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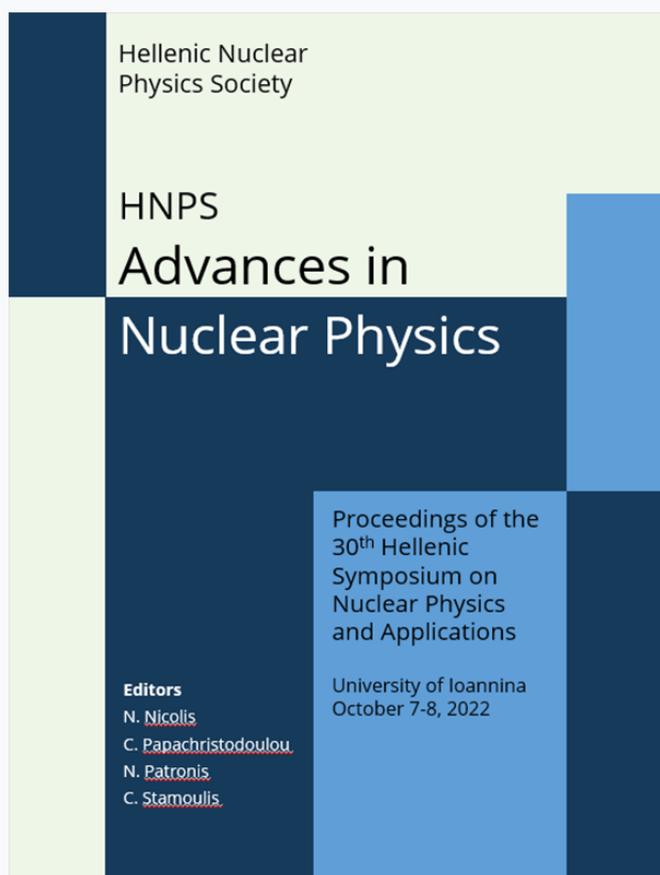
A study of the reaction 55Mn(p,4n)52Fe: excitation function and medical applications

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A study of the reaction ^{55}Mn(p,4n)^{52}Fe: excitation function and medical applications

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Abstract   The present study concerns the medical applications and production of ^{52}Fe via the reaction ^{55}Mn(p,4n)^{52}Fe together with the reference reaction ^{27}Al(p,x)^{22}Na employed in cross section measurements. Experimental excitation functions from threshold up to 200 MeV are compared with the predictions of the TALYS 1.95 code and the semi-empirical formulas SPACS and Silberg & Tsao. We obtained two TALYS parameter sets for the ^{55}Mn(p,4n)^{52}Fe and ^{27}Al(p,x)^{22}Na reactions which give a good description of the excitation functions for energies up to 85 MeV. Discrepancies observed at higher energies require further investigation. The semi-empirical formulas provide a good description of the excitation functions above 120 MeV.

Keywords   Proton-induced reactions, Pre-equilibrium decay, Medical isotope production, ^{52}Fe

INTRODUCTION

Radioactive isotopes are widely used in nuclear medicine for diagnostic or therapeutic purposes. Each application requires specific decay characteristics of the isotope in use. For diagnostic applications, the patient's radiation dose is required to be the lowest possible, thus isotopes with a relatively low half-life are taken under consideration.

^{52}Fe is the only radioisotope of iron with decay characteristics suitable for in vivo visualisation of its distribution in diagnostic nuclear medicine. It has a half-life of 8.23 h and decays by positron emission (56%) and EC (44%), both modes de-exciting through the emission of a γ-ray of 169 keV [1]. It is thus suitable for imaging by positron emission tomography (PET) techniques. ^{52}Fe can be also employed in ^{52}Fe/^{52m}Mn generator systems [2] as a source of short lived (21.1 min half-life) ^{52m}Mn, which also decays by positron emission (98%) and is well suited for PET applications.

In the present study excitation functions for the production of ^{52}Fe and ^{22}Na are studied. The ^{55}Mn(p,4n)^{52}Fe reaction seems to be the best route for medical production of the isotope ^{52}Fe according to ref. [3], while the reaction ^{27}Al(p,x)^{22}Na is employed as a monitor reaction in cross section measurements [4]. Experimental data are compared with the theoretical calculations of the TALYS code (version 1.95) and the semi-empirical formulas SPACS and Silberberg-Tsao (S-T), for proton energies from threshold up to 200MeV.

