Experimental Cross Sections for proton induced reactions on ^{147}Sm and ^{149}Sm

Complementary study: Measurements of the ratio between the cross sections of ^{147,149}Sm(p,γ)^{148,150}Eu and ^{148,150}Sm(p,n)^{148,150}Eu reactions

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Abstract

We propose to measure the absolute cross sections of ^{148,150}Sm(p,n)^{148,150}Eu reactions at the TANDEM accelerator facility of IFIN HH. Using these values we will obtain the ratio between the cross sections of ^{147,149}Sm(p,γ)^{148,150}Eu and ^{148,150}Sm(p,n)^{148,150}Eu reactions cross section and determine the absolute values for the (p,γ) reactions on ^{147,149}Sm at incident energies of direct interest for astrophysics. With these measurements we continue a series of experimental studies on physical quantities of relevance for the astrophysical p - process. This study is complementary to our previous measurements of cross sections of proton induced reactions on ^{147,149}Sm. Count-rate estimates based on previous experimental studies are presented which indicate that 8 days of beam time will be required for target irradiation.

I. SCIENTIFIC MOTIVATION

The optical model parameters for charged particles (proton - alpha) are key ingredients in reaction cross sections evaluations widely used to calculate astrophysical reaction rates. At incident energies below the Coulomb barrier, the predictions of different optical model parameterizations are tested against experimental cross sections for the (p,γ) and (p,n) channels, the only open channels. Experimental data below the Coulomb barrier are difficult to measure and for this reason are scarce. In the rare earth region and particularly for the Samarium isotopes, there are insufficient experimental data.

This experiment aims to obtain the ratio between the cross sections of ^{147,149}Sm(p,γ)^{148,150}Eu and ^{148,150}Sm(p,n)^{148,150}Eu reactions in order to determine the absolute cross sections for (p,γ) reactions on ^{147,149}Sm and is part of an extended experimental study [1] concerning the nucleosysntesis of proton-rich nuclei performed by our group at the TANDEM facility, IFIN-HH. The selected nuclei are in the vicinity of ^{144,146}Sm isotopes, a highly interesting region for the p - process dynamics. The relative abundance of ^{144,146}Sm can be considered a chronometer for the p - process [2], the first isotope being stable and the second one having a halflife of 1.03 $\times 10^8$ years.

This study continues a series of gamma ray spectroscopy measurements on the cross sections of (p,γ) and (p,n) processes on ^{147,149}Sm using the activation method. Proton beams of energies between 3.5 - 8.5 MeV delivered by the IFIN-HH Tandem accelerator, bombarded stacks of ^{147,149}Sm thin targets. The induced activity was measured with a pair of large volume HPGe detectors in close geometry in an special low background shielded area, thus allowing absolute cross section measurements down to tens of microbarns. The results were compared with the predictions of the Hauser Feshbach statistical model calculations performed with the code EMPIRE 3.1 Rivoli.

The enriched ^{147,149}Sm targets contained small shares of other Sm isotopes besides the desired ones, including ^{148,150}Sm. At the incident energies used for our measurements, the ^{148,150}Sm(p, n) channels were open and had a significant contribution to the production of ^{148,150}Eu. Thus we measured the population cross sections of ^{148,150}Eu due to both ^{147,149}Sm(p, γ)^{148,150}Eu and ^{148,150}Sm(p, n)^{148,150}Eu reactions and we compared the experimental values with the calculations performed using the Empire code. These theoretical calculations are not tested against any experimental data, due to the lack of measurements on the Samarium isotopes. Therefore we propose to experimentaly distinguish the contribution of each of the two open channels by measuring the absolute cross sections for the

^{148,150}Sm(p,n)^{148,150}Eu reactions using the activation method. For this we require a high efficiency low background γ detection setup.

II. REPORT ON THE PREVIOUS MEASUREMENTS ON ^{147,149}SM

Our group has performed a series of three off beam gamma ray spectroscopy measurements in 2009, 2011 and 2012 aimed to obtain the absolute cross sections for the proton induced reactions on ^{147,149}Sm at incident energies between 3.5 and 8.5 MeV using the activation method. We obtained the absolute cross sections for the ^{147}Sm(p,n)^{147}Eu and ^{149}Sm(p,n)^{149}Eu reactions and the combined cross sections of the ^{147,149}Sm(p,γ)^{148,150}Eu and ^{148,150}Sm(p,n)^{148,150}Eu reactions at six incident energies.

