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Determination of integral cross sections of ^{3}H in Al foils monitors irradiated by protons with energies ranging from 40 to 2600 MeV

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Abstract

The results of ^3H production in Al foil monitors ($\sim 59\ mg/cm^2$ thickness) are presented. These foils have been irradiated in 15×15 mm polyethylene bags of $\sim 14\ mg/cm^2$ thickness together with foils of Cr ($\sim 395\ mg/cm^2$ thickness) and ^{56}Fe ($\sim 332\ mg/cm^2$ thickness) by protons of different energies in a range of $0.04 - 2.6$ GeV. The diameters of all the foils were 10.5 mm. The irradiations were carried out at the ITEP accelerator U−10 under the ISTC Project # 3266 in 2006−2009. ^3H has been extracted from Al foils using an A307 Sample Oxidizer. An ultra low level liquid scintillation spectrometer Quantulus1220 was used to measure the ^3H $\beta-$spectra and the SpectraDec software package was applied for spectra processing, deconvolution and ^3H activity determination. The values of the $Al(p,x)^3H$ reaction cross sections obtained in these experiments are compared with data measured at other labs and with results of simulations by the MCNP6 radiation transport code using the CEM03.03 event generator.

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1 Introduction

Tritium is a gaseous product of nuclear reactions, whose formation, in addition to the issues of radiation production in specific parts of nuclear installations, causes additional environmental problems, associated with its high migration ability. This stimulates an interest in the study of the production cross-sections of this nuclide in different structural materials of nuclear installations. A compilation of the experimental values of the cross-sections of the reaction $Al(\mathrm{p,x})^3H$, taken from data libraries [1,2] and together with values obtained in this work in comparison with the simulated data both in [3] and in this work are presented in Fig. 1.

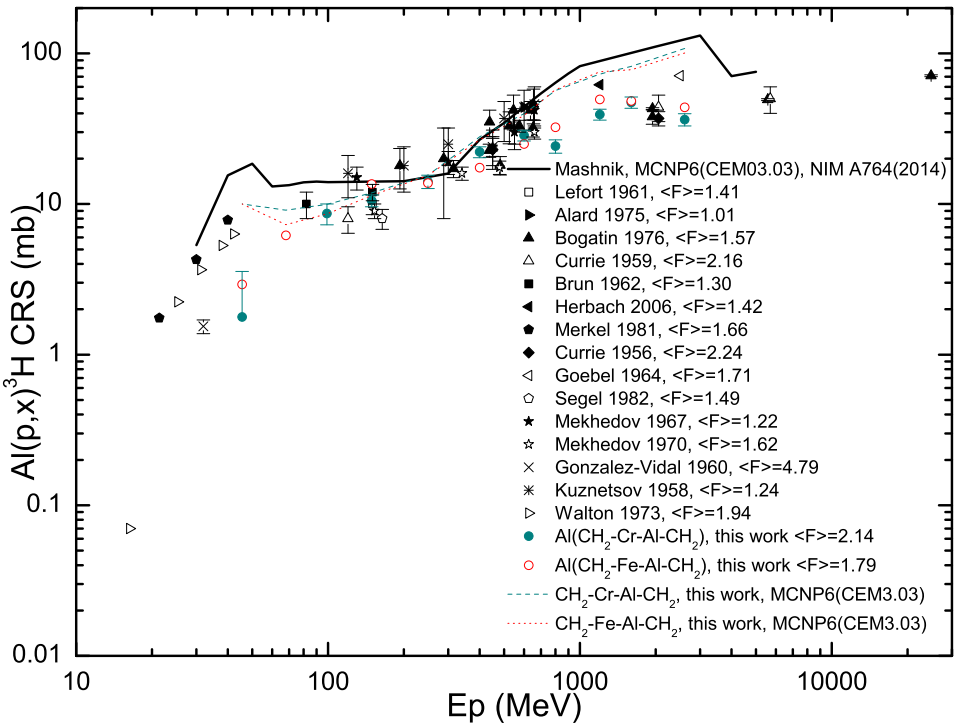

Figure 1: $Al(\mathrm{p,x})^3H$ reaction cross-sections measured in [1,2], simulated [3] as well as obtained in this work.

