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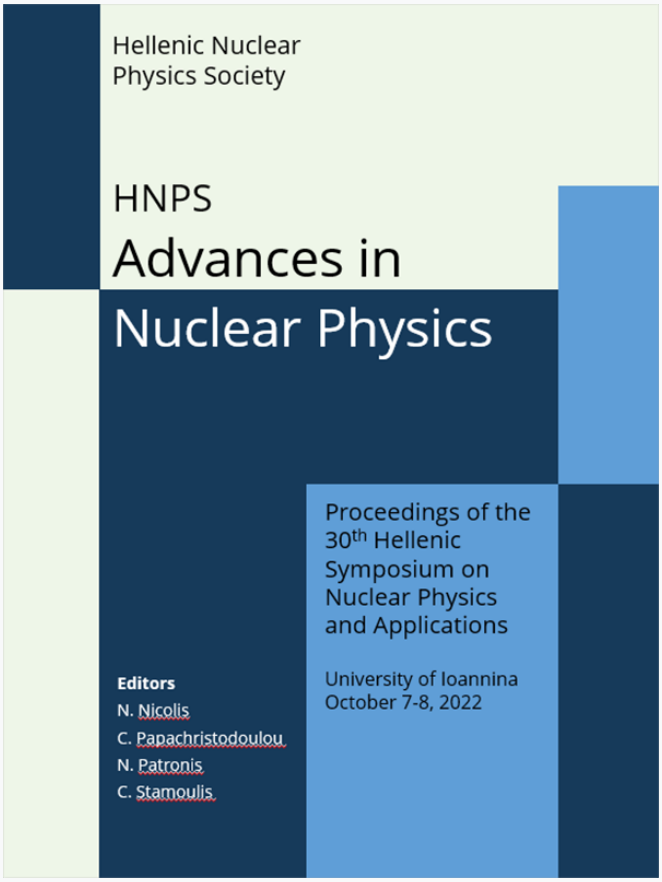

A study of proton-induced reactions on natural Silicon targets

Nikolaos George Nicolis, Georgia Zafeiri

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A study of proton-induced reactions on natural Silicon targets

G. Zafiri and N.G. Nicolis

Department of Physics, The University of Ioannina, Ioannina 45110, Greece

Abstract Experimental excitation functions of isotopes produced in reactions p + ^{nat}Si are compared with the results of nuclear reaction program TALYS 1.95 and semi-empirical cross section formulas. We consider excitation functions of 7 isotopes (^{28}Mg, ^{26}Al, ^{24,22}Na, ^{18}F and ^{10,7}Be) produced in $^{nat}Si(p,x)$ reactions at bombarding energies of 20-144 MeV. They are compared with the predictions of the code TALYS 1.95, the semi-empirical formulas of Silberberg-Tsao (code yieldx) and SPACS. Comparisons of the results of the code TALYS 1.95 and previously published results of code ALICE are made. The predictive power of code TALYS 1.95 may be questioned for reaction products with mass number very much smaller than the target and of semi-empirical formulas at lower energies.

Keywords Proton-induced reactions, excitation functions, soft errors

INTRODUCTION

Silicon is a major component of many semiconductor devices. Such devices located in satellites and spacecrafts are exposed to a solar cosmic proton flux. The cosmic protons cause nuclear reactions in silicon after penetrating the semiconductor devices, resulting in possible damage. Calculations with nuclear reaction codes and semi-empirical formulas are useful in technology applications dealing with soft errors arising in proton bombardment produced by cosmic rays or accelerators in silicon-containing devices.

In the present work, we study the bombardment energy dependence of isotope production in proton-induced reactions on a natural silicon target. Experimental data consist of 7 excitation functions of isotopes produced in the p + ^{nat}Si reaction [1, 2]. Comparisons are made with the predictions of the nuclear reaction program TALYS 1.95 [2], semi-empirical formulas of Silberberg-Tsao (code yieldx) [3], SPACS [4] and previously published results of code ALICE [5]. We examine the validity and compare the predictions of these formulas in the energy region of 20-144 MeV.

NUCLEAR REACTION PROGRAM AND SEMI-EMPIRICAL FORMULAS USED IN THE PRESENT WORK

In the present work, we employ the nuclear reaction program TALYS 1.95 and the semi-empirical formulas of Silberberg-Tsao (code yieldx) and SPACS, in order to determine the cross-section of ^{28}Mg, ^{26}Al, ^{22,24}Na, ^{18}F and ^{7,10}Be. TALYS is a nuclear reaction program, in which a suite of nuclear reaction models has been implemented into a single code system [3]. Version 1.95 incorporates the modifications suggested by Demetriou et al. [4] in a recent study of the p+^{nat}Si reaction in the energy range from 25 to 65 MeV. In our work, we use an additional set of cross section data for the production of ^{18}F [2] and consider a wider bombarding energy range from threshold up to 144 MeV.

The formula of Silberberg and Tsao [5] takes into consideration pairing effects, density of states in the product nucleus and enhancement factors for the light evaporation products. The SPACS formula [6] takes into consideration the dependence on the collision energy as well as shell-structure and even-odd effects.