The experimental procedure of the activation method involves the irradiation of the selected targets and the off beam measurement of the induced activity of the reaction products. For an accurate determination of the reaction cross sections, several physical quantities were precisely measured before and during the experiment, such as the width of the targets, the share of the various isotopes within the targets, the intensity of the proton beam, the efficiency of the detection system and the timing information related to the irradiation and measurement procedures.

The continuous proton beams delivered by the TANDEM accelerator at IFIN HH were impinged on stacks of thin metallic self-supporting highly enriched (approximately 95 %) ^{147}Sm and ^{149}Sm targets. The intensity of the proton beam was aquired using an ORTEC 439 digital current integrator. Examples of the proton beam's time dependence are shown in Figure 1. Each stack of foils placed in beam contained two Samarium targets alternating with two Aluminium foils and, at the end of the stack, a Copper and a Tantalum foil. The Aluminium foils acted as recoil nuclei catchers while the Copper foil was used to renormalise the proton beam current. The first Al foil, placed between the two Samarium targets, acted also as an energy degrader for the incident proton beam.

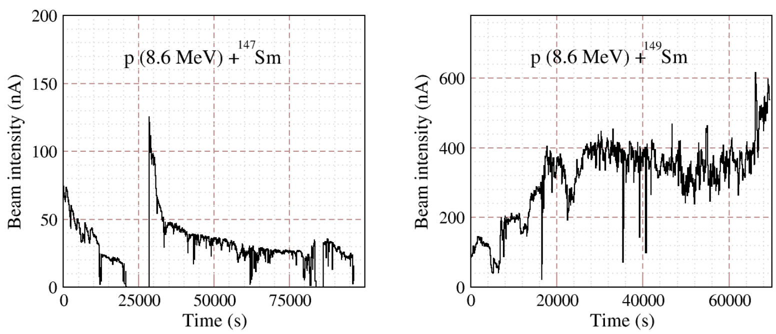

FIG. 1: Time dependence of the beam current continuously monitored in the first irradiation campaign, in 2009.

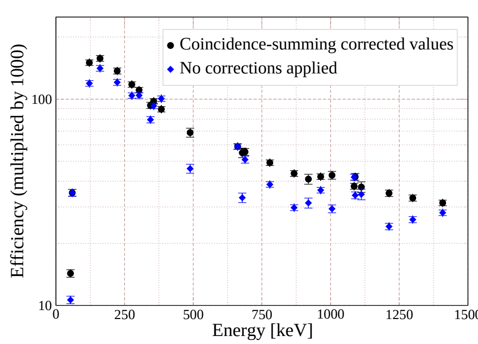

FIG. 2: Efficiency measurements for a HPGe detector using ^{133}Ba, ^{137}Cs, ^{152}Eu and ^{241}Am standard calibration sources. Comparison between the values obtained taking into account the summing effect and the uncorrected values.

The activity of each reaction product was measured in close geometry with a pair of large volume HPGe detectors, each detector being placed facing the irradiated target at about 0.5 cm from it. We applied coincidence summing corrections using the Monte Carlo simulation code GESPECOR [3] to the gamma spectroscopy measurements on the calibration sources and also on the activity of the reaction products. Figure 2 shows a comparison between two efficiency calibrations performed with and without summing correction for the same detector. The efficiency values corrected taking into account the summing effects present a more natural response with much lower changes as a function of energy.

The reaction products population, respectively the production of ^{147}Eu ($T_{1/2}$ = 24 days), of ^{148}Eu ($T_{1/2}$ = 54 days), of ^{149}Eu ($T_{1/2}$ = 93 days) and of ^{150}Eu^{iso} ($T_{1/2}$ = 13 hours), were determined using the spectra evaluation of the strongest transitions from their subsequent decays. The experimental values obtained for the reaction cross sections are reproduced in Figure 3 and Figure 4 along with the theoretical calculations performed with the code EMPIRE 3.1 Rivoli using the global optical potentials of Koning and Delaroche for incident protons and neutrons. The input parameters were taken from the RIPL-3 database [4] , [5] and from the internal systematics of the EMPIRE code.

