IL NUOVO CIMENTO **44 C** (2021) 129
DOI 10.1393/ncc/i2021-21129-y

Communications: SIF Congress 2020

Production of ^{117m}Sn in ^{nat}Cd and ^{nat}In targets with an α-beam

L. De Dominicis(1)(2)(3)(*) F. Barbaro(4)(5), L. Canton(4), M. P. Carante(6), A. Colombi(5)(6), A. Fontana(6), L. Mou(2), G. Pupillo(2), A. Stolarz(3) and P. J. Napiorkowski(3)

(1) *Dipartimento di Fisica, Università di Padova - Padova, Italy*
(2) *INFN, Laboratori Nazionali di Legnaro - Padova, Italy*
(3) *Heavy Ion Laboratory, University of Warsaw - Warsaw, Poland*
(4) *INFN, Sezione di Padova - Padova, Italy*
(5) *Dipartimento di Fisica, Università di Pavia - Pavia, Italy*
(6) *INFN, Sezione di Pavia - Pavia, Italy*

received 14 January 2021

Summary. — The conversion electrons and γ-rays emitter ^{117m}Sn is a promising theranostic radionuclide produced mainly at nuclear reactors with low specific activity. The variety of possible applications suggests the necessity of a larger production, more likely reachable at cyclotrons. The irradiation of ^{nat}Cd and ^{nat}In targets with the 30 MeV α-beam, available at the Heavy Ion Laboratory (HIL) of Warsaw, aims to measure the production cross-sections of ^{117m}Sn and its contaminants. Theoretical calculations are also performed to support the experimental results.

1. – Introduction

Tin-117m is a short-range conversion electron emitter useful in the treatment of bone metastasis pain. The most intense conversion electrons have energies of 126.82 keV (65.7%), 129.360 keV (11.65%) and 151.56 keV (26.5%) [1]. The corresponding range in tissue is 0.22–0.29 mm, resulting in a highly localized dose delivery. The ^{117m}Sn decay is accompanied by the emission of γ-rays, of energies 158.56 keV (86.4%) and 156.02 keV (2.113%), useful in the diagnostic phase, making ^{117m}Sn a theranostic radionuclide.

^{117m}Sn is not regularly used in medical routine yet, but different chelators have been developed and are at the stage of pre-clinical and clinical trials. The stannic form ^{117m}Sn(4+)-DTPA gave good results in the treatment of primary and metastatic bone

(*) Corresponding author. E-mail: `lucia.de.dominicis@lnl.infn.it`

malignancies [2]. The targeting molecule ^{117m}Sn-DOTA-Annexin can be employed for the imaging and treatment of the vulnerable plaque [3].

At present, ^{117m}Sn is mainly produced at nuclear reactors through the neutron capture ^{116}Sn(n,γ)^{117m}Sn or the inelastic neutron scattering ^{117}Sn(n, n$'$)^{117m}Sn. The need of high flux reactors, highly enriched target materials and long irradiation times makes this route of production commercially expensive and limits the implementation in smaller facilities [4, 5]. The alternative is the displacement of the production at cyclotrons with the aim of reaching higher specific activities. In this work, the ^{117m}Sn production, using the α-beam delivered by the U-200P cyclotron available at HIL, is studied.

2. – Methods

At the HIL cyclotron, the internal configuration of the new station allows the irradiation of a target with a 30 MeV α-beam. In this configuration the beam forms an angle of 20° with the target surface. Targets are composed according to the stacked-foils technique, consisting in the alternation of several thin foils. ^{nat}Cd (6 μm) or ^{nat}In (11 μm) foils are chosen as target foils where ^{117m}Sn production takes place. ^{nat}Cu (11 μm) and ^{nat}Ti (11 μm) monitor foils are used to control the beam flux across the target, exploiting the occurrence of reference reactions recommended by the International Atomic Energy Agency (IAEA) [6]. A ^{nat}Al thicker foil (21 μm) is placed between the target foils to reduce the incident energy of the beam from one target foil to the other. To know the energy of the α-beam in each foil the software SRIM is used [7]. Till now two stacked-foils targets, each one containing two target foils, have been irradiated: one including ^{nat}Cd target foils and the other the ^{nat}In ones.

