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Test of a ^{3}He target for transfer reactions in inverse kinematics

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Summary. — With the aim of studying exotic nuclei close to the proton dripline, an innovative ^{3}He target was produced and tested in a collaboration between the Materials Science Institute of Seville (Spain) and the Legnaro National Laboratories (Italy). The target was manufactured with a new technique that aims to reduce the costs while providing high quality targets. The target was tested at the Legnaro National Laboratories. The results of this test are presented in this contribution

1. – Introduction

In the last years, in the field of nuclear physics, great efforts have been made to produce and study nuclei far from the valley of stability. This has promoted the construction of facilities that produce Radioactive Ion Beams (RIBs) to push our knowledge to the limits of nuclear existence. One way to make use of these beams is via direct reactions, in particular transfer reactions [1]: thanks to their selectivity, these reactions allow the direct population of the states of interest, which is important, for example, when measuring the lifetimes of low-lying states. Among the light nuclei which can be employed as target material, ^{3}He is one of the most promising choices for the study of neutron-deficient nuclei as it can be used in two-proton transfer reactions, which yield a more exotic final nucleus. For this purpose a solid target containing ^{3}He [2] was produced with an innovative technique in a collaboration between the Legnaro National Laboratories (LNL), Italy, and the CSIC-Materials Science Institute of Seville, Spain. The properties of the target were then tested at the LNL with a stable beam of ^{64}Zn.

2. – ^{3}He target test

The new target, produced via a sputtering technique, consists of a thin (650 nm) layer of ^{nat}W; ^{3}He aggregates are embedded inside the metallic layer. The density of ^{3}He is $\sim 3{\cdot}10^{17}$ atoms/cm^2 (equivalent to 1.4 μg/cm^2), which makes up 7% of the whole target composition. Contaminants such as ^{12}C and ^{16}O are also present in large quantities, 3% and 11% respectively. At the back of the target, a gold foil with 10 mg/cm^2 thickness is added: it serves both as a supporting structure for the W target and as a stopper for the residual nuclei, which allows for the measurement of lifetimes via the Doppler Shift Attenuation Method.
The test was performed with a beam of ^{64}Zn, accelerated by the PIAVE-ALPI [3, 4] accelerator complex at an energy of 275 MeV and intensity varying between 0.5 and 5 pnA. Two identical targets were used for 11 hours each. For this test experiment, the GALILEO [5] γ-ray array was employed together with the Neutron-Wall [6] neutron detector array and the EUCLIDES [7] light charged particle detector array.

3. – Test results

One of the main concerns with this new kind of target was the evaporation of ^{3}He. In fact, solid targets containing ^{3}He had already been produced in the past via implantation techniques [8], but they were subject to strong evaporation, due to heating caused by the beam energy loss, and they could therefore only be used in low-energy experiments. In order to monitor this phenomenon, the EUCLIDES array was used: ^{3}He was expelled out of the target due to the elastic scattering and was detected in the ΔE-E telescopes. The counting rate is directly proportional to the density of ^{3}He inside the target, therefore by analyzing this value it was possible to determine the effect of evaporation. The result is presented in Figure 1, which shows the change in counting rate normalized over the

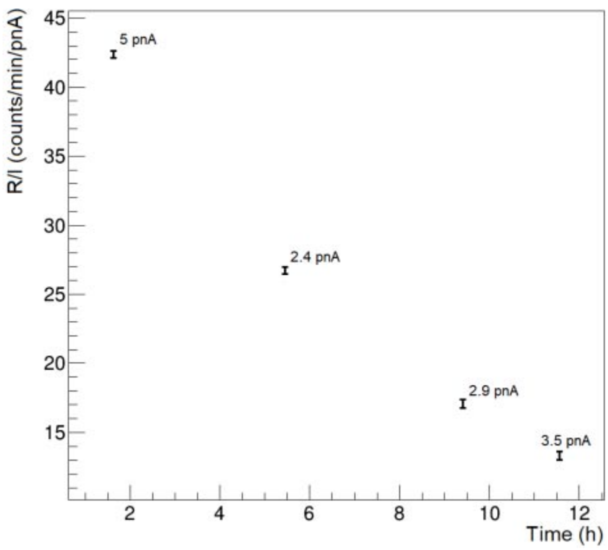

Fig. 1. – Counting rate of the ^{3}He as a function of the beam time for one of the forward EUCLIDES detectors. The rate is normalized over the beam intensity.

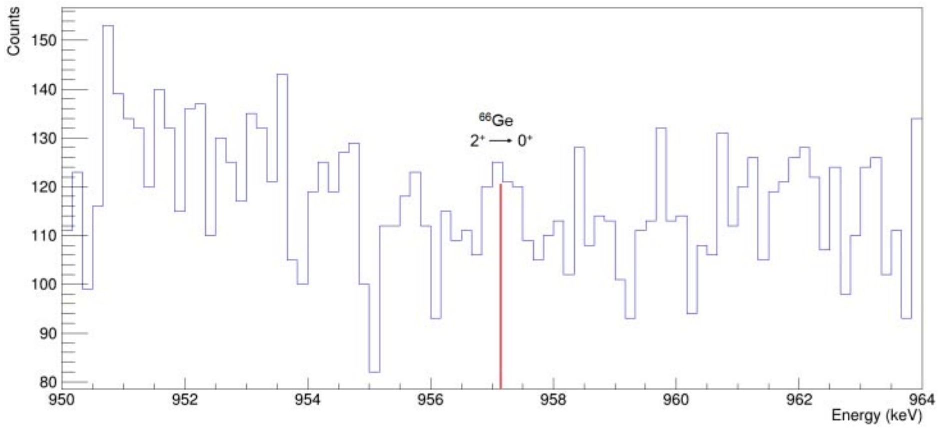

Fig. 2. – Neutron-gated γ-ray energy spectrum, zoomed in on the region around 957 keV. The red line highlights the structure attributed to the $2_1^+ \rightarrow 0_{g.s.}^+$ transition of ^{66}Ge.

beam intensity as a function of beam time. In a 11 hours time lapse, with beam current between 2.4 and 5 pnA, the rate drops by a factor 3: this suggests that ^{3}He does indeed evaporate from the target. On the other hand, one needs to consider the fact that in future applications this kind of target will be used with RIBs, whose intensity is expected to be 4-5 orders of magnitude lower than the one of the described experiment: in those conditions, the impact of ^{3}He evaporation from the target should be negligible.

