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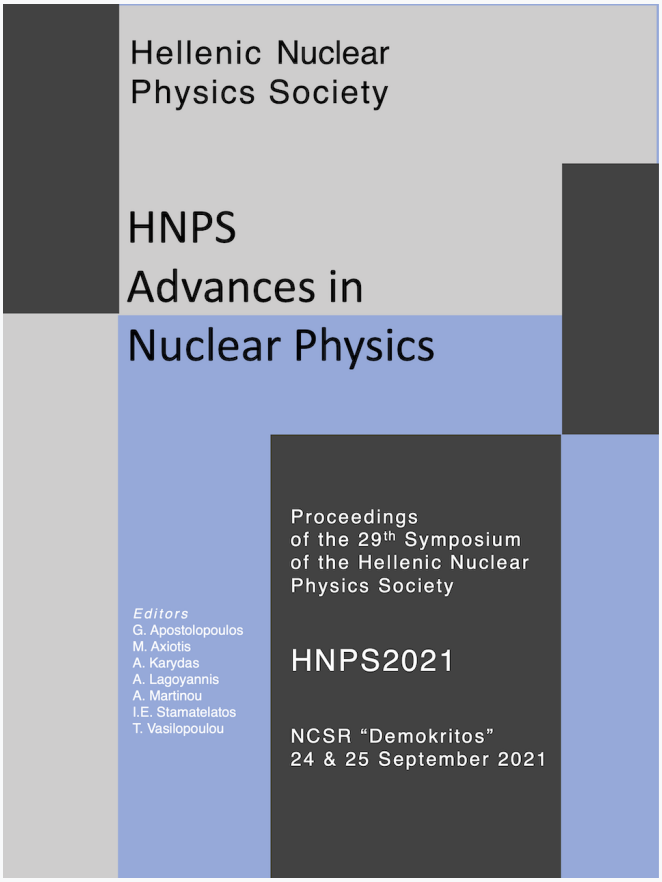

Empirical Description of Isotope Production in 0.01-2.5GeV p+natFe Reactions

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Empirical Description of Isotope Production in 0.01-2.5 GeV p+^{nat}Fe Reactions

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Abstract Experimental excitation functions of isotopes produced in $^{nat}Fe(p,x)$ reactions are compared with the results of empirical cross section formulas. We consider excitation functions of 16 isotopes (^{36}Cl, ^{38}Ar, ^{42,43}K, ^{44}Ti, ^{46,47,48}Sc, ^{48,51}Cr, ^{52}Fe, ^{52,54}Mn and ^{55,56,57}Co) produced in $^{nat}Fe(p,x)$ reactions at bombarding energies from threshold up to 2.6 GeV. They are compared with the predictions of the empirical formulas of Rudstam, Silberberg-Tsao and SPACS. In the middle-energy range, the formulas provide (in the stated order) a progressively improved description of the experimental excitation functions of the dominant isotopes. At the highest energies, the limiting values of the dominant excitation functions are well described by the EPAX formula (Version 2.1). The predictive power of these formulas could be questioned at low energies close to the threshold, reaction products with a mass much smaller than the target and possibly low cross section channels.

Keywords Spallation reactions, Empirical formulas, Isotope production

INTRODUCTION

Spallation reactions are defined as interactions between relativistic projectiles, mostly hadrons, and a target nucleus which is smashed into many fragments. Spallation reactions have numerous applications in accelerator-driven systems (ADS), transmutation of nuclear waste, spallation neutron sources and the production of exotic isotopes.

A spallation reaction may be considered to occur in two stages. In the first stage, the projectile interacts with the target nucleus and triggers a cascade of nucleon-nucleon collisions, known as the Intra-Nuclear Cascade. The second stage is the de-excitation process which occurs when the target remnant (prefragment) reaches thermal equilibrium. It is best described by the compound nucleus decay model. The production of isotopes in spallation reactions are described with empirical, two-step and microscopic models.

In the present work, we study the bombarding energy dependence of isotope production in proton-induced spallation reactions on a natural iron target. Experimental data consist of 16 excitation functions of isotopes produced in the p + ^{nat}Fe reaction at 10-2600 MeV [1]. Comparisons are made with the predictions of the empirical formulas. We examine the validity and compare the predictions of these formulas in a wide energy range.

EMPIRICAL FORMULAS USED IN THIS PRESENT WORK

Most empirical formulas rely on a factorization of the cross section for isotope production by a mass yield and a charge dispersion term. The functional form of these terms is suggested by the reaction models. Adjustable parameters are obtained from fits to experimental data. In the present work, we employ the formulas developed by Rudstam [2], Silbeberg and Tsao [3], SPACS [4] and the complete fragmentation limit described with the EPAX formula (Version 2.1) [6]. Among Rudstam's

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formulas, the version CDMD, was found to provide a better agreement with the experimental data than CDMD-G. The formula of Silberberg and Tsao improves the formula of Rudstam taking into consideration pairing effects, density of states in the product nucleus and enhancement factors for the light evaporation products. The SPACS formula was inspired by the EPAX formula. It takes into consideration the dependence on the collision energy as well as for shell-structure and even-odd effects. The EPAX formula corresponds to the complete fragmentation limit of the spallation reaction.

