PRODUCTION OF ^{111}In BY IRRADIATION OF NATURAL CADMIUM WITH DEUTERONS AND PROTONS IN NRCAM CYCLOTRON

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This paper investigates the production of ^{111}In by irradiation of natural Cadmium with deuterons and protons of different energies from 8 to 15 MeV and 15 to 30 MeV, respectively. The measured thin-target yield for the production of ^{111}In reached a maximum of 15.52 and 28.5 μCi/μAh per mg/cm^2 at 15 MeV and 21 MeV for deuterons and protons respectively. These optimum deuteron energies were confirmed by results from the ALICE code to be 15 and 20 MeV for a thin target. For these optimum energies, the impurities produced by interfering reactions were identified experimentally and found to be mostly short-lived compared to ^{111}In. For commercial production of ^{111}In, natural Cadmium was irradiated at various energies of deuterons and protons.

1 Introduction

Cadmium-111, known as one of the cyclotron radioisotopes used for the detection and localization of tumors and inflammatory lesions, is normally produced by irradiation of natural Silver or enriched Cadmium-111 and Cadmium-112 with protons or alpha particles bombardment.[1,2]

The production of ^{111}In from natural Cadmium had been planned by utilizing the Cyclone-30 cyclotron at Nuclear Center for Agriculture and Medicine, Karaj, Iran. The research was carried out to investigate the production of ^{111}In through irradiation of natural Cadmium. In this paper the results of irradiation of natural Cadmium by 8 to 15 MeV deuterons and 15 to 30 MeV protons are presented.

2 Experimental Procedure

2.1 Target Preparation

Natural Cadmium is first electrodeposited on copper backing target. Copper is chosen as the substrate due to its suitable heat conduction. In this process, KCn is added to $CdSO_4$ in stoychiometric ratio of 1:1 as follows:

$CdSO_4 + 2\ KCn$ ----------------- $Cd(Cn)_2 + K_2SO_4$

$Cd\ (Cn)_2 + 2\ Cn$------------------ $[\ Cd\ (Cn)_4]$

The resultant complex is kept at pH of 10 to 11.5, then few drops of Hydrazine Hydride is added to depolarize the solution. The prepared solution is then poured in a cell specially designed for the simultaneously electroplating of 4 targets. Within the cell, the Pt anode electrode is placed in the center of the 4 targets. The current used is about 100 mAmps. The elongated ellipsoid target's area plated are about 12.5 cm^2.

Through exploiting the computer program codes , "RANGE" and "TRIM", the range and stopping power of deuterons and protons with different energies for Cadmium are determined. At thickness of about 10 micron, e.g. for 15 MeV energy incident deuterons the energy loss is about 242 KeV. Considering the irradiation of target at $\theta = 6°$, coating 1μm of Cadmium is sufficient to provide 10μm effective thickness. Taking into account the area and the density of plated Cadmium, the amount of coated material is equivalent to 9.6 mg. Based on this calculation all prepared targets should have the same amount of platted Cadmium and hence the same thickness. According to Faraday's law, the electroplating time for 9.6 mg Cadmium is about 3 minutes.

2.2 Target Irradiation

The Copper-platted-Cadmium targets situated on special shuttles is sent through the cyclotron solid target room by rabbit system. The shuttles geometry is designed such that the targets see the beam at an angle of 6°. Then the target is bombarded with the intensity of 10μAh deuterons. The beam current was measured by current integrator which is connected to Faraday Cup. Afterwards, the target cooling system is shut off and target is guided through to the hot cell by rabbit system.

2.3 Dissolving the target

The irradiated platted Cadmium is dissolved in a 15 ml of concentrated HBr. Through dissolving the target some copper is dissolved in the solution. Then few drops of the solution is diluted for gamma spectroscopy.

2.4 Gamma spectroscopy

In the gamma spectroscopy the relative method is chosen. Taking into account the measured efficiencies for standard sources at different positions of the same geometry, the activities of radioisotopes for the prepared samples were measured by calculating the peak area in the recorded spectrum and using detector efficiencies and branching ratio values. ^{111}In is produced in deuteron bombardment by the (d,n) reaction on ^{110}Cd and the (d,2n) reaction on ^{111}Cd. This can also be produced by (p,n) reaction on ^{111}Cd, (p,2n) reaction on ^{112}Cd, and (p, 3n) reaction on ^{113}Cd.

3 Results and Discussion

The reaction cross section is calculated by using the values of activity, beam current, and weight of sample. The variation of measured cross section for ^{111}In and In terms of deuteron and proton energies are shown in Figure 1 and 2 respectively.

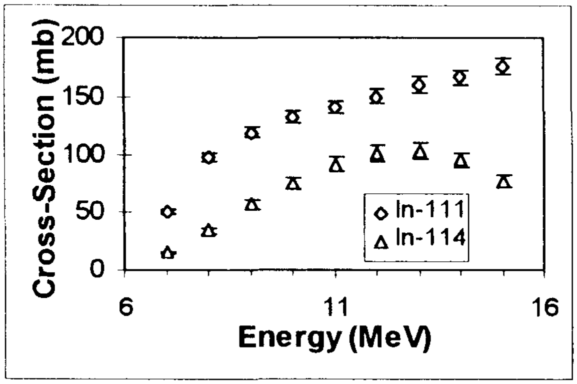
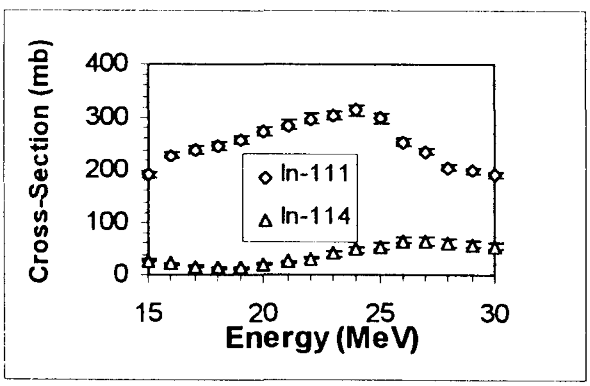


Figure. 1. Excitation function for the production of ^{111}In and ^{114}In by deuteron bombardment of natural Cadmium.

