Cross-Section measurements for the Reaction $^{nat}Cr(d,x)^{52g,cum}Mn$: Preliminary Results

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INTRODUCTION

Manganese-52 (^{52}Mn) is a radionuclide that decays through both positron emission and EC modes, with a medium-long half-life ($t_{1/2}$ = 5.591 d).

As a positron emitter, Mn-52 has a possible use in nuclear medicine as a radiotracer for PET, useful to investigate biological and physiological processes occurring on the same time scale of its decay; the low energy of the positrons emitted (244.6 keV) and the short range in the tissues (0.63 mm) [1] would allow to acquire diagnostic images of a quality similar to those obtained with radiotracers already in use, such as fluorine-18 (250 keV; 0.62 mm) [2]. Moreover, the transition element manganese, has stable isotopes with useful paramagnetic properties for MRI procedures.

Goal of the approved METRICS research project, funded by CSN5 INFN, is thus to develop a new approach, based upon a perfect molecular matching probe, for both PET and MRI, by using paramagnetic and radioactive manganese isotopes to afford an unprecedented type of multi-modal (MMI) PET/MRI hybrid imaging.

Currently manganese is produced by irradiation with protons on chromium targets; production with deuteron beams could be more advantageous in terms of higher yields: an accurate knowledge of thin-target excitation function for $^{nat}Cr(d,x)^{52}Mn$ reaction is necessary for this purpose to determine purity as well.

Published data are scarce and rather dated: the aim of the present work, carried out by the INFN LASA research group in the framework of METRICS project, was therefore to provide more experimental data. A wide energy range, from 6 MeV up to 29 MeV, for the production of the radionuclide concerned was investigated.

The determination of the best irradiation parameters using deuterons, to yield ^{52}Mn, in as high as possible radionuclidic purity form, for the MMI approach with the new hybrid PET/MRI tomography now available, is therefore mandatory.

EXPERIMENTAL

The excitation functions were measured by using the stacked-foils technique, covering the deuteron energy range from 6 MeV to 29 MeV. Stacks of thin foils consist of alternating series of chromium layers having natural isotopic composition (4.35% ^{50}Cr, 83.79% ^{52}Cr, 9.5% ^{53}Cr, 2.36% ^{54}Cr), high purity aluminum ones (acting as both energy degrader and monitor reaction foils), ended by a titanium layer, as final monitor foil.

In particular, four prepared stacks, contained 4 Cr targets, 16 Al foils and 4 Ti monitor foils, were irradiated at different beam energies.

^{nat}Cr foils were prepared, with a nominal thickness of about 20 μm and a general relative uncertainty of ±2%, by the Department of Chemistry, Materials and Chemical Engineering "Giulio Natta" of Milan Polytechnic, by electro deposition technique on 16 μm thick Al foils. The true value of target thickness was accurately determined by a weighing procedure afterwards.

All irradiations were carried out with the cyclotron (AVF IBA-C70XP, K = 70, beam current up to 2x375 μA) of ARRONAX facility located in Saint-Herblain (FR) at different incident energies with a constant current of about 150 nA for a duration of 1 h. The excitation functions were obtained from four foil stacks irradiated in four different irradiation experiments. After the irradiations the targets were delivered with the authorized transportation service to LASA in Segrate (MI) to perform all the scheduled measurements stage.

The activity was measured, without any chemical processing, by using a calibrated high purity germanium (HPGe) detector (EG&G Ortec, 15% relative efficiency, FWHM = 2.2 keV at 1.33 MeV). All foils were measured in the same geometrical configuration as that used for the detectors calibration sources in order to avoid corrections for different geometries. The distance from the detector cap was chosen in order to reduce dead time and pile up errors to negligible values (< 0.1%). The first measurements of the samples were started within few days after end of bombardment (EOB) and measurements continued periodically for about 4-5 months to follow the decay of manganese-52:
in general the counts in the peak in the region of interest exceed 10 000.

RESULT AND DISCUSSION

The foils of the stacked foil targets were measured, positioning them on the detector with the beam-on side showing towards the detector cup. The experimental cross-sections σ(E) [$cm^2 = 10^{27}mb$] for each target were calculated from equation (1), taking into account also the decay factor to correct for the decay during the counting time ($D(t_{count})$) and the growing factor to correct the decay during the irradiation time ($G(t_{irr})$):

$$\sigma(E) = \frac{A \cdot M \cdot Z \cdot e}{\rho x \cdot N_A \cdot Q \cdot \lambda} \cdot G(t_{irr}) \cdot D(t_{count}) \cdot e^{\lambda \cdot \Delta t}\,, \quad (1)$$

with:

$$D(t_{count}) = \frac{\lambda t_{count}}{1 - e^{-\lambda t_{count}}}\,, \quad (2)$$

$$G(t_{irr}) = \frac{\lambda t_{irr}}{1 - e^{-\lambda t_{irr}}}\,, \quad (3)$$

where A is the activity [Bq], M denotes the atomic mass [g·mol^{-1}], N_A is Avogadro's constant [atom·mol^{-1}], e the electron charge [C], Z the atomic number of the projectile, λ the decay constant [s^{-1}] of the investigated radionuclide, Q is the integrated deuteron charge [C], ρx the mass thickness [g·cm^{-2}] of the target, and Δt the waiting time from the EOB [s].

