Experimental study of the ^{64}Zn (α, γ)^{68}Ge fusion reaction

Proposal submitted by:
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Accelerator: 3 MV

Beam: α, Energy = 7.4-8.4 MeV (in step of 0.2 MeV), intensity=1 µA.
Time requested: 9 days.
Purpose: completion of the measurements started in 2016, as per proposal B-062, approved by PAC in Apr 2016.

Introduction

Since the beginning of the operation of the 3 MV tandetron accelerator found in IFIN-HH we have demonstrated its capabilities for direct measurements for nuclear astrophysics: appropriate energy range, stability, diversity of projectiles, high currents. We have also shown that an additional opportunity is provided by the ultra-low background laboratory the institute has in a salt mine located at about 100 km north of Bucharest-Magurele, in Slanic-Prahova [1, 2], the microBequerel laboratory. With a well shielded Ge detector a background reduction factor up to 4000 was obtained (relative to the surface background of the same unshielded detector).

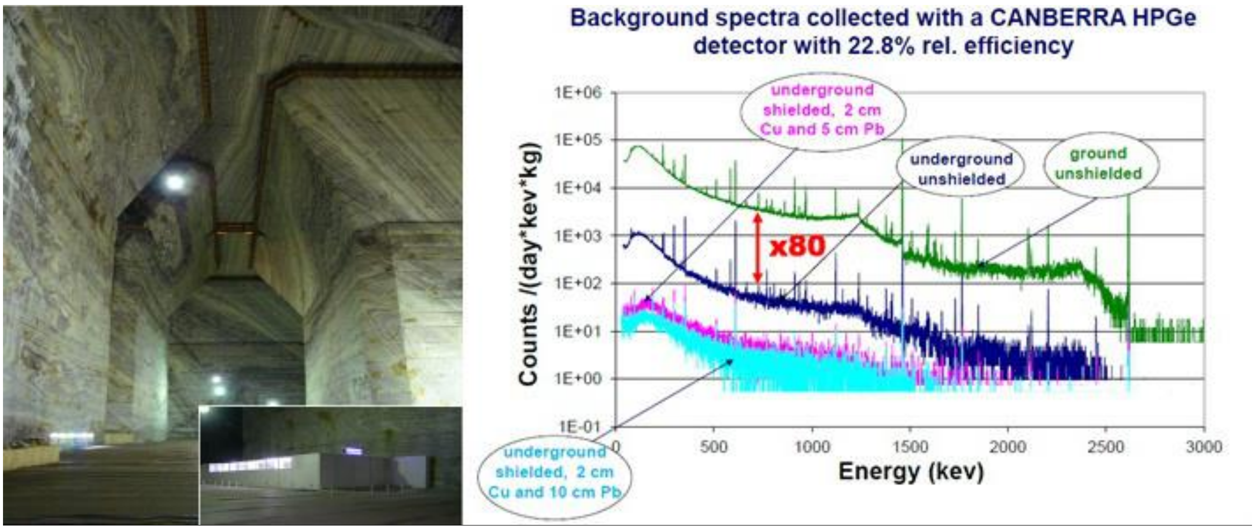

Figure 1. Background from the salt mine (µBq laboratory) [2].

We concluded that this laboratory can be competitive for direct nuclear astrophysics measurements induced by alpha particles and light ions. We used these findings and strengthened them on cases that can use this combination of facilities. For now we want to continue a program that goes on two distinct lines:

- Continue the study of reactions between light ions like ^{12}C and ^{16}O down into the Gamow window or as close as possible to it (one proposal with the Lanzhou group at this PAC);
- Proceed with the program using α-beams to measure α-induced reactions on proton rich nuclei (two proposals last year). Selection at this point was being done for

reactions that produce activations that are long enough for the targets to be transferred to Slănic. We need extra beamtime to complete these measurements.

$^{64}Zn(\alpha,\gamma)^{68}Ge$ fusion reaction

The nucleosynthesis of elements heavier than iron is particular because their synthesis requires energy so their production cannot be the source that powers a star. Therefore, their existence in nature must be explained by other process than He-burning, C-, O- or Si-burning in massive stars. Most of the heavy elements are produced through neutron capture reactions; the two processes of neutron capture: s- and r- processes. However, on the proton-rich side of the valley of nuclear stability there are almost three dozen of heavy stable isotopes that cannot be produced by this two processes. One process that is able to produce proton-rich isotopes is the γ-process which occurs through γ-induced reactions on heavy isotopes. In stellar environment the high energy wing of the Planck distribution is energetic enough to remove neutrons from heavy isotopes. p-isotopes are produced through consecutive (γ, n) reactions which lead the material to the proton-rich region. In this way isotopes become more and more neutron-deficient and charged particles emitting (γ, p) and (γ, α) reactions start to play an important role and influence the p-isotopes abundances. γ-induced reactions take place at high temperatures and different explosive scenarios are proposed for the γ-process. The most intensively studied is the O/Ne layer of core collapse supernovae, but type Ia supernovae are also considered.

The Gamow window for this reaction is between 4 and 6.5 MeV (the γ-process temperature is around 3 GK) with only two channels opened: $^{64}Zn(\alpha,\gamma)^{68}Ge$, $^{64}Zn(\alpha,p)^{67}Ga$ and the third one $^{64}Zn(\alpha,n)^{67}Ge$ has a threshold at 9.5 MeV. Therefore, we have to take into account that the experimental study of γ-process related reactions is of high importance in order to provide direct data for the γ-process networks and to check the reliability of statistical model calculations. In order to complete the measurements from last year we decided to study the $^{64}Zn(\alpha,\gamma)^{68}Ge$ reaction [4,5,6,7].