After the irradiation, the target is disassembled and the activity in each foil is measured with a Canberra HPGe detector. A first fast γ-acquisition of each foil is performed immediately after the end of bombardment (EOB) to detect all the produced radionuclides, also the short-lived ones. Then, starting from the day after the EOB, once per day, the foils undergo longer measurements. In this way the decays of the produced radioactive nuclei are followed to monitor any interference in γ-peaks and decay chains.

Calculations of cross-sections and their uncertainties are performed for each spectrum following the procedure suggested by Otuka *et al.* [8]. The final cross-section value associated to each radioisotope is a weighted average of all the single results corresponding to each acquisition of the same foil.

The experimental investigation is completed with a theoretical analysis using two nuclear reaction codes: TALYS (1.9), providing multiple results from different models, and FLUKA (2018.2.dev), based on Monte Carlo simulations. A detailed overview of the cross-section and thick-target yield calculations is described by Barbaro *et al.* [9].

3. – Results and discussion

In table I are presented the preliminary results of the ^{117m}Sn cross-section obtained for both ^{nat}Cd and ^{nat}In target foils. Those values are reported in figs. 1 and 2 where they are compared to the theoretical cross-section estimations and to the experimental data published in EXFOR database [10].

Both the preliminary results from ^{nat}In, in fig. 1, and from ^{nat}Cd, in fig. 2, seem to be compatible with the old data and theoretical predictions. The spread of experimental data, noticeable at energies above the range investigated, suggests the need for more measurements. Other irradiation runs are planned to cover energies until 30 MeV.

TABLE I. – *Preliminary cross-section values for* ^{nat}In,^{nat}Cd$(\alpha, x)^{117m}$Sn *and* ^{nat}Cd$(\alpha, x)^{113}$Sn.

^{nat}In targets		^{nat}Cd targets		
Energy (MeV)	cross-section (mb) ^{117m}Sn	Energy (MeV)	cross-section (mb) ^{117m}Sn	^{113}Sn
14.79 ± 0.95	0.0059 ± 0.0014	14.11 ± 0.79	0.64 ± 0.06	1.09 ± 0.14
22.41 ± 0.65	4.8938 ± 0.3883	20.83 ± 0.58	13.45 ± 0.71	107.4 ± 5.7

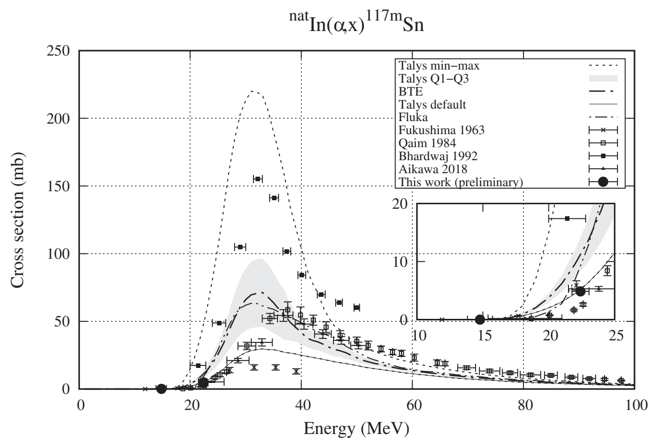

Fig. 1. – Production cross-section for ^{nat}In$(\alpha, x)^{117m}$Sn.

