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Letter to the Editor

CROSS SECTIONS FOR THE PRODUCTION OF ^{11}C IN C TARGETS BY 3.65 A GeV PROJECTILES

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The absolute cross sections for the production of ^{11}C in C targets by 3.65 A GeV protons, deuterons, ^{4}He- and ^{12}C-ions were measured. Annihilation radiation from ^{11}C was counted using a large-volume NaI(Tl), and a BaF_2 detector. The flux measurement technique, based on registration of charged particles by means of a thin nuclear emulsion layer rotating in a beam, as well as a fission chamber, was used. The results are compared with earlier measurements of the cross sections in carbon targets using high-energy projectiles, and with Glauber theoretical predictions as well.

In a previous paper [1] we described a monitoring system for relativistic particles and nuclei accelerated at the Dubna synchrophasotron. Using this system, the cross sections of monitoring reactions of the type ^{27}Al(projectile, X)^{24}Na at 3.65 A GeV have been measured [2]. In the present paper we report on cross-section measurements for the production of ^{11}C in C targets by 3.65 A GeV protons, deuterons, ^{4}He- and ^{12}C-ions. A set of precise cross-section values for the ^{12}C(projectile, X)^{11}C reactions is needed for absolute flux determinations by means of the well-known activation technique. The above reactions are convenient for this purpose because the final nuclide ^{11}C is quite insensitive to production by secondary particles, produced in nuclear reactions induced by high-energy particles and nuclei. Moreover, these cross sections could also provide useful information for various theoretical descriptions of high-energy collisions.

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Table 1
Cross sections for the ^{12}C(projectile, X)^{11}C reactions at 3.65 A GeV

Projectile	Cross section [mb]
Protons	27.3 ± 0.5
Deuterons	35.2 ± 0.7
^{4}He-ions	42.0 ± 0.7
^{12}C-ions	58.5 ± 1.1

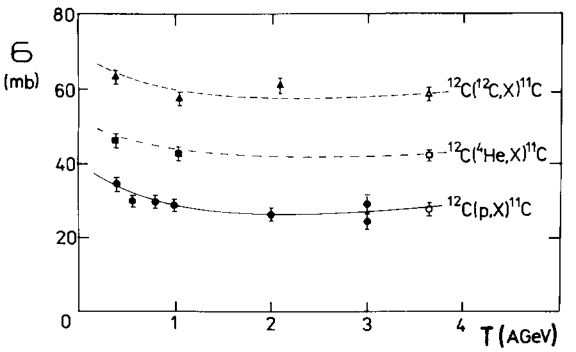

Fig. 1. Excitation functions for ^{11}C production by high-energy protons, ^{4}He- and ^{12}C-ions on C targets. Our data are indicated by open symbols; the appropriate lines are guides to the eye.

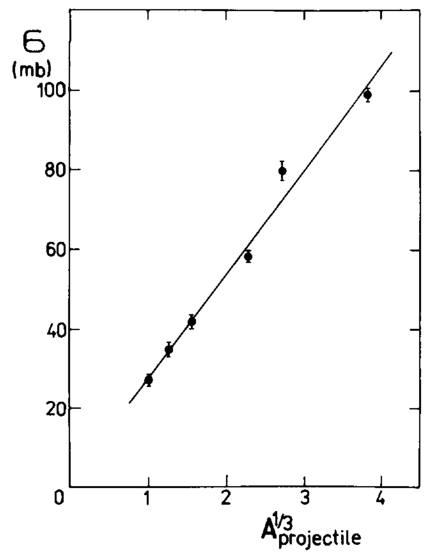

Fig. 2. Dependence of cross sections for ^{11}C production on projectile mass. Also shown for comparison are cross sections for production of ^{11}C from ^{20}Ne and ^{56}Fe projectiles at 1.05 and 1.7 A GeV, respectively. The solid line approximates the least-squares fit of $\sigma = 1.8 + 25.7A^{1/3}$.

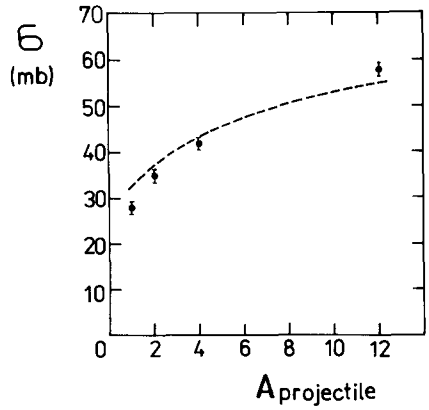

Fig. 3. Comparison of cross sections for ^{11}C production by 3.65 A GeV projectiles with Glauber theoretical calculations (dashed line).

The cross-section measurements were carried out in an external beam of the Dubna synchrophasotron in three stages. First, low-intensity runs were made in which beam particles and nuclei were counted with a thin nuclear emulsion layer rotating in a beam, and ^{11}C activity was produced in a 2.54 cm thick graphite block. Second, the ^{11}C activity induced in a 0.16 cm thin polystyrene target was measured relative to the standard fission-chamber beam monitor [1,3] in high-intensity runs. Finally, the ^{11}C activity in a thick target was also determined at high beam intensities relative to the fission chamber calibrated with nuclear-emulsion counts. The appropriate cross sections were determined from these three runs. The experimental procedure of the beam flux measurement by means of the nuclear emulsion and the fission chamber KNT-8 used in this experiment was identical to that used previously in measuring ^{27}Al(projectile, X)^{24}Na cross sections. The ^{11}C activity produced in the polystyrene and thick graphite block was determined by counting annihilation radiation, using a large-diameter 15 cm × 15 cm NaI(Tl) and a $3.2 \times 3.2 \times 15.0$ cm^3 BaF_2 [4] detector, from several counts covering a total time span of at least one ^{11}C half-life. In order to stop positrons, polystyrene targets were counted sandwiched between two thin copper discs.

The cross sections for the production of ^{11}C in C targets by 3.65 A GeV projectiles are listed in table 1. The errors quoted to the tabulated values are only of statistical nature. They are almost entirely from counting statistics of the ^{11}C activity measurements in thick graphite blocks and beam particles counting, as well. The results are compared in fig. 1 with similar data for the $^{12}C(p, X)^{11}C$ [5], $^{12}C(^{4}He, X)^{11}C$ [6] and $^{12}C(^{12}C, X)^{11}C$ [7] reactions, respectively. As can be seen, cross sections of the appropriate reactions show a limiting behavior at energies under study. This fact corresponds to the hypothesis of limiting fragmentation [8]. Following the concept of factorization (scaling) [9], the cross sections for the ^{12}C(projectile, X)^{11}C reactions for various projectiles should be proportional to $A^{1/3}$. This dependence is illustrated in fig. 2. Here, cross sections [10] for the $^{12}C(^{20}Ne, X)^{11}C$ and $^{12}C(^{56}Fe, X)^{11}C$ reactions at 1.05 and 1.7 A GeV, respectively, are also included because of the validity of limiting fragmentation at these energies. Finally, in fig. 3 we compare our data with simple Glauber theoretical calculations [7]. Good agreement between cross sections for the production of ^{11}C in C targets by 3.65 A GeV projectiles and Glauber theory is evident.

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