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Measurements of alpha induced reaction cross sections on ^{113}In relevant to the astrophysical p-process

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^{113}In(α,γ)^{117}Sb and ^{113}In(α,n)^{116}Sb reaction cross sections have been measured with the activation method in the beam energy range between 9 and 14 MeV. The targets were prepared by means of evaporation of 93.1 % enriched ^{113}In on Aluminum backing foils, and bombarded with alpha beams provided by the cyclotron accelerator of ATOMKI. The activities were determined by off-line detection of the decay gamma rays with a HPGe detector in a low background environment. Preliminary cross sections are presented and compared with the predictions of statistical model calculations using the NON-SMOKER code. The comparison will provide a further test of the statistical models used in network calculations for the astrophysical p-process nucleosynthesis.

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1. Introduction

The elements heavier than iron are mainly synthesized by two mechanisms referred to as the slow neutron capture process (s-process) and the rapid neutron capture process (r-process). An additional mechanism, the p-process, is responsible for the production of 35 proton rich stable isotopes whose abundances are typically less than 1 % of the total isotopic abundances. These so-called p-nuclei between Se and Hg are shielded by stable nuclei from the production via the s- and r-processes. The required reaction rates for the modeling of the astrophysical p-process [1] are usually obtained from statistical model calculations. Recent alpha capture experiments on ^{106}Cd [2], $^{92, 94}$Mo [3] and ^{112}Sn [3, 4] indicate that the measured reaction cross sections are not correctly described by global parameterizations. ^{113}In is one of the very few p-nuclei having odd number of protons. In order to extend the experimental database for the astrophysical p-process and to test the reliability of statistical model predictions in this mass range, the alpha capture cross sections of ^{113}In have been measured close to the astrophysical relevant energy range from 6.76 to 10.18 MeV at 3.0 x 10^9 K (the Gamow window, as seen in Figure 3) and compared with NON-SMOKER statistical model results.

2. Experimental

The targets were made by evaporating isotopically enriched ^{113}In (93.10 %) onto high purity thin (d=2.4 μm) Al foils. The ^{113}In metal piece was evaporated from a carbon crucible heated by a DC current. The Al foil was placed 5.4 cm above the crucible in a holder defining a circular spot with a diameter of 12 mm on the foil for ^{113}In deposition. This procedure made it possible to determine the target thickness by weighing. The weight of the Al foil was measured before and after the evaporation with a precision better than 5 μg, and the ^{113}In number density could be determined from the difference. Altogether five enriched targets were prepared with thicknesses varying between 168 μg/cm^2 and 289 μg/cm^2, corresponding to the number of ^{113}In atoms per cm^2 between 8.3 x 10^{17} and 1.4 x 10^{18} with uncertainties between 7 % and 8 %.

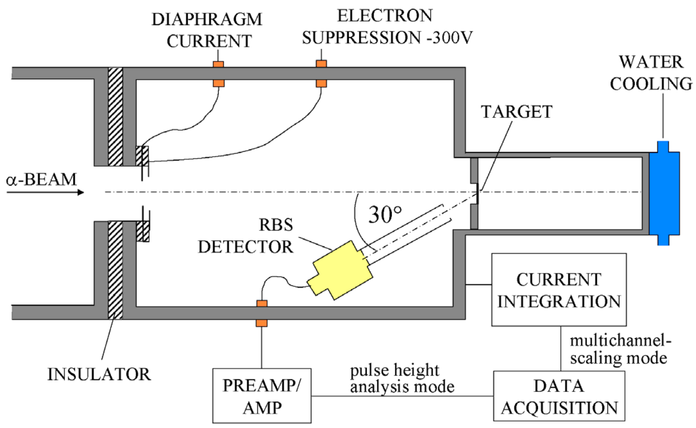

Figure 1. A drawing of the target chamber used for the irradiation.

^{113}In targets were irradiated with an alpha beam starting from the center of mass energy $E_{c.m.}$= 8.69 MeV increasing by about 0.50 MeV lab energy steps. A diagram of the target chamber is shown in Figure 1. After the last beam defining aperture, the whole chamber served as a Faraday cup to measure beam current. -300 V was applied at the entrance of the chamber to suppress secondary electrons. The integrated current was recorded in every 10 seconds by using multi channel scaler. A surface barrier detector was placed into the target chamber at 150° relative to the beam direction to detect backscattered particles and to monitor the target stability. Due to the relatively low melting point of ^{113}In, the beam current was limited below 800 nA to avoid target deterioration. The beam stop behind the target was directly water cooled. The length of irradiation was chosen based on the half-life of the activation product and beam energy, in the range of 2 and 12 h. Due to steeply decreasing cross sections at low beam energies, the longer irradiation time was applied for low-energy measurements to obtain sufficient statistics. Since the cyclotron cannot accelerate α-beam in the center of mass energy rage between 9.66 and 10.62 MeV, the energy points of $E_{c.m.}$ = 9.69 MeV, $E_{c.m.}$ = 10.20 MeV and $E_{c.m.}$ = 10.73 MeV were measured with energy degrader foils located 3 mm before the target.

