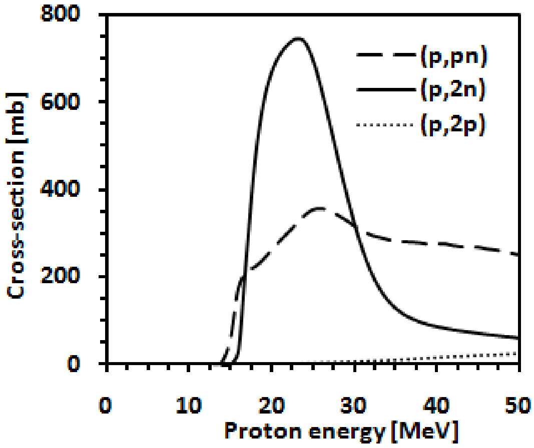

Fig.1 Excitation function for ^{124}Xe(p,2n)^{123}Cs, ^{124}Xe(p,pn)^{123}Xe and ^{124}Xe (p,2p)^{123}I reactions given by TALYS-1.4 code.

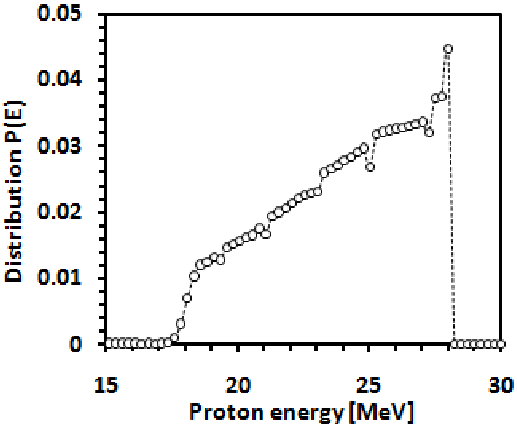

Fig. 2 Normalized energy distribution function for protons in the gaseous xenon target given by MCNPX.

Table 1: Comparison between the experimental and the simulation thick target yield via the ^{124}Xe(p,x) reaction for production of ^{123}I radionuclide at after 6.6 h growth time.

Thick target yield (mCi/µAh)	
MCNPX	Experimental [4]
20.46	15 (Tarkanyi 1991) 25 (Firouzbakht 1987) 27.8 (Kurenkov 1989) 21 (Hermanne 2011)

References

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