Measurement of lifetimes and absolute cross-sections in the region of heavy mass *p* – nuclei (part III)

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Scientific motivation: The proton-rich nuclei heavier than Fe (the so-called *p* – nuclei) are produced by a combination of the (γ, n), (γ, p) and (γ, α) reactions on existing *s* or *r* nuclei at temperatures around a few GK, characteristic of explosive environments. To adequately describe the *p* – process nucleosynthesis, one needs reliable information on the thousands of reactions involved, but also on the structure of the excited states of the nuclei taking part at these processes. Our group started years ago a series of experimental studies [1,2] aimed to fill the lack of information concerning these measurable quantities (excitation functions for the absolute cross – sections, excitation functions for the astrophysical *S* factors and lifetime measurements for the excited levels of the involved nuclei).

One of the most interesting region of heavy *p* – nuclei is the one around ^{144}Sm and ^{146}Sm isotopes, the first one being stable and the second having $T_{1/2} = 1.03 \times 10^8$ y. In fact, their relative abundance can be considered as a *p* – process chronometer [3]. As in all the other cases of interest for the nuclear astrophysics, one needs informations not only on the these nuclei, but also on the neighbouring nuclei involved in the reaction chains (Pm, Sm, Eu, Gd isotopes).

In the past years we performed experimental investigations on the nuclear structure in this region by studying the ^{147}Eu isotope [4]. The level scheme was completed by adding 14 new levels, and the lifetimes were measured (or a lower limit was indicated) for 12 of the already known levels.

In order to add more information about the nuclei in this region, we also need to know absolute values of the light particle induced reaction cross sections. Theoretical calculations of these cross sections can be performed using various models, but they need to be confirmed experimentally. Very recently, the results of the ^{149}Sm(n,α)^{146}Nd cross section measurement at 6 MeV incident energy were published [5], which together with previously reported ^{147}Sm(n,α)^{144}Nd at the same neutron energy [6] can be used to test statistical-model predictions for the isotopic effect [7]. In the same context, the absolute cross sections for proton or alpha particle induced reactions on the same Sm isotopes are of big interest.

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Figure 1 shows the calculations performed using the NON-SMOKER code [8] for the reactions induced on ^{147}Sm and on ^{149}Sm by protons.

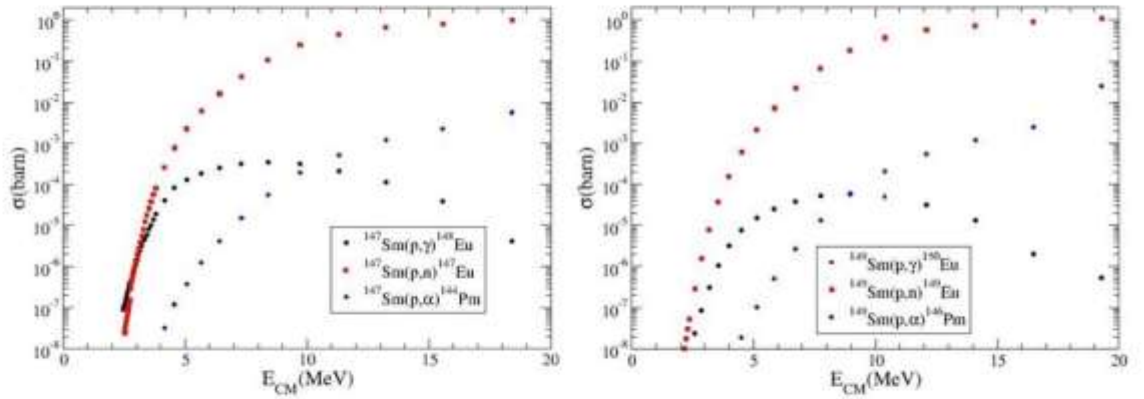

Figure 1:*The calculated cross-section for the proton-induced reacions on ^{147}Sm (left) and on ^{149}Sm (right) using the NON-SMOKER code.*

Previous measurements:

A first experiment (three days of beam time) was performed in December 2009, in which the absolute cross sections for the ^{147}Sm(p,n)^{147}Eu, ^{147}Sm(p,γ)^{148}Eu, ^{149}Sm(p,n)^{149}Eu and ^{149}Sm(p,γ)^{150}Eu reactions were measured at the proton energies of about 8.5 and 7.5 MeV. The proton beam delivered by the Tandem accelerator of IFIN-HH was used to irradiate two stacks, each of them composed by a ^{147}Sm (or ^{149}Sm) target, an aluminium foil, another target and a tantalum foil. The aluminium foil between the two targets was used as an energy degrader for the proton beam before the second Sm target, and also to collect the recoils flying out of the first Sm target, while the last tantalum foil was only used to collect the recoils from the second Sm target. The two ^{147}Sm targets had a thickness of 5.4 mg/cm^2 and the two ^{149}Sm targets of 1.8 mg/cm^2. The aluminium foils were 80 μm thick, giving an energy of the proton beam of about 1 MeV less than the incident one for the second Sm target.