After each irradiation, the target was removed from the target chamber and then transported to the γ-counting system to measure the ^{117}Sb and ^{116}Sb activities which has been produced by the investigated reactions (Table 1.), ^{113}In(α,γ)^{117}Sb and ^{113}In(α,n)^{116}Sb. The target was placed at 3.5 cm from the end cap of a HPGe detector having 40 % relative efficiency. To reduce the room background, the detector was shielded with 10 cm thick lead bricks. The counting for each run lasted between 2 and 11 h depending on the counting statistics. Figure 2 shows an off-line γ-ray spectrum taken after a 2.88 h irradiation with α beam of 12 MeV for a counting time of 1.24 h indicating the γ-lines used for cross section measurements.

Table 1. Decay parameters of the ^{113}In + α reaction products [5] and measured photopeak efficiencies at the relevant γ-energies, used for the analysis.

Reactions	Product	$T_{1/2}$ (minute)	E_γ (keV)	γ-Emission Prob. (%)	Detection Eff. (%)
^{113}In(α,γ)	^{117}Sb	168	158.6	85.9	5.7
^{113}In(α,n)	^{116}Sb	15.8	931.8	24.8	0.9
	^{116m}Sb	60.3	407.4	38.8	1.9

3. Results and Discussion

The (α,γ) and (α,n) cross sections of ^{113}In have been measured in the beam energy range between 9 and 14 MeV, which includes a part of the astrophysical relevant energy range as seen in Figure 3. The measured cross sections have also been compared with the Hauser-Feschbach statistical model calculations obtained with the standard settings of the statistical model code NON-SMOKER [6]. Figure 3 shows that the model calculations for ^{113}In(α,γ)^{117}Sb reaction overestimate the measured values by factors between 2 and 4. A better agreement is observed for ^{113}In(α,n)^{116}Sb cross section values, within the uncertainties, although deviations up to a factor of 1.5 can still be found. It is worth noting that Ref [3] assigns an uncertainty as high as a factor of 10 to the calculated cross sections of alpha induced reactions. This introduces a significant uncertainty in p-process model calculations, therefore, further experimental investigations of the relevant α-induced reactions are highly needed.

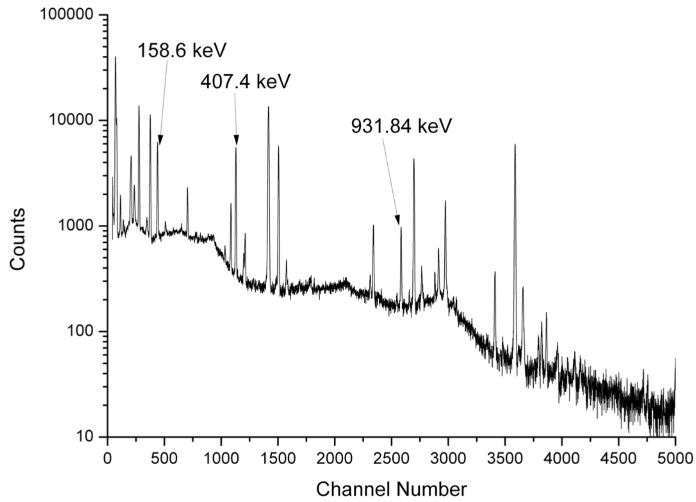

Figure 2. Activation γ spectrum taken after irradiating a target with the α beam of 12 MeV. The γ-lines listed in Table 1 are indicated by arrows. The other peaks are either from laboratory background or from the other γ-transitions.

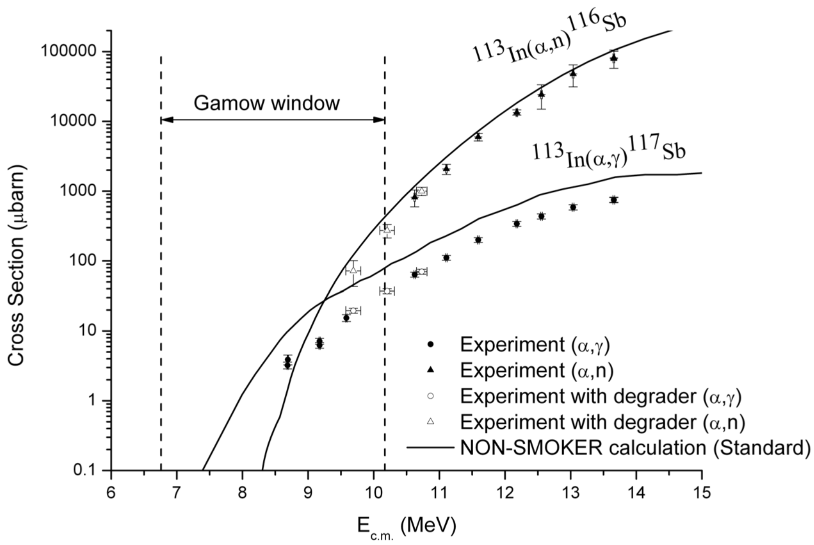

Figure 3. The cross sections for ^{113}In(α,γ)^{117}Sb and ^{113}In(α,n)^{116}Sb reactions in comparison with standard NON-SMOKER calculations [6].

The final analysis is in progress. Astrophysical S-factors and reaction rates are going to be provided, and different input parameters will be used for the model calculations since the standard calculations have shown some deviation from the experimental data.

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