DATA COMPARISONS

Closed symbols in Figures 1 and 2 show the experimental excitation functions of the isotopes ^{28}Mg, ^{26}Al, ^{22,24}Na, ^{18}F and ^{7,10}Be. The red, purple, green and blue line in Figures 1-2 show the results of the program TALYS using the Gilbert and Cameron Composite Level Density formula (CLD), the Back-Shifted Fermi Gas model (BFG), the Generalized Superfluid Model (GSM) and the Microscopic Level Densities (MLD) model, respectively.

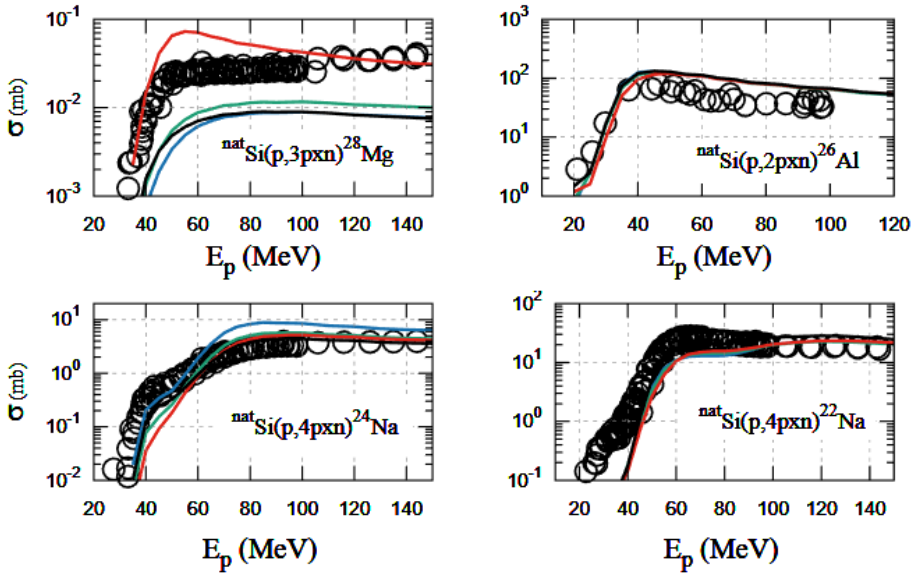

Figure 1. *Experimental excitations functions of ^{nat}Si(p,x)^{28}Mg, ^{nat}Si(p,x)^{26}Al, ^{nat}Si(p,x)^{22,24}Na compared with TALYS calculations using four level density models: CLD (blue), BFG (green), GSM (red) and MLD (black)*

The CLD, BFG and MLD predictions are similar for all isotopes. These calculations underestimate the production of ^{28}Mg, ^{18}F and ^{7,10}Be. The GSM improves the description of ^{28}Mg and agrees with the predictions of the other level density models for the rest of the isotopes. We conclude that the best description is obtained with the GSM.

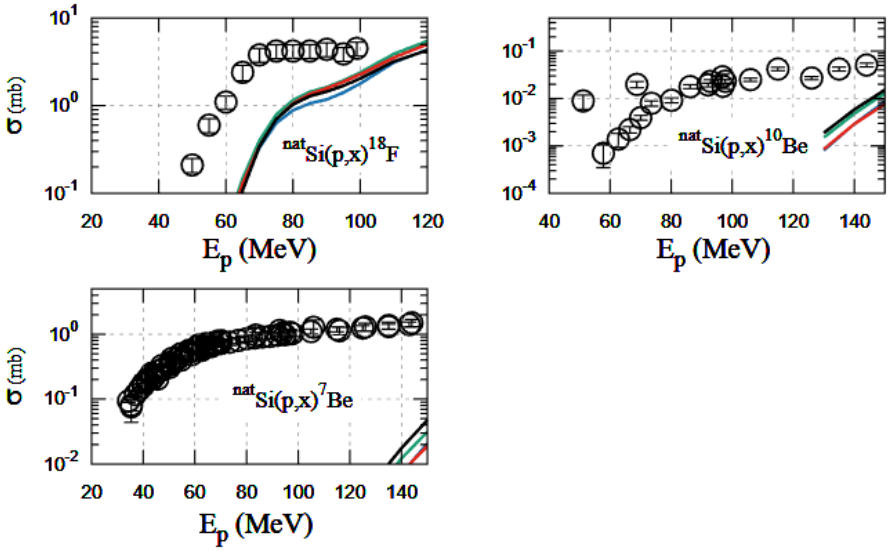

Figure 2. *Experimental excitations functions of ^{nat}Si(p,x)^{18}F, ^{nat}Si(p,x) ^{7,10}Be compared with TALYS calculations using four level density models: CLD (blue), BFG (green), GSM (red) and MLD (black)*

The dashed purple line and solid red line in Figures 3-4 shows the results of the SPACS and Silberberg-Tsao formulas, respectively. At low proton energies (Ep<60MeV) close to the threshold both formulas overpredict the excitation functions of all isotopes. At higher proton energies, the description of the experimental excitation functions improves by both formulas. At these energies, the Silverberg-Tsao formula provides a better description of the ^{7,10}Be production than SPACS.