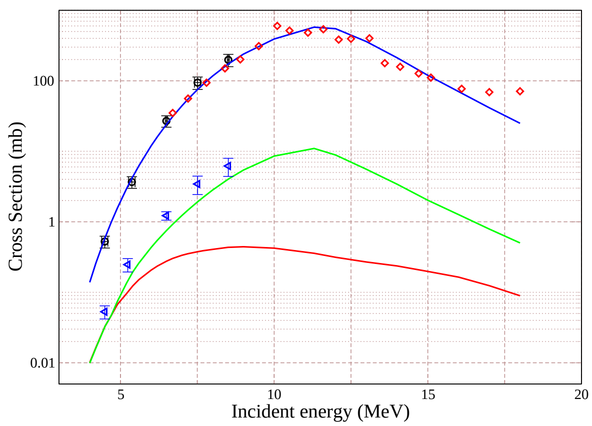

FIG. 3: Cross sections of proton induced reactions on a higly enriched Sm target (approximately 95 % ^{147}Sm, 2 % ^{148}Sm). Shown are: experimental values for the ^{147}Sm(p,n)^{147}Eu reaction: ○ - this work, ◇ - [6]; – - EMPIRE calculations for the ^{147}Sm(p,n)^{147}Eu reaction; ◁ - experimental values for the combined cross section of the ^{147}Sm(p,γ)^{148}Eu and ^{148}Sm(p,n)^{148}Eu reactions (this work); – - EMPIRE calculations of the total production of ^{148}Eu; – - EMPIRE calculations for the ^{147}Sm(p,γ)^{148}Eu reaction.

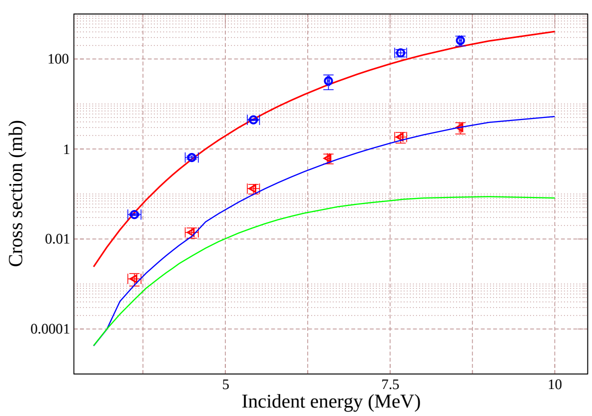

FIG. 4: Cross sections of proton induced reactions on a higly enriched Sm target (approximately 95 % ^{149}Sm, 2 % ^{150}Sm). Shown are: ○ - experimental values for the ^{149}Sm(p,n)^{149}Eu reaction - this work; – - EMPIRE calculations for the ^{149}Sm(p,n)^{149}Eu reaction; ○ - experimental values for the combined cross section of the ^{149}Sm(p,γ)^{150}Eu and ^{150}Sm(p,n)^{150}Eu reactions (this work); – - EMPIRE calculations of the total production of ^{150}Eu; – - EMPIRE calculations for the ^{149}Sm(p,γ)^{150}Eu reaction.

III. EXPERIMENTAL OVERVIEW

We propose to measure the absolute cross sections of ^{148,150}Sm(p,n)^{148,150}Eu reactions using the activation method at 6 different energies between 3.5 and 8.5 MeV for each isotope. For incident beam energy, the target stacks having three Sm layers alternating with aluminum foils will be irradiated using the scattering chamber mounted on the beam line 5 and, after that, its decay spectra will be measured off-line with a specially designed low-background setup consisting into a pair of large volume HPGe detectors surrounded by Pb walls clothed with Cu and Al plates on the inside. The HPGe detectors of about 50% will be mounted in close-to-detection geometry in order to maximize the detection efficiency. The absolute cross sections for each reaction populating a certain decaying nucleus will be extracted from the peak areas of the corresponding characteristic γ-rays.

IV. BEAM TIME REQUEST

We want to measure proton induced cross sections on two Sm isotopes at six energies each (4 stacks of 3 target foils) in the 3.5 - 8.5 MeV range, corresponding to the proton beam incident energies used in the previous activation experiments on the same isotopes. We request 15 shifts (5 days) beam time per each isotope, which sums up to a total of 10 days of beam time. The proton beam should have an intensity of about 300 nA, kept constant as much as possible, thus allowing a precise extraction of the absolute cross sections.

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