In 2016 we have studied the $^{64}Zn(\alpha,p)^{67}Ga$ fusion reaction that was approved by the Proposal Advisory Committee and took place in October 2016. During the experiment we irradiated natural zinc targets by alpha beam with energies in the laboratory frame between 5.4-8 MeV with a step of 0.2 MeV. The thick target yield for the $^{64}Zn(\alpha,p)^{57}Ga$ reaction was determined through measurements of γ-ray yield following the decay of ^{67}Ga ($T_{1/2}$=78.28 h) in two laboratories microBequerel and NAG (Nuclear Astrophysics Group) where the gamma rays (184.6, 209.0, 300.2 and 393.5 keV) were detected with HPGe detectors with relative efficiencies of 120% and 100% respectively.

The $^{64}Zn(\alpha,p)^{57}Ga$ cross section have been determined from the extracted thick-target yield Y(E).

$$\sigma(E) = \frac{1}{N_v}\frac{dY(E)}{dE}\frac{dE}{dx} \quad (1)$$

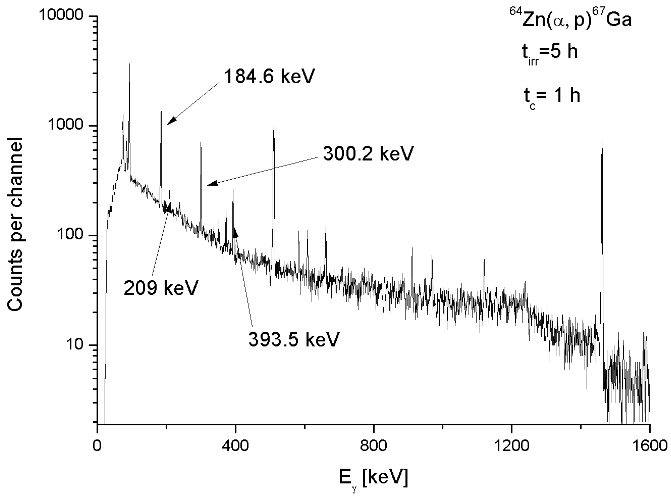

Figure 2. Gamma rays from activation measurements.

The preliminary results obtained from the de-activation measurements are represented in Figure 3 and it is clear that we have obtained comparable results with the ones from previous experiments.

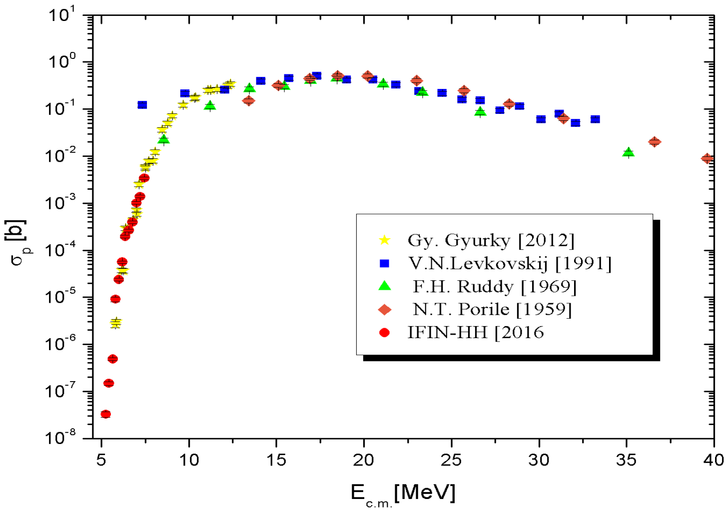

Figure 3. Experimental cross section for ^{64}Zn (α, p)^{67}Ga in comparison with previous experiments [5, 6, 7].

Plan for the Proposed Project

During the experiment we plan to irradiate natural zinc targets with energies between 7.4 and 8.4 MeV with a step of 0.2. For the ^{64}Zn (α, γ)^{68}Ge ($T_{1/2}$ =271 d) reaction we plan to do de-activation measurements in microBequerel and NAG laboratories. To increase the sensitivity, we also want to use two HPGe detectors with relative efficiencies of 100% placed one in front of the other and a plastic scintillator for β–γ coincidences. In addition, prompt in-beam gamma-rays will be detected with two HPGe detectors in close geometry for as long as the reaction cross section will be sufficiently large for those gammas to be extracted from the background of the target hall.

One additional goal of this experiment is to test with beam the gamma-beta coincidence system of high resolution and high sensitivity that we have designed and built in the last year. We plan to use 2-3 days in the first allotment requested.

The total required beam time is 9 days as follows:

- in the first 4 days we plan to irradiate 4 targets at different energies (8.4 and 8.2 MeV) and measure them as follows: in the first day we irradiate 2 targets at 8.4 MeV which will be measured, one at the salt mine and the other at IFIN; in the second day we will irradiate at 8.2 MeV and wait almost 24 days for the first target to be measured until we measure the second target.
- after approximately one month we plan to irradiate the following 4 targets (8 and 7.8 MeV) and to repeat this procedure for all targets.

$E_{lab.}$ [MeV]	Number of targets	Beam time [h]	Waiting time [days]	Measuring time [days]
8.4	2	1.5	1	24
8.2	2	1.5	24	24
8	2	2	1	24
7.8	2	2.5	24	24
7.6	2	2.5	1	24
7.4	2	3	24	24

Table 1. Details of the necessary beam time.

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