^{26}Mg target for nuclear astrophysics measurements

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Abstract. Two nuclear reactions of astrophysical interest, ^{26}Mg(^{3}He,d)^{27}Al and ^{26}Mg(d,p)^{27}Mg, were measured for extraction of the Asymptotic Normalization Coefficients. Investigation of the target composition is presented, as well as the effects that showed up during analysis of the in-beam data obtained on CANAM accelerators in the Nuclear Physics Institute of the Czech Academy of Sciences (NPI CAS).

1 Introduction

One of main challenges of nuclear astrophysics is to explain origins and ratios of observed chemical elements abundances, since there are still questions in heavier elements production. Abundance of ^{27}Al is an essential check of models describing ^{26}Al production in Mg-Al cycle compared to observation of gammas from ^{26}Al decay in the galaxy [1]. Next challenge is to understand quantitatively the observed galactic distribution of ^{26}Al via ratio between ground and isomeric state in ^{26}Al in novae. This ratio may be influenced by destruction of ^{26}Si, which decays to ^{26}Al [2] . Nuclear reactions of charged particles in stars proceeds with energies below Coulomb barrier, so the cross sections are very low. Direct measurements in laboratory conditions are difficult and sometimes not feasible, therefore indirect methods are used. One of them is the method of "Asymptotic Normalization Coefficients" (ANC). This technique allows to extract normalization of nuclear overlap function tail for single particle transfer, which determines the direct capture reaction rate and the cross section of direct process. ANC can be evaluated from the analysis of direct nuclear reactions measured in laboratory conditions (elastic scattering, transfer reactions) [3, 5]. Using ^{26}Mg target, the studies of ^{26}Mg(d,p)^{27}Mg (as a mirror nucleus to ^{26}Si(p,g)^{27}P) and ^{26}Mg(^{3}He,d)^{27}Al reactions were measured to extract ANC.

2 Setup

Measurement of an angular distribution of reaction products is necessary for extraction of ANC. ^{26}Mg targets were used for in-beam irradiation of cyclotron U120M in NPI CAS. This cyclotron is operated under "Center of Accelerators and Nuclear Analytical Methods" (CANAM infrastructure). Angular distributions of the nuclear reaction products were measured with a set of dE/E telescopes consisting of 2 silicon detectors, 500 um and 5 mm thick respectively on VME ADC electronics. Beam energy

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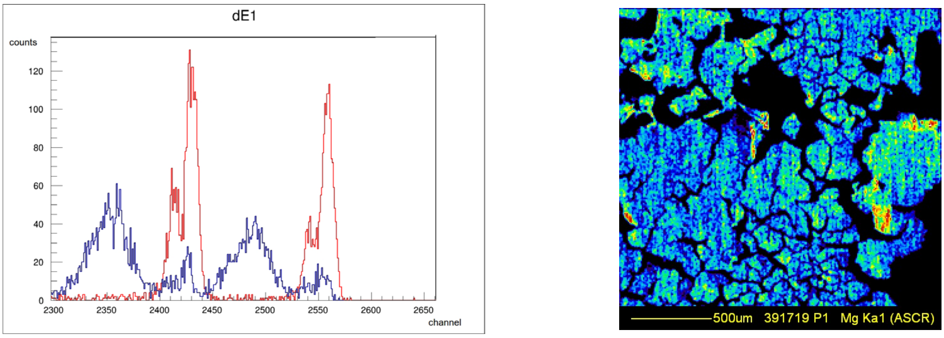
of ^{3}He^{2+} was 25 MeV with typical intensities up to 20 enA. Set of data was acquired by 4 moving telescopes, covering angles from 7 to 61 degrees in laboratory system and 2 stationary telescopes as "beam monitors" (angles of 15 and 35 degrees was chosen for ^{26}Mg(^{3}He,d) reaction). For this type of measurement, thin target foils containing pure target isotope are preferred. Targets containing ^{26}Mg on carbon backing were used for the measurement, together with mylar target and pure carbon foil, with similar properties to magnesium target backing. Thin dE detectors were calibrated with ^{244}Cm+^{238}Pu alpha particle source. A number of peaks from (^{3}He,^{4}He) reactions, together with (^{3}He,^{3}He) scattering peaks on ^{12}C and ^{16}O nuclei, were identified in the dE detector energy spectrum. They were used for precise calibration of detectors with a simultaneous fine variations of the beam energy (T_{beam}) and detector angles. Thick E-detectors were calibrated on the basis of dE calibration and the deuterons from the reaction. Reaction products from ^{26}Mg(^{3}He,d) were identified in deuteron reaction channel afterwards. A complex program [5] was used for kinematic calibration, which allows to fit energy calibration of detectors, T_{beam} and detectors angles for all telescopes simultaneously. In the result, it allows to identify every peak in the energy spectrum and extract their angular distributions.