^{52}Mn has also a metastable level ($t_{1/2}$ = 21.1 m) at E = 377.749 keV, that decays for a small fraction (IT = 1.085%) by isomeric transition to the longer lived ground state. In our experimental conditions it was not possible to measure this contribution separately: the results reported also take into account the cumulative production of ^{52m}Mn.

The experimental data are compared with theoretical prediction reported in the TENDL 2017 [3] on-line library obtained with the TALYS code.

In Fig 1 the experimentally measured excitation function for ^{nat}Cr(d,x)^{52g,cum}Mn reaction route is reported, compared to past experimental data available in literature [4-10] as well as that from simulation. These are preliminary results being evaluated; for this reason, error bar is not given.

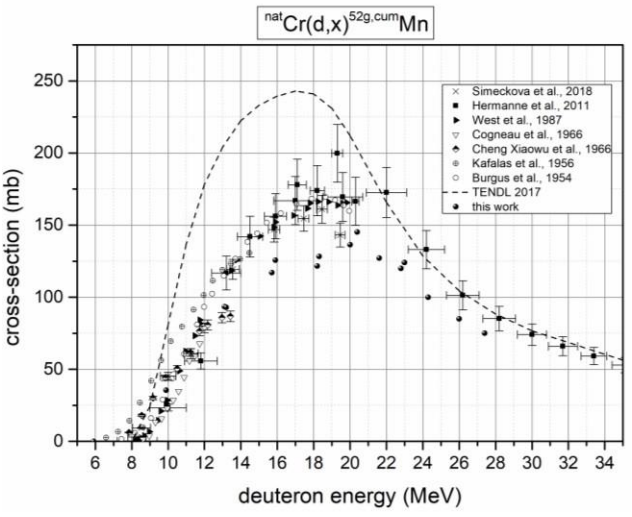

Fig. 1. Excitation function for ^{nat}Cr(d,x)^{52g,cum}Mn nuclear reaction.

In the study of ^{52}Mn production, we must consider also the production of the long half-life radionuclide ^{54}Mn ($t_{1/2}$ = 312.2 d) as a radioisotopic impurity.

In Fig 2 the experimentally measured cross-section for the ^{nat}Cr(d,x)^{54}Mn reaction route is reported, compared with the few data present in literature [4,5,9], and with the expected result from TENDL 2017 simulation.

Data obtained in this work result lower than published data. Also theoretical data from TENDL 2017 overestimate the experimental cross-sections.

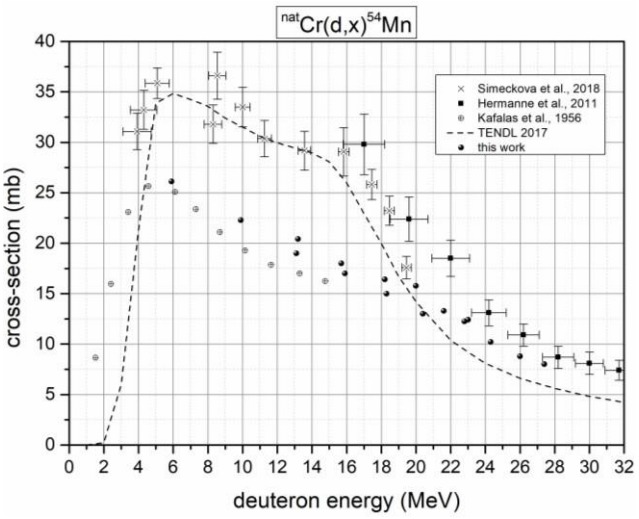

Fig. 2. Excitation function for ^{nat}Cr(d,x)^{54}Mn nuclear reaction.

CONCLUSION

The excitation functions of the nuclear reactions ^{nat}Cr(d,x)^{52g,cum}Mn and ^{nat}Cr(d,x)^{54}Mn were measured covering the deuteron energy range from 6 MeV to 29 MeV.

As obtained from the experimental preliminary results reported in this paper, the optimal energy range for the production of ^{52}Mn via cyclotron route is 28–12 MeV. In fact, the cross-section reaches its maximum value in this energy range. Furthermore, in this range the production of the long-lived radioisotopic impurity due to ^{54}Mn is minimized. Further investigations and comparison analyses with the proton-driven routes for ^{52}Mn production are underway.

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