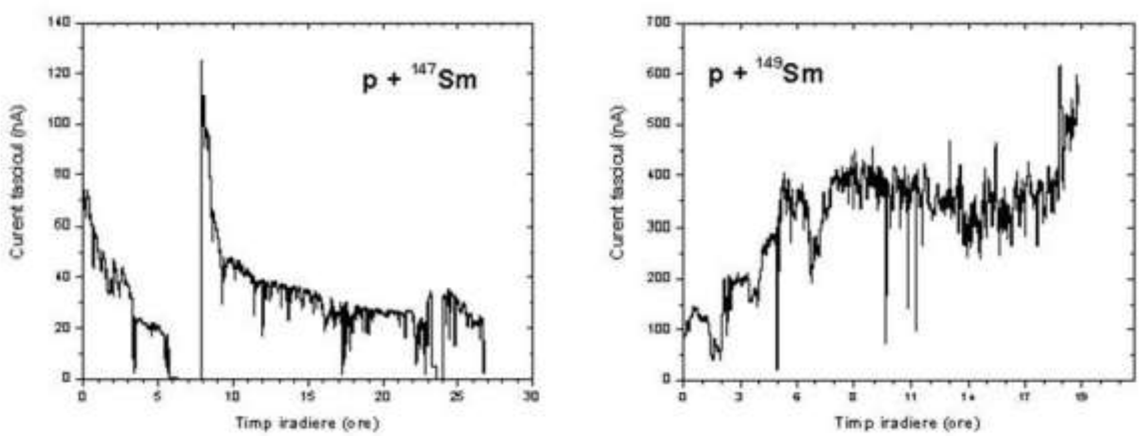

Fig. 2: *The evolution of the beam current during the irradiation of the ^{147}Sm (left) and ^{149}Sm (right) targets in the December 2009 experiment.*

The beam current was continously monitorized (see Fig. 2), to ensure an accurate data analysis for the off-line activity measurements. These were done 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% were mounted in close geometry in order to maximize the detection efficiency. Gamma rays from the subsequent decays of the produced nuclei were recorded, as follows: ^{147}Eu ($T_{1/2}$ = 24.1 d), ^{148}Eu ($T_{1/2}$ = 54.5 d), ^{149}Eu ($T_{1/2}$ = 93.1 d), ^{150}Eu^{m} ($T_{1/2}$ = 12.8 h) and ^{150}Eu ($T_{1/2}$ = 36.9 y).