A comparison of the simulated excitation functions of the $Al(\mathrm{p,x})^3H$ reaction with various experimental data sets reveals that the mean squared deviation factor $< F >$, often used to assess the predictive power of codes [4], is within the range from ~ 1 to ~ 5. In addition to the above, the spread of the experimental data is much wider than the experimental uncertainties.

2 Justification of the experiments, simulation and results

During 2006 - 2009, under the framework of the ISTC Project # 3266, the ITEP synchrotron was used to determine cross sections of residual nuclei production in Cr, ^{56}Fe, and other thin samples induced by 0.04 – 2.6 GeV protons. All the samples were placed inside polyethylene bags together with Al foils to monitor proton flux. Both the samples and foils were thin enough ($\ll 1 g/cm^2$) to get a negligible degradation of proton energy within each "sample-foil" sandwich. That is why the losses of residual nuclei heavier ^{7}Be could be neglected. The main project results obtained by γ–spectrometry of the irradiated samples can be found in [4, 5].

Subsequently, the idea arose to measure tritium inside the irradiated samples and foils. The event generator CEM03.03 inside the MCNP6.1.1 transport code was used to simulate the spectra of tritium nuclei produced by the protons and showed that a significant part of produced tritium has a range above the foils thickness (see Fig. 2).

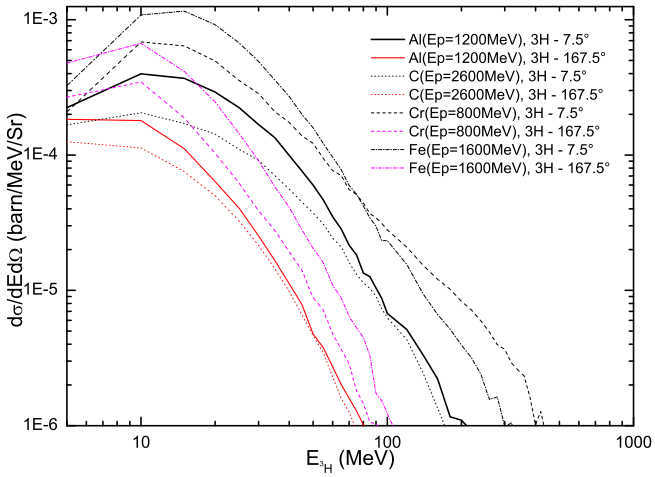

Figure 2: Energy spectra at different angles of ^{3}H nuclei released from the Al, C, Cr and ^{56}Fe nuclei irradiated by 1200, 2600, 800 and 1600 MeV protons, accordingly.

This fact leads to some redistribution of tritium produced in the polyethylene, samples, and monitor layers through the exchange of tritium nuclei. Therefore, the cross section results obtained in this work are not quite identical to the cross section for tritium production in Al presented in [1, 2]; we identify our results as "integral" cross sections. Nevertheless, as shown in this work, the obtained results can certainly be used to verify the nuclear models of radiation transport codes.

^3H activity in Al foil was determined using a low-background spectrometric α-, β-radiometer, Quantilus 1220, and a system of automatic sample preparation, A307 Sample Oxidizer. An analysis of the measured β-spectra was carried out with the SpectraDec code [6]. The formula for determining the reaction rate and cross-section production of ^3H are presented in [5].

All results were simulated using the CEM03.03 event-generator incorporated in the radiation transport code MCNP6.1.1 [7]. The real parameters (thickness, diameter, density) of irradiated samples (Al, Cr, ^{56}Fe) were modelled, including the thickness of polyethylene bags in the appropriate layers-cells.

3 Conclusion

Simulated values of independent cross-sections of ^3H production in Al [5], together with the calculations of the integral cross-sections and measured values, are shown in Fig. 1. The values of $< F >$ for Al from pair $Cr \leftrightarrow Al$ are equal to 2.14 and 1.79 from pair $^{56}Fe \leftrightarrow Al$ (see details in [5]).

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