COMPARISON WITH p+^{nat}Fe EXCITATION FUNCTION DATA

We limit our discussion to the production of isotopes close to the target. Closed symbols in Figures 1-4 show the experimental excitation functions of the isotopes ^{36}Cl, ^{38}Ar, ^{42,43}K, ^{44}Ti, ^{46,47,48}Sc, ^{48,51}Cr, ^{52}Fe, ^{52,54}Mn and ^{55,56,57}Co. The black dashed line shows the EPAX fragmentation limit. The red, blue and yellow line shows the results of the SPACS, Rudstam and Silberberg-Tsao formulas, respectively.

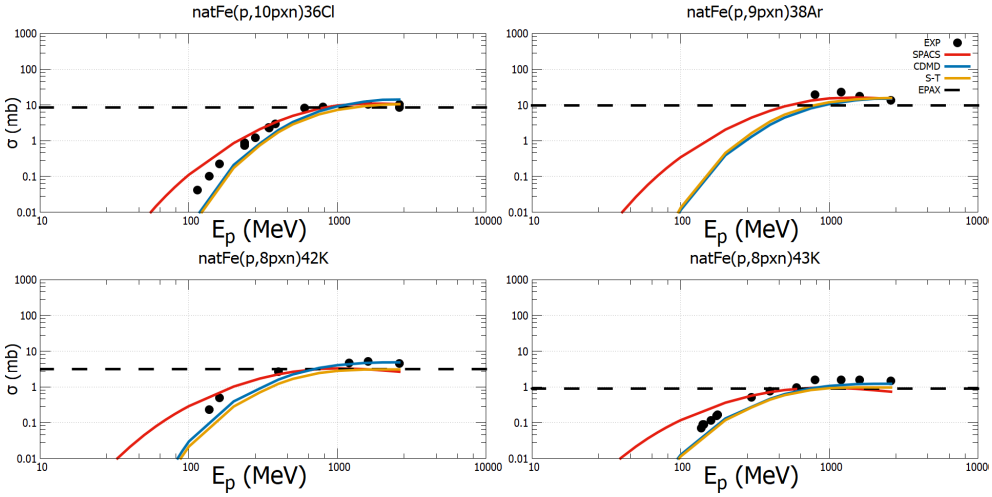

Fig. 1. *Experimental excitations functions of ^{nat}Fe(p,x)^{36}Cl, ^{nat}Fe(p,x)^{38}Ar, ^{nat}Fe(p,x)^{42,43}K compared with Rudstam, Silberberg-Tsao, SPACS and EPAX calculations.*

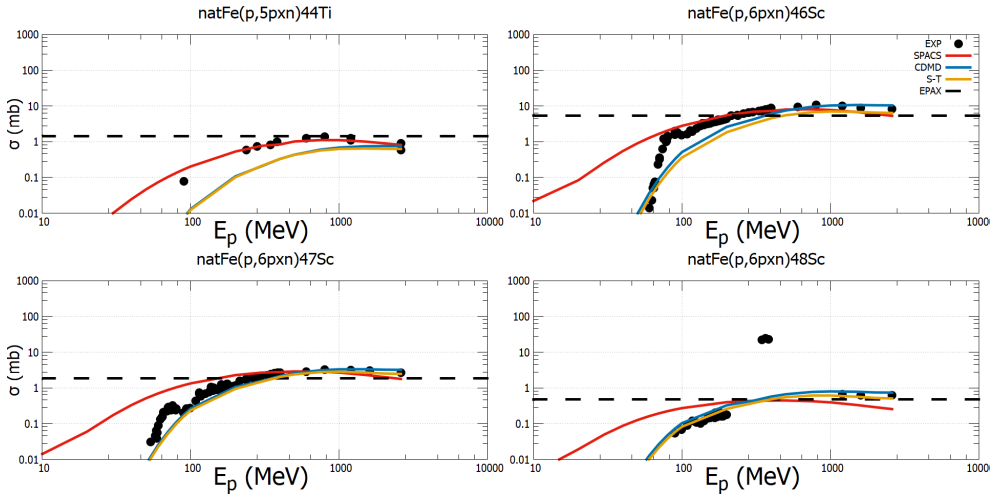

Fig. 2. *Experimental excitations functions of ^{nat}Fe(p,x)^{44}Ti, ^{nat}Fe(p,x)^{46,47,48}Sc compared with Rudstam, Silbeberg-Tsao, SPACS and EPAX calculations.*