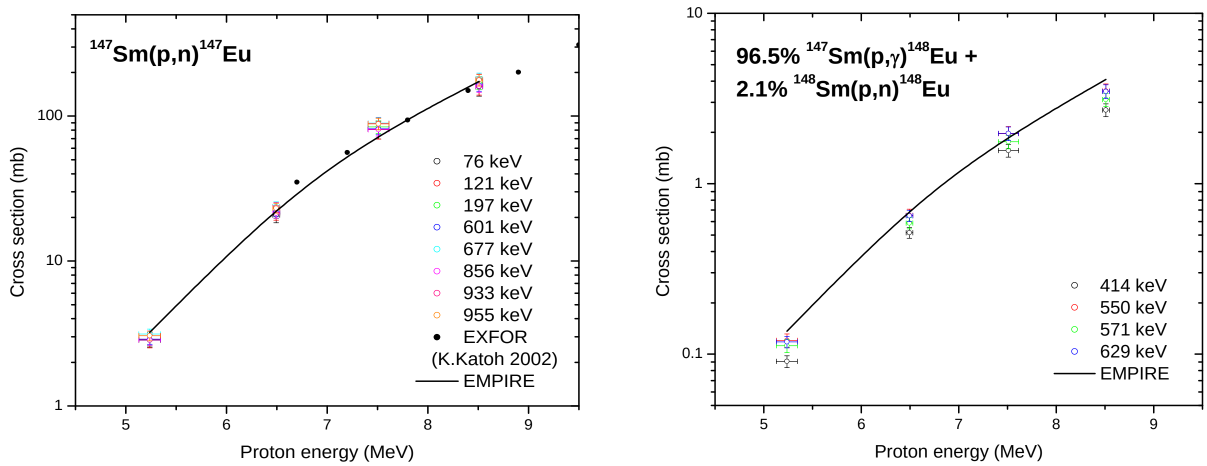

***Figure 3**: Preliminary results for the measurements of the (p,n) (left) and (p,γ) (right) reactions cross sections on ^{147}Sm. Various points for the same incident energy corresponds to various γ-ray peaks used in the analysis. The continuous lines are the calculations using the EMPIRE code.*

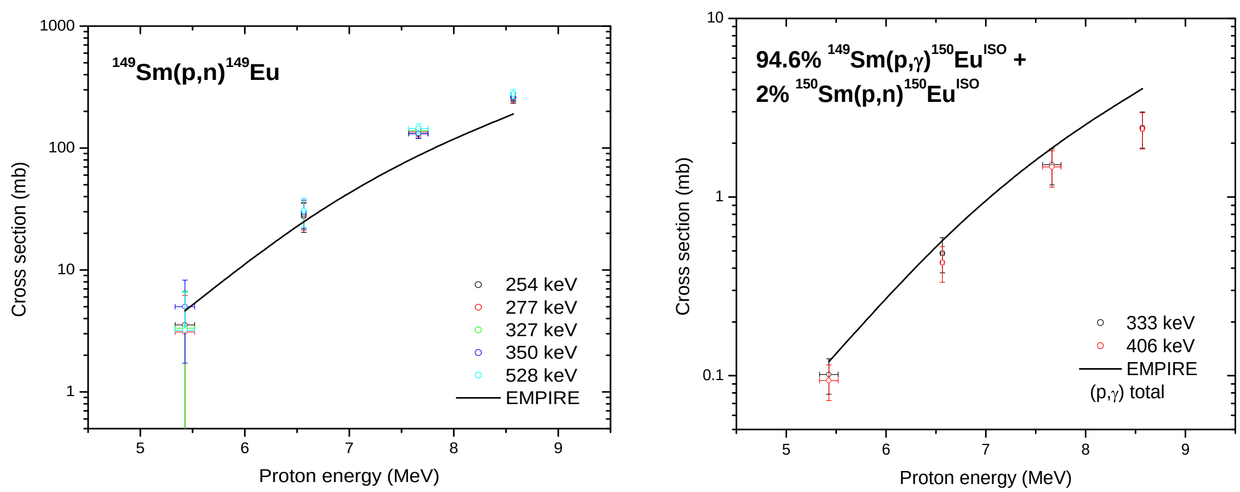

***Figure 4**: Same as above, but for the reactions on ^{149}Sm.*

Following the same procedure, a second experiment was performed in February 2010, at a lower proton beam energy (of about 6.6 MeV).

By using the gamma rays following the decays of the produced Eu isotopes, the absolute cross-sections for the production reactions could be extracted. Accurate energy and efficiency calibration measurements were made, using very precise calibrated low-intensity sources (^{133}Ba, ^{137}Cs, ^{60}Co, ^{241}Am, ^{152}Eu). Preliminary results for the absolute cross sections of the (p,n) and (p,γ) reactions on the ^{147}Sm and ^{149}Sm are presented in Fig. 3 and 4, showing the different values of the cross sections obtained using different γ-rays following the decays of the obtained Eu isotopes.

Proposed experiment: We propose to continue the previously started measurements to the proton induced reactions on the same isotopes (^{147}Sm and ^{149}Sm) at 2 different (and lower) energies. As the previous measured points were around 8.5, 7.5, 6.5 and 5.5 MeV, we intend to use an incident proton beam of about 4.6 MeV, which gives an average energy in the first Sm target of about 4.5 MeV, and after the energy loss in the Al foil placed between the 2 Sm targets, an average energy of about 3.5 MeV in the second target, thus extending the energy interval covered by the measurements.

Beam time request: As the cross section values are expected to be lower than the previously measured ones, we ask for a total of 5 days of beam-time. The proton beam should have an intensity of 200-300 nA, kept constant as much as possible, thus allowing a precise extraction of the absolute cross sections.

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