3 Target characteristics

Identification of peaks in the above-mentioned energy spectra allows to qualitatively characterize chemical composition of target. Target thickness was measured using energy loss method for alpha particles, measured with ^{244}Cm+^{238}Pu alpha particle source. Energy loss of alpha particles in the medium of known chemical composition is proportional to its thickness. Results obtained from energy loss tables for alpha particles were confirmed with Monte Carlo simulations in TRIM. Data from the "beam-monitor" telescope were used to determine stoichiometric proportions of the magnesium target and to check the beam energy together with stability during the irradiation. Stoichiometry of magnesium target was done by evaluation of ^{16}O reactions yields in mylar target, which was irradiated as well as carbon foil target. Yields of ^{16}O(^{3}He,^{4}He)^{15}O reaction are crucial, due to assumption, that oxygen in the target belongs to MgO. Analysis of spectra obtained with carbon target allowed to evaluate thickness of carbon backing in the magnesium target. It has uncovered an oxygen admixture in carbon backing, which was considered as the "background oxygen" and subtracted from oxygen yields in the magnesium target. Based on oxygen yields obtained with the mylar target, the amount of magnesium (corresponding to MgO) was evaluated to 135,1 +/- 6,7 μg/cm^{2}, as a mean value obtained from the reactions ^{16}O(^{3}He,^{3}He)^{16}O (highest yields on a peak background) and ^{16}O(^{3}He,^{4}He)^{15}O to the ground state (no peak background). This value was used to evaluate differential cross sections (quantitatively evaluate angular distributions) of ^{26}Mg(^{3}He,d)^{27}Al.

4 Discussion

During the data analysis, a number of effects appeared with the impact on evaluated thickness of ^{26}Mg. The effect of in-beam oxygen depletion was observed in the mylar target. By analysis of yield-to-charge dependence of the first mylar exposition, a correction to the yield at zero-charge was made. The yields of reactions on ^{12}C and ^{26}Mg were charge-stable. More severe problem, was the target inhomogeneity observed in the magnesium target thickness measurement (fig. 1a). Based on this observation, RBS (Rutherford back-scattering) scanning of this target was performed at Tandetron facility of NPI CAS in Rez (CANAM infrastructure). The results of this microbeam scanning confirmed the significant inhomogeneity of magnesium layer in the target (fig. 1b). This fact makes impossible the direct target thickness measurement with alpha particle source. The above mentioned in-beam data comparison for mylar and carbon targets was used for the evaluation of the "effective"



(a)

(b)

Figure 1: Analysis of magnesium layer thickness in target: (a) target thickness measurement with ^{244}Cm+^{238}Pu alpha particle source; (b) RBS analysis of magnesium layer in the target.

thickness in the magnesium target beam spot. The assumption of the chemical form of pure MgO in the target was checked, due to hygroscopic properties of this material. The beam-monitor data did not show any trend of oxygen yields in the magnesium target with the beam charge collected. There is a need for the new, good quality target. The best solution could be pure metallic form, prepared by rolling to 100-200 μm thick foils. However, preparation of this type of target would be challenging even in top laboratories. The decision was made to prepare MgO sputtering targets on carbon backing, in cooperation with Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud in Catania. A set of perfect quality targets was manufactured, together with pure carbon backing targets. This method do not simplify the complicated spectra obtained from MgO+C target, but there are homogeneous, quality targets with samples of carbon backing for subtraction. A methodology of Mg target irradiation, together with mylar foil and carbon backing at the same angle, allows to quantitatively characterize the stoichiometry in the Mg target and to evaluate cross sections from the acquired spectra for the forthcoming measurements of ^{26}Mg(d,p)^{27}Mg reaction without doubts, as well as to perform a control run on (^{3}He,d) reaction to normalize the previous data from the discussed target.

5 Summary

Angular distributions of two nuclear reactions ^{26}Mg(^{3}He,d)^{27}Al and ^{26}Mg(d,p)^{27}Mg were measured. The target analysis showed the inhomogeneity of magnesium layer, which was confirmed by RBS micro-beam scanning. Based on reactions on ^{12}C and ^{16}O in mylar and carbon targets, the effective thickness of the magnesium layer was estimated. The new, high quality targets were manufactured in INFN LNS together with carbon backing samples, which allows to quantitatively evaluate angular distributions of the investigated reaction products as well as to confirm the results obtained with the previous target. This publication was supported by OP RDE, MEYS, Czech Republic under the project SPIRAL2-CZ, CZ.02.1.01/0.0/0.0/16-013/0001679.

References

[1] Champagne et al., Nuclear Physics A**512** (1990)

[2] Timofeyuk et al., Physical Review C **78** (2008) 054322
[3] A.M. Mukhamedzanov et al., Physical Review C **56** (1997) 1302
[4] C.A. Gagliardi et al., Physical Review C **59** (1999) 1149
[5] J.Mrazek, computer code calibNR, https://github.com/jaromrax/calibNR (-2018)