The results for production yield of ^{111}In for 15 to 30 MeV proton energies indicated that for a thin target the optimum proton energy is about 21 MeV.



3.1 Theoretical calculations of cross section

Alice 91 code[4] for calculation of cross section is employed in this work. The interaction of protons and deuterons with natural Cadmium are investigated. Natural Cadmium consists of eight isotopes with different abundance as follows: ^{106}Cd(1.22 %), ^{108}Cd (0.88 %), ^{110}Cd (12.39 %), ^{111}Cd (12.75 %), ^{112}Cd (24.07 %) and ^{113}Cd (12.26%).
The calculation is performed for isotope (A, Z, N) and its recoils until (A-4, Z-4, N) and (A-4, Z, N-4). The calculated results are presented for protons and deuterons in Figure 3 and 4 respectively.
As can be seen from Figure 3 the energy increments of 0.2 MeV are used for protons in the energy range of 15-30 MeV.

Although it has been observed experimentally (see Fig. 1) and theoretically (see Fig. 3) at deuteron energies of 7 to 15 MeV cross sections for production of ^{111}In increases with energy and reaches to a maximum value at 14 to 15 MeV, but the yield is not too high. Therefore, deuteron irradiation is not recommended for commercial production. In the case of proton irradiation as indicated in Figure 4 , the optimum proton energy for production of ^{111}In is about 21 MeV. At this energy contribution of other nuclide such as ^{114}In is negligible.

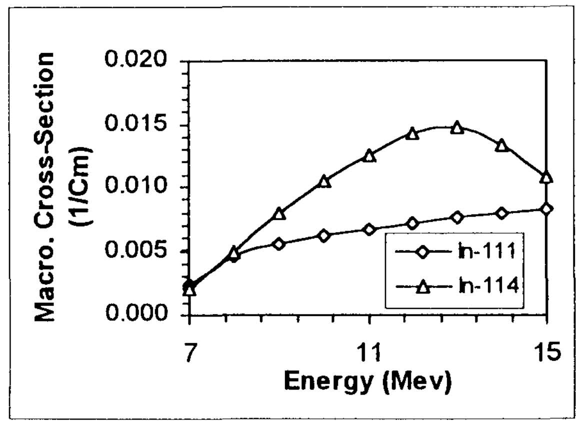


Figure 3. Cross section of ^{111}In and ^{114}In by deuteron bombardment of natural Cadmium (ALICE code)

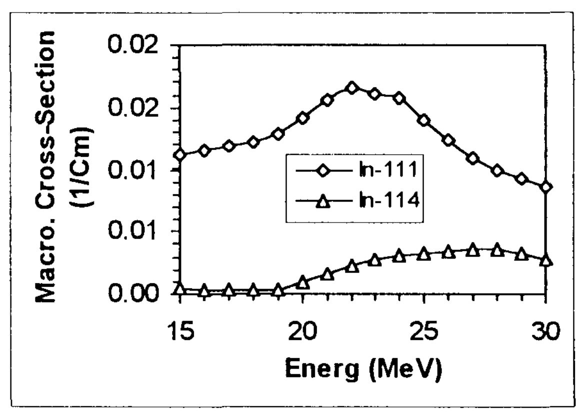


Figure. 4. Cross section of ^{111}In and ^{114}In by proton bombardment of natural Cadmium (ALICE code)

3.2 THE ^{111}In YIELD IN THICK TARGETS & COMMERCIAL PRODUCTIONS

Taking into accounts the measured cross-sections for 15 to 30 MeV protons and 8 to 15 MeV deuterons, and their energy loss for different thicknesses, one can calculate the production yield for the thick targets[3]. The obtained values are presented in Table 1 and 2.

Table 1. Thick targets yields for deuteron bombardment

ENERGY (MeV)	Yield of ^{111}In µCi/µAh	Yield of ^{114}In µCi/µAh
8	45.4	<0.2
9	67.5	<0.2
10	81.0	0.2
11	86.6	0.22
12	135.1	0.25
13	140.5	0.3
14	146.2	0.32
15	167.5	0.35

For commercial production, the thick targets are prepared by electroplating of Cadmium with thickness of 80-100 µm and the targets are bombarded for 6 hr at an average beam current of 100 µA.

Table 2. thick Target yields for proton bombardment

ENERGY	Yield of 111In µCi/µAh	Yield of 114In µCi/µAh
15	185.6	< 1.1
16	236.4	< 1.1
17	247.8	< 1.1
18	454.6	1.1
19	266.3	1.2
20	278.1	1.5
21	290.4	2.2
22	328.3	2.9
23	434.2	5.2
24	540	6.5
25	559.5	7.9
26	589.5	8.7
27	331.8	10.6
28	748.5	12.5
29	835.2	13.8
30	940.5	15.7

Acknowledgments

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