TALYS CODE AND SEMI-EMPIRICAL FORMULAS

TALYS is a computer code system developed in NRG Petten (NL) and CEA (FR). It can perform nuclear model calculations for reactions, covering an energy range from 1 keV to 200 MeV. It is an exact implementation of the most modern nuclear models for direct, compound and pre-equilibrium reactions. It also contains an integrated optical model and various level density models. TALYS can provide theoretical predictions for total and partial cross-sections, as well as excitation functions [5]. The goal of the present study is to obtain TALYS code parameter sets [6] which give a good description of the excitation functions under investigation.

Furthermore, in this work the semi-empirical formulas SPACS and Silberberg – Tsao (S-T) are

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used, both being nuclear spallation reaction models providing theoretical calculations for cross-sections. The formula of S-T [7] takes into consideration pairing effects, density of states in the product nucleus and enhancement factors for the light evaporation products. The SPACS formula [8] 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.

RESULTS AND DISCUSSION

TALYS code calculations for the excitation function for the production of ^{52}Fe via the ^{55}Mn(p,4n)^{52}Fe reaction, are shown in Fig. 1. As seen in Fig. 1, the present calculations are in good agreement with the experiment [4] (presented with closed symbols), up to 85 MeV. The parameter set used for the code's calculations was [ldmodel=5, preeqmode=4, rvadjust p 0.5 and avadjust p 1.5]. Discrepancies observed above 90 MeV can be linked to energy dependant parameters that are not taken under consideration, but require further investigation.
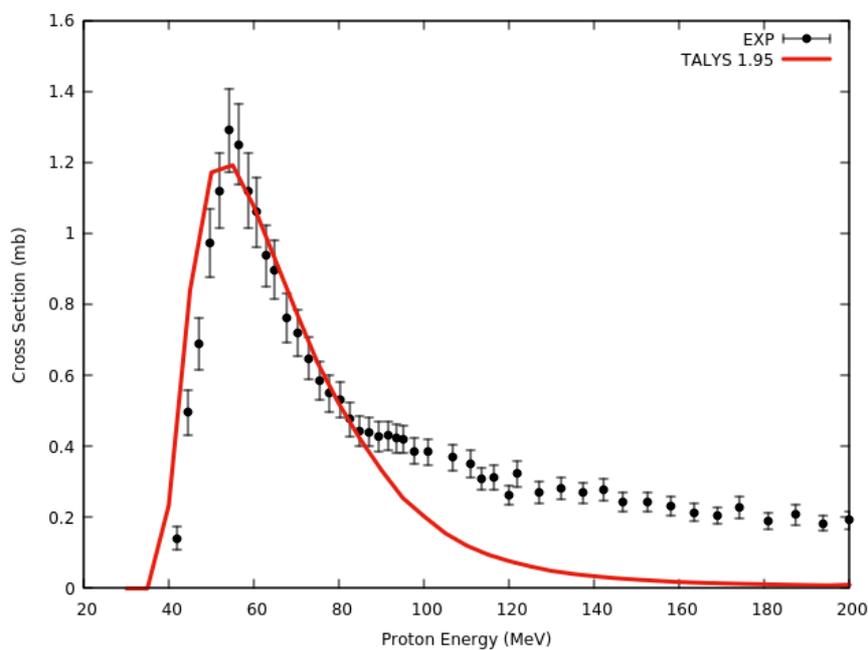

Figure 1. *Excitation function for the production of ^{52}Fe via the ^{55}Mn(p,4n)^{52}Fe reaction. TALYS code calculations are compared with experimental results [4].*

In Fig. 2, TALYS code calculations for the excitation function for the production of ^{22}Na via the ^{27}Al(p,x)^{22}Na are presented. The parameter set used for these calculations is [best, preeqmode=3], where "best" is recommended parameters for proton induced reactions on Aluminum targets found in TALYS code directories. As seen in Fig. 2, a good description is obtained for energies up to 75 MeV. At higher energies, this second peak that the TALYS code predicts, is linked to the (p,3n+2p) channel, which gives a significant contribution to the total cross section after 80 MeV as compared to e.g. (p,n+p+d) or (p,2n+3He). Further investigation may contain a reduction of its contribution to the total cross section in order to obtain a better description.