The production of contaminant radionuclides is also investigated because the purity of the product is a key point in medical field. Among the Sn-isotopes, the most troublesome is ^{113}Sn ($T_{1/2} = 115.9$ d) since it has a half-life longer than ^{117m}Sn ($T_{1/2} = 14.00$ d) and hence it is worthless to wait for its decay. In both ^{nat}Cd bombarded foils, ^{113}Sn is

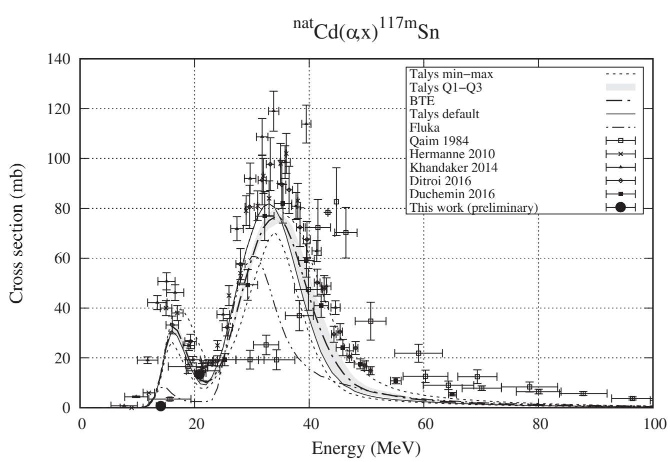

Fig. 2. – Production cross-section for ^{nat}Cd$(\alpha, x)^{117m}$Sn.

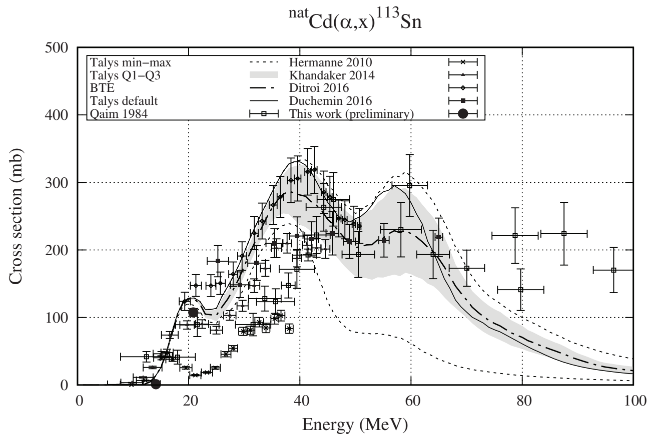

Fig. 3. – Production cross-section for ^{nat}Cd$(\alpha, x)^{113}$Sn.

produced. Values of cross-section are reported always in table I and represented in fig. 3 where they seem to be compatible with previous data and theoretical calculations. On the contrary, in ^{nat}In targets, ^{113}Sn is not produced in the energy range considered. So, even if the cross-section values are lower in the energy range considered, with ^{nat}In a higher radinuclidic purity is reached.

4. – Conclusions

The HIL 30 MeV α-beam is used to investigate the production of ^{117m}Sn in ^{nat}In and ^{nat}Cd target foils. The cross-section values obtained with ^{nat}Cd are higher but the radionuclidic purity in ^{nat}In is more promising. Further measurements are planned to complete the preliminary results presented.

* * *

The experiment is performed in the framework of the ENSAR2 project of the European Horizon 2020 Program.

REFERENCES

[1] NuDat 2.8 Database, `https://www.nndc.bnl.gov/`.
[2] Bishayee A. *et al.*, *J. Nucl. Med.*, **41** (2000) 2043.
[3] Stevenson N., *Radiother. Oncol.*, **118** (2016) S97.
[4] Maslov O. D. *et al.*, *Appl. Radiat. Isot.*, **69** (2011) 965.
[5] Vučina J. *et al.*, in *Fifth Yugoslav Nuclear Society Conference* (IAEA) 2004, pp. 325–328.
[6] IAEA Monitor reaction 2017, `https://www-nds.iaea.org/medical/monitor_reactions.html`.
[7] Ziegler J. F. *et al.*, *Nucl. Instrum. Methods: Phys. Res. B*, **268** (2010) 1818.
[8] Otuka N. *et al.*, *Radiat. Phys. Chem.*, **140** (2017) 502.
[9] Barbaro F. *et al.*, *Nuovo Cimento C*, **43** (2020) 136.
[10] Database EXFOR, `https://www-nds.iaea.org/exfor/exfor.htm`.