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Neutron-induced light charged particle production in carbon at 96 MeV

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Abstract

Differential cross sections of charged particle production, i.e., p, d, t, ^{3}He-ions and α-particles, in 96 MeV neutron–carbon interactions have been measured at laboratory angles in the range 20° to 160° in steps of 20°. The experimental techniques are described as well as the procedures for acquisition, analysis, reduction and correction of the data.

Results including double differential, energy-differential, angle-differential and total particle production cross sections are reported and constitute the first data set with five ejectiles at such a high neutron energy. Thanks to the low-energy thresholds, 50% of the production cross section of α-particles, and 85% of the production cross sections of protons and deuterons, could be measured. For α-particles, the measured fraction is much higher than what has been achieved earlier at lower energies.

The results on the hydrogen isotopes agree fairly well with a previous measurement at 95 MeV and with recent GNASH calculations. For the helium isotopes, however, there are important discrepancies in spectral shape and magnitude between the new results and the model calculations.

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1. Introduction

In the last few decades, major efforts in nuclear physics have concentrated on nuclear fusion and fission, which have led to an abundance of data on neutron-induced reactions for energies below 20 MeV. Above this energy, the data libraries are, however, quite meagre.

Data in the mid-energy range, i.e., up to 150 MeV, are needed for the understanding of fundamental nuclear processes. They are needed to gain more insight in the effective nucleon–nucleus interaction [1], and provide useful means to investigate the nuclear structure [2] and characterize the global features of the reaction dynamics.

The energy region around 100 MeV is complicated from a theoretical viewpoint, since the number of open reaction channels is large. For example, with 96 MeV neutrons incident on ^{12}C, there are more than 100 open reaction channels that can give rise to a proton. Any theory has to consider different reaction mechanisms such as direct, compound and pre-equilibrium, and when appropriate, a competition between them. Even with a theory, where all these mechanisms have been included, at hand, the theory still has to be validated and benchmarked [3] by experimental data.

The International Nuclear Data Committee (INDC), of the International Atomic Energy Agency (IAEA), has, in its recent summary report [4], highlighted the need for improving the databases and recommended that future scientific activities should focus on fast-neutron cross section measurements. Attempts should be made to remove deficiencies in the data on fast-neutron interactions with, e.g., biologically relevant nuclei, such as carbon, oxygen and nitrogen. Carbon, which is studied in this work, can be considered as a prototype nucleus for testing theory and available computer codes.

Of particular interest is the reaction $(n, n'3\alpha)$, as it is believed to play an important role in α-particle production [5], and very little direct experimental information concerning this reaction channel exists in the literature [6,7]. Measurements of inclusive spectra of α-particle production with low energy thresholds are useful for the understanding of the nuclear reaction mechanism and in particular of the role of the $(n, n'3\alpha)$ process.

Furthermore, nuclear carbon data are requested for, e.g., dosimetry and radiation therapy [8], where an appropriate assessment of the effects of the radiation on tissues, characterised by the absorbed dose, requires not only accurate information on the particle yield, but also on their distributions in energy and angle [9–11]. This information is best accessible through double-differential cross section measurements. Carbon data are useful also for determining the response of neutron detectors based on organic scintillators [12].

Although one of the first light charged particle production measurements [7] at energies above 20 MeV was carried out as early as 1953, only recently has the interest in neutron-induced cross section measurements at higher energy increased. To date, a limited number of experiments for neutron reactions with light nuclei, e.g., ^{12}C and ^{16}O, have been performed at energies between 20 and 100 MeV. The UC Davis group has reported double-differential cross sections for production of p, d, t, ^{3}He-ions and α-particles from carbon at neutron energies of 27.4, 39.7 and 60.7 MeV [13]. Proton and deuteron production from carbon at slightly higher energies, i.e., 65 and 75 MeV, was measured using the neutron source TIARA at Takasaki in Japan [14]. Data for