In Figures 3 and 4, SPACS and S-T model calculations are shown, in comparison with experimental data. The goal was to see which model provides a better description for the excitation functions under investigation. As seen in Fig. 3, for the ^{55}Mn(p,4n)^{52}Fe reaction's excitation function, the SPACS model calculations are in good agreement with the

experimental data for proton energies above 120 MeV. While in Fig. 4, S-T model calculations give a good description of the reference reaction's excitation function for energies above 120 MeV.
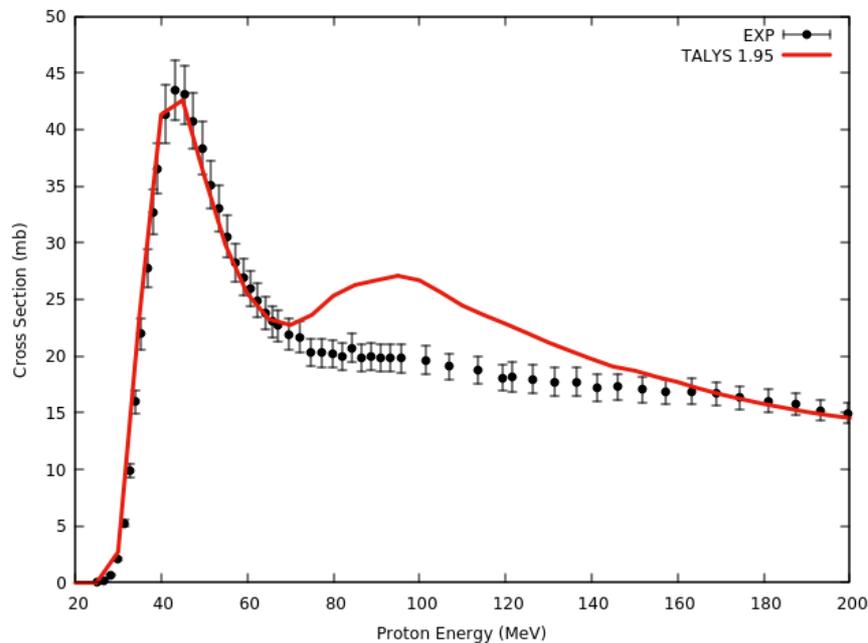

Figure 2. *Excitation function for the production of ^{22}Na via the reference reaction ^{27}Al(p,x)^{22}Na. Experimental data [4] are compared with TALYS code calculations.*
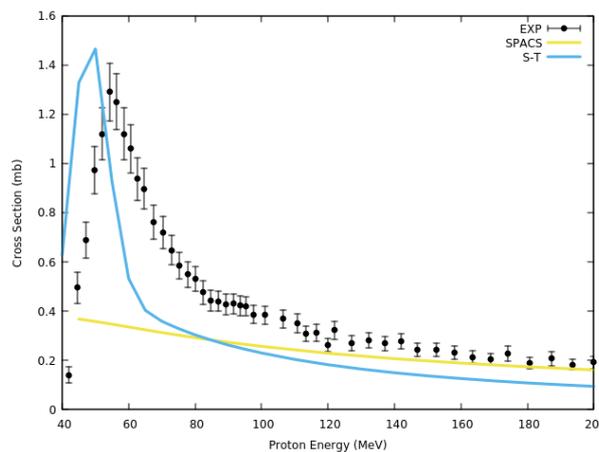

Figure 3. *Excitation function for the production of ^{52}Fe via the ^{55}Mn(p,4n)^{52}Fe reaction. SPACS and S-T model calculations are compared with experimental data.*
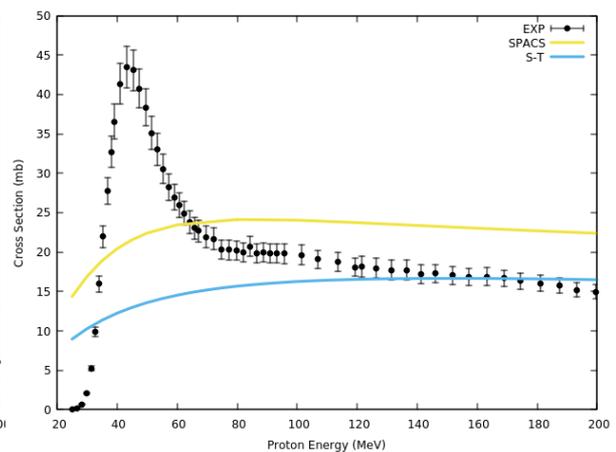
Figure 4. *Excitation function for the production of ^{22}Na via the ^{27}Al(p,x)^{22}Na reaction. SPACS and S-T model calculations are compared with experimental data.*

CONCLUSIONS

We have managed to obtain two TALYS code parameter sets which give a good description of the excitation functions for energies up to 85 MeV. Discrepancies observed at higher energies require further investigation. Meanwhile, the SPACS and S-T semi-empirical formulas are able to describe the ^{55}Mn(p,4n)^{52}Fe and ^{27}Al(p,x)^{22}Na reactions' excitation functions respectively, both for proton energies above 120 MeV.

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