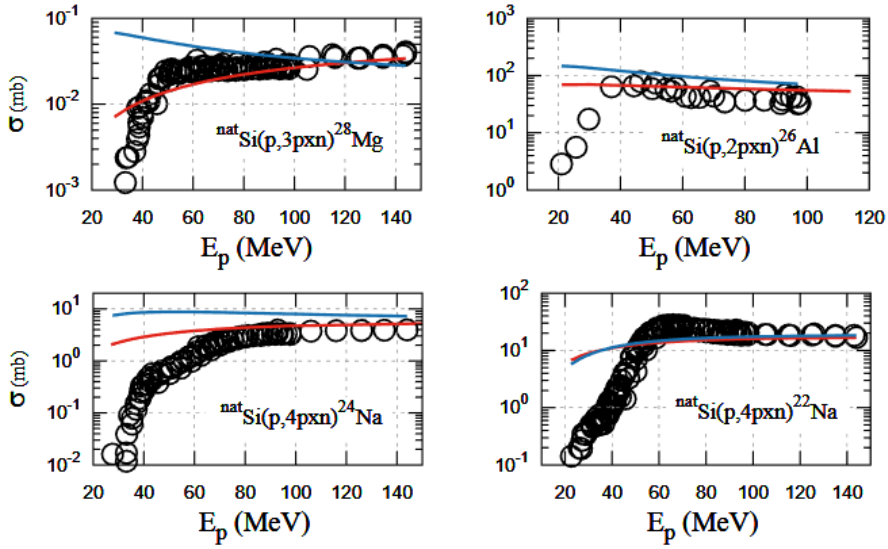

Figure 3. *Experimental excitations functions of ^{nat}Si(p,x)^{28}Mg, ^{nat}Si(p,x)^{26}Al, ^{nat}Si(p,x)^{22,24}Na compared with the formulas of Silberberg-Tsao (red curve) and SPACS (blue curve)*

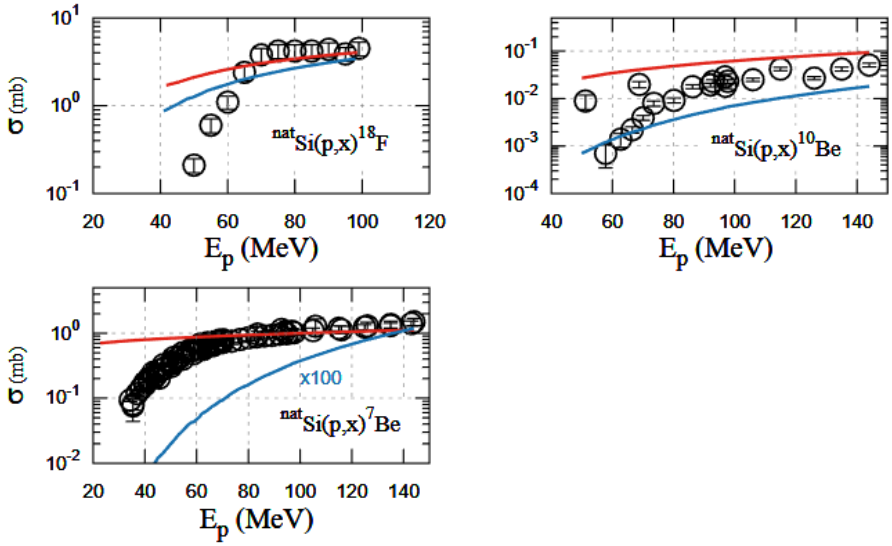

Figure 4. *Experimental excitations functions of ^{nat}Si(p,x)^{18}F, ^{nat}Si(p,x)^{7,10}Be compared with the formulas of Silberberg-Tsao (red curve) and SPACS (blue curve)*

RESULTS AND DISCUSSION

The TALYS program provides the best description for the most excitation functions using the Generalized Superfluid model for the level densities. However, it underestimates the production of ^{7,10}Be and ^{18}F. The underestimation of ^{7,10}Be excitation functions could be related to the fact that TALYS does not include evaporation of these clusters. Had such decay modes been included, they could enhance the production of ^{19}F as well. In Ref. [2] a good description of excitation functions in

p+^{nat}Si reactions was obtained with the hybrid model nuclear reaction code ALICE. Compared to the best set of parameters given in Ref. [2], our calculation with TALYS with GSM level densities provides a better description of the shapes of the excitation functions.

The SPACS and Silberberg-Tsao formulas describe well the excitation functions of heavy residues at bombarding energies higher than 60 MeV. The Silberberg-Tsao formula describes ^{7,10}Be production better than SPACS. At lower energies (<60 MeV), both formulas overpredict the experimental cross sections of all isotopes.

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