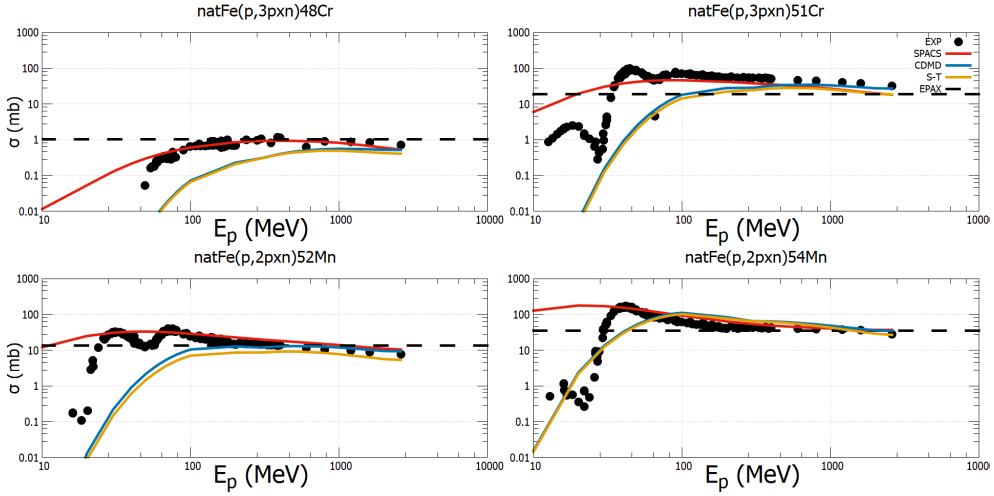

Fig. 3. *Experimental excitations functions of $^{nat}Fe(p,x)^{48,51}Cr$, $^{nat}Fe(p,x)^{52,54}Mn$ compared with Rudstam, Silberberg-Tsao, SPACS and EPAX calculations.*

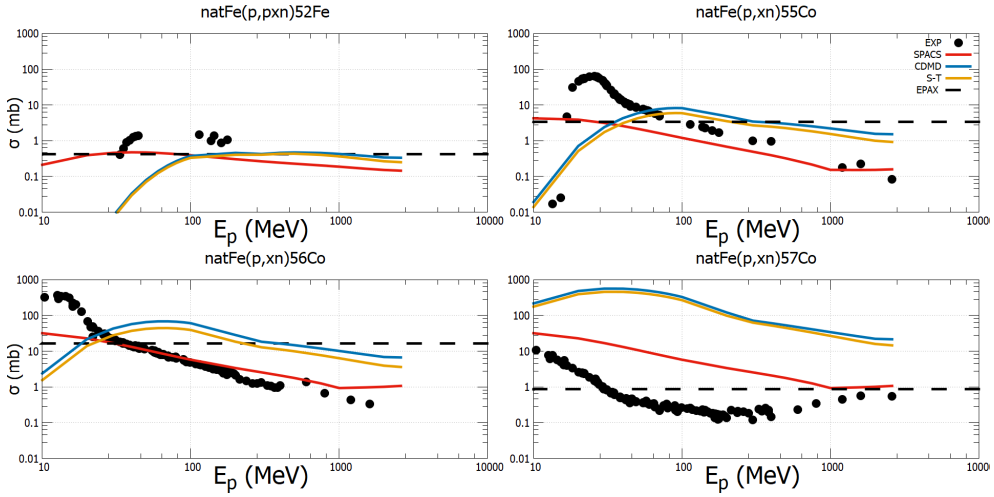

Fig. 4. *Experimental excitations functions of $^{nat}Fe(p,x)^{52}Fe$, $^{nat}Fe(p,x)^{55,56,57}Co$ compared with Rudstam, Silberberg-Tsao, SPACS and EPAX calculations.*

CONCLUSIONS

The SPACS formula provides the best description for most excitation functions of $p + {}^{nat}Fe$ and bombarding energies above the threshold. This finding is consistent with a detailed comparison of these formulas with high-resolution measurements of isotopic yields for the reaction ^{56}Fe+p [6]. However, in the present study we realize that SPACS does not offer an improvement in the prediction of the thresholds compared with the older formulas of Rudstam and Silberberg-Tsao. Furthermore, deviations from experiment occur in channels such as ^{55,57}Co, where a final product is produced as a sum of contributions from various isotopes of the target natural composition. The excitation functions of products of $p + {}^{nat}Fe$ reactions at the highest energies are well described by the EPAX formula.

References

[1] R. Michel and N. Otuka, Database for Proton Induced Residual Production Cross Sections up to 2.6 GeV, (http://www-nds.iaea.org/publications/).
[2] G. Rudstam, Z. Naturforschg. 21a 1027 (1966)
[3] R. Silberberg and C.H. Tsao, Astrophys J. Suppl. 25 315 (1973); Astrophys J. Suppl. 25 335 (1973)

[4] C. Schmitt, K.-H. Schmidt, A. Kelic-Heil, Phys. Rev. C 90 (2014) 064605; Phys. Rev. C 94 (2016) 039901
[5] K. Suemmerer and B. Blank, Phys. Rev. C 61 034607 (2000)
[6] N.G. Nicolis, T.I. Katsigianni, K. Korakas, A. Miliadou, and D. Tasioudis, (Contribution to this volume)