Another important part of the study covered the two-proton transfer reaction ^{3}He(^{64}Zn,n)^{66}Ge. From the neutron-gated γ-ray energy spectrum, no clear peaks coming from the de-excitation of ^{66}Ge are observed; however, as shown in Figure 2, a structure barely emerging from the background can be identified at 957 keV, which corresponds to the energy of the $2_1^+ \rightarrow 0_{g.s.}^+$ transition of ^{66}Ge. The estimated background is 433 counts, with the structure containing 56 counts over it; the probability of this being a random fluctuation is 0.004. Moreover, this structure can only be seen in the neutron-gated spectrum, while it disappears in proton-gated or α-gated spectra. All of this lead to the identification of these events as real ones caused by the de-excitation of ^{66}Ge. The reaction cross section was evaluated to be around 0.3 mb.

During the discussed investigation neutron angular distributions were measured with the Neutron-Wall array, which consist of 45 detectors placed at 5 different angles relative to the direction of the beam. The first ever angular distribution measurement with this array was performed during this experiment for neutrons emitted in the fusion-evaporation reaction ^{16}O(^{64}Zn,1p2n)^{77}Rb, identified through their coincidence with the 470 keV transition of the final nucleus and a gate on multiplicity one for neutrons. The measured distribution, compared to the one calculated with the statistical model code for fusion-evaporation LILITA_N11 [9], is shown in Figure 3. The calculated distribution well reproduces the experimental data. This suggests that despite the low angular resolution ($\sim 11^{\circ}$ for the array placed at 50 cm from the target position), a distribution that does not have narrow peaks or deep valleys can be accurately measured. Furthermore, it suggests that the neutrons scattering between different detectors, where the first interaction does not leave a signal in the detector, do not have a significant impact on the measurement. Simulations suggest that these kind of events happen 1.8% of the times. Given this

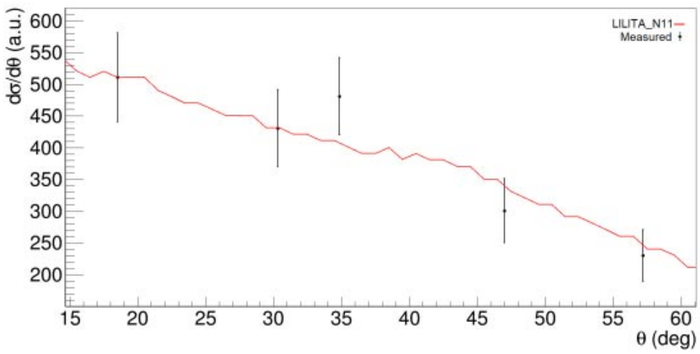

Fig. 3. – Angular distribution of neutrons in coincidence with γ rays from ^{77}Rb. The red curve represents the calculated distribution obtained with the statistical model code LILITA_N11 [9].

positive result, an attempt was made at measuring the distribution of neutrons from the two-proton transfer reaction: from this, it would be possible to evaluate the angular momentum of the excited states of the final nucleus populated in the reaction [1]. This measurement was performed by considering neutrons in coincidence with γ rays at 957 keV. The very low statistics, however, made this measurement not possible. As such, no significant result could be obtained from this attempted measurement.

4. – Conclusions and future perspectives

The test experiment showed that the target suffers from ^{3}He evaporation due to the heating caused by the beam, but the effect is limited and should not be a problem when working with RIBs. Moreover, a first time measurement of neutron angular distributions was performed with the Neutron-Wall detector: the result is in agreement with calculations. The two-proton transfer reaction was also studied, but the statistics proved to be too low to gather any significant result.

REFERENCES

[1] F. Zardi, *Reazioni di trasferimento*, in *Teoria delle collisioni fra ioni pesanti, Parte II - Le collisioni radenti* (INFN Sezione di Padova, Padova) 1979.
[2] A. Fernandéz, D. Hufschmidt, V. Godinho, M. C. Jiménez de Haro, patent pending.
[3] A. Lombardi, *et al.*, *LNL-INFN Annual Report 2003*, (2003) 199.
[4] G. Fortuna, *et al.*, *Nucl. Instrum. Meth. A*, **287** (1990) 253.
[5] J. J. Valiente-Dobón, *et al.*, *LNL-INFN Annual Report 2014*, (2014) 95.
[6] Ö. Skeppstedt, *et al.*, *Nucl. Instrum. Meth. A*, **421** (1999) 531-541.
[7] D. Testov, *et al.*, *LNL-INFN Annual Report 2015*, (2015) 105.
[8] W. H. Geist, *et al.*, *Nucl. Instrum. Meth. B*, **111** (1996) 176-180.
[9] Extensively modified version of the original code LILITA written by J. Gomez del Campo and R. G. Stockstad, Oak Ridge National Laboratory, Report No. TM7295, `http://web.ornl.gov/info/reports/1981/3445605518062.pdf`, unpublished.