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Excitation function for the ^{27}Al(p, x)^{24}Na monitor reaction

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1. Introduction

Aluminium (Al), a silvery-white, soft, nontoxic and nonmagnetic metal, has wide applications as an important structural material for research reactor, aerospace industry (due to their high strength-to-weight ratio), other areas of transportation, building, and so on. It is also widely used as a corrosion resistant material. Al is found abundantly in the earth's crust, but not free in nature. Furthermore, it is one of the available elements in lunar surface materials, in stony meteorites as well as in the earth's atmosphere [1]. Accurate knowledge of the interaction phenomena of proton with aluminum is therefore essential for the design and operation of accelerators, for radiation protection in space and on earth, and also for the optimization of radionuclide production leading to various practical applications.

On the other hand, in activation experiment, an exact calculation of the radionuclidic yields requires precise determination of the energy and intensity of the bombarding particles. Faraday cup measurements of the beam current are sometimes not possible and/or not accurate enough. However, the use of monitor reactions could be used with a high accuracy to monitor beam parameters, especially in a charged particle activation analysis (CPAA). The formation of ^{24}Na radionuclide in the interaction of proton with Al can be advantageously utilized for monitoring proton beam parameters, especially for measurements in a relatively short time after the end of a irradiation. The International Atomic Energy Agency (IAEA) have already compiled and provided a set of recommended data for some important monitor reactions including ^{27}Al(p,x)^{24}Na. Currently, we are investigating the proton-induced production cross sections of residual radionuclides from various target elements, and frequently using the IAEA recommended monitor reactions of interest. Therefore, we ought to cross check the IAEA recommended data for some important monitor reactions through further experimental measurements, and also measure the excitation function of the ^{nat}Al(p,x)^{24}Na reaction with a high precision in the energy range from 40 MeV down to the threshold energy.

2. Experimental

The experimental setup and the methods of data analysis were similar to those described elsewhere [2]. Some important features relevant to the present work are discussed as follows. A well established stacked-foil activation technique combined with a high-resolution γ-ray spectrometry was employed to determine the excitation function for the ^{27}Al(p,x)^{24}Na reaction. A high-purity (>99.999%) aluminium foil with 100-μm thickness was used as the target for irradiation. Monitor foils of copper (>99.98 % purity, 100-μm and 50-μm thickness) with known cross-sections were also included in the stack. The stacked-foils were irradiated for 60 minutes by proton energy of 42.1 MeV with a beam current of about 100 nA from an external beam line of the MC-50 cyclotron at the KIRAMS. After the irradiations and an appropriate cooling time, the induced gamma activities emitted from the activated foils were measured by using an n-type coaxial ORTEC high-purity germanium (HPGe) detector. The spectrum analysis was done using the Gamma Vision 5.0 (EG&G Ortec) program. The photo peak efficiency curve of the gamma spectrometer was calibrated with a set of standard point sources. The proton beam intensity was determined by using the monitor reaction ^{nat}Cu(p,x)^{62}Zn [3]. The proton energy degradation along the stacked foils was calculated by using the computer program SRIM-2003 [4]. The decay data of the radioactive products were taken from the NUDAT database [5].

The uncertainty of the proton energy for each foil in the stack was estimated from the relevant processes: uncertainties for the incident beam energy, the target thickness, and the beam straggling. However, the combined uncertainty in each cross-section was estimated based on the error propagation formula using the following uncertainties: statistical uncertainty of the gamma-ray counting (0.5-10 %), uncertainty in the monitor flux (~7 %), uncertainty in the efficiency calibration of the detector (~4 %) and so on. The overall uncertainties of the cross-sections measurements were in the range of 8-17 %.

3. Theoretical calculations

The excitation function for the ^{27}Al(p, x)^{24}Na reaction at the proton energies up to 50 MeV were theoretically calculated by using the model calculations by the code TALYS [6] with mostly the default values of various models, but the very important inputs like the discrete energy levels, level densities of the nuclides involved in the calculations have been taken care of in a proper way during the calculations.

4. Results and Discussion

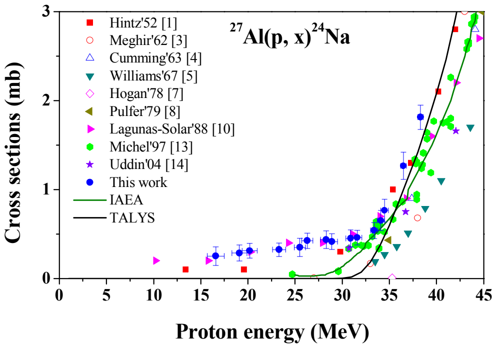

Fig. 1. Excitation function for the ^{27}Al(p, x)^{24}Na reaction

^{24}Na has a long-lived ground state radionuclide ^{24g}Na ($T_{1/2}$=14.96 h) and a very short-lived isomeric state ^{24m}Na ($T_{1/2}$=0.02 s), whereas the isomeric state radionuclide completely decays to the ground state by an IT (99.95 %) process. The measured cross-sections of the ^{24g}Na radionuclide are a cumulative one, because the counting process was started after a sufficient cooling time for the complete IT decay of ^{24m}Na to ^{24g}Na. The measured excitation function of ^{24g}Na is shown in Fig. 1 together with the available literature values and the data from the model calculations. The formation of the ^{24g}Na radionuclide is also contributed by the emission of various particles through the direct reaction channels. The contribution of the ^{27}Al(p, 3p+n) (Q=-31.43 MeV) reaction formed a sharp increase above its threshold energy at around 31 MeV, whereas the cross sections below 31 MeV were contributed by the other competing reaction channels ^{27}Al(p, p+^{3}He) (Q=-23.71 MeV), and ^{27}Al(p, 2p+d) (Q=-29.20 MeV). The present results are in good agreement with the data reported by Hintz et al. [7], Michel et al. [8], and Lagunas-Solar et al. [9], but a considerable discrepancy is obtained with other measurements [10-15]. The data calculated by the model code TALYS revealed a good agreement for both the shape and magnitude with the measured data. The present results were compared with the IAEA recommended data [3] and an overall good agreement was found.

4. Conclusions

Excitation function for the ^{27}Al(p,x)^{24}Na nuclear reaction was measured in the energy region 40 MeV down to the threshold energy with an overall uncertainty of about 17%. The present data give a fairly good description of the excitation function with the available literature data for ^{24}Na production cross-sections from proton-induced reactions on Al. The formation of ^{24}Na in the interaction of proton with Al can be advantageously utilized for monitoring the proton beam parameters for the measurements in a relatively short time after the end of irradiation. The IAEA recommended values for ^{27}Al(p,x)^{24}Na nuclear process was verified by the present investigations.

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