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THE CALCULATIONS OF (P,XN) REACTIONS CROSS SECTIONS OF ^{203,205}Tl TARGET NUCLEI BY USING PROTON CYCLOTRON

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Abstract: In this study, the new calculations on the excitation functions of ^{203}Tl(p,2n)^{202}Pb, ^{203}Tl(p,3n)^{201}Pb, ^{203}Tl(p,4n)^{200}Pb, ^{205}Tl(p,2n)^{204}Pb, ^{205}Tl(p,3n)^{203}Pb and ^{205}Tl(p,4n)^{202}Pb reactions have been carried out in the 5-70 MeV incident proton energy range. In these calculations, the pre-equilibrium effects have been investigated. The pre-equilibrium calculations involve hybrid model, geometry dependent hybrid model and the cascade exciton model. The calculated results are compared with the experimental data taken from the literature.

Key words: ^{203,205}Tl, Pre-equilibrium reactions, Exciton model, Proton cyclotron

PROTON SİKLOTRONU KULLANARAK ^{203,205}Tl HEDEF ÇEKİRDEKLERİNİN (P,XN) REAKSİYON TESİR KESİTLERİNİN HESAPLANMASI

Özet: Bu çalışmada, 5-70 MeV proton gelme enerji aralığında; ^{203}Tl(p,2n)^{202}Pb, ^{203}Tl(p,3n)^{201}Pb, ^{203}Tl(p,4n)^{200}Pb, ^{205}Tl(p,2n)^{204}Pb, ^{205}Tl(p,3n)^{203}Pb ve ^{205}Tl(p,4n)^{202}Pb reaksiyonlarının uyarılma fonksiyonlarının yeni hesaplamaları yapılmıştır. Bu hesaplamalarda, denge-öncesi etkiler incelenmiştir. Denge öncesi hesaplamalar için; hibrid model, geometri bağımlı hibrid model ve cascade exciton model kullanılmıştır. Hesaplanan sonuçlar literatürden alınan deneysel verilerle karşılaştırılmıştır.

Anahtar kelimeler: ^{203,205}Tl, Denge-öncesi reaksiyonlar, Exciton model, Proton siklotronu,

INTRODUCTION

Today, by using cyclotrons and nuclear reactors can be produced a lot of radioisotopes (QAIM 2001). These isotope production alternatives are spallation reaction, high energy proton induced fission, isotope separation etc. (BEYER 2006). A cyclotron can accelerate a proton particles to energies higher than 30 MeV. Consequently, higher reaction processes such as (p,4n) or generally (p,xn) or even (p,xn,yp) processes are possible (x = 1,2,3…. and y = 1,2,3,…). Such a multipurpose cyclotron with the option of high particle beam intensity and well developed tools for beam diagnosis and a certain variation of particle beam energy is an excellent universal instrument supporting commercial isotope production and Research and Development (R&D) in the field of medical isotope application for diagnosis and therapy. Research and Development needed for development of alternative technologies producing carrier-free radioisotope preparations for therapy (BEYER 2006).

In the radioisotope production programmers, nuclear reaction data are mainly needed for optimization of production routes. This process involves a selection of the projectile energy range that will maximize the yield of the product and minimize that of the radioactive impurities. Recently, many evaluated excitation functions of commonly used production reactions can be found in the literature (QAIM 2001). Nuclear reaction calculations which are based on standard nuclear reaction models can be helpful for determining the accuracy of various parameters of nuclear models and experimental measurements. Calculations which are based on nuclear reaction models play an important role in the development of reaction cross sections (CHADWICK 2001). In this manner, in the present study, ^{203}Tl(p,2n)^{202}Pb, ^{203}Tl(p,3n)^{201}Pb, ^{203}Tl(p,4n)^{200}Pb, ^{205}Tl(p,2n)^{204}Pb, ^{205}Tl(p,3n)^{203}Pb and ^{205}Tl(p,4n)^{202}Pb reactions were investigated in a range of 5–70 MeV energy. Excitation functions for pre-equilibrium calculations were newly calculated by using hybrid model, geometry dependent hybrid model and cascade exciton model. Calculation results are also compared with the available excitation functions measurements in literature.

BASIC CALCULATIONS METHODS OF CASCADE-EXCITON MODEL

The Cascade-Exciton Model (CEM) assumes that the reactions occur in three stages. The first stage is the intranuclear cascade in which primary particles can be rescattered several times prior to absorption by, or escape from the nucleus. The excited residual nucleus remaining after the emission of the cascade particles determines the particle-hole configuration, that is, the starting point for the second, pre-equilibrium stage of the reaction. The subsequent relaxation of the nuclear excitation is treated in terms of the exciton model of pre-equilibrium decay, which includes the description equilibrium evaporative third stage of the reaction. The Cascade-Exciton Model combines essential features of the intranuclear cascade model (INC) with the exciton model. The Cascade-Exciton Model assumes that the nuclear reactions proceed through three stages: INC, pre-equilibrium and equilibrium (or compound nucleus). Generally, these three components may contribute to any experimentally measured quantity. (BARASHENKOV & TONEEV 1972, GUDIMA et al. 1983, BARASHENKOV et al. 1969).

$$\sigma(p)dp = \sigma_{in}\left[N^{cas}(p) + N^{prq}(p) + N^{eq}(p)\right]dp \quad (1)$$

The CEM combines essential features of the intranuclear cascade model (INC) with the exciton model. The inelastic cross section σ_{in} is not taken from the experimental data or independent optical model calculations, but it is calculated within the cascade model itself. Hence the CEM predicts the absolute values for calculated characteristics and does not require any additional data or special normalization of its results.

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BASIC CALCULATIONS METHODS OF HYBRID AND GEOMETRY DEPENDENT HYBRID MODEL

The hybrid model for pre-compound decay is formulated by Blann (BLANN & VONACH 1983) as

$$\frac{d\sigma_\upsilon(\varepsilon)}{d\varepsilon} = \sigma_R P_\upsilon(\varepsilon)$$

$$P_\upsilon(\varepsilon)d\varepsilon = \sum_{\substack{n=n_0\\ \Delta n=+2}}^{\bar{n}} \left[{}_n\chi_\upsilon N_n(\varepsilon,U)/N_n(E) \right] g\, d\varepsilon \left[\lambda_c(\varepsilon)/(\lambda_c(\varepsilon)+\lambda_+(\varepsilon))\right] D_n \quad (2)$$

where $P_\upsilon(\varepsilon)d\varepsilon$ represents number of particles of the ν (neutron or proton) emitted into the unbound continuum with channel energy between ε and ε + dε. The quantity in the first set of square brackets of Eq.(2) represents the number of particles to be found (per MeV) at a given energy (with respect to the continuum) for all scattering processes leading to an "n" exciton configuration. It has been demonstrated that the nucleon-nucleon scattering energy partition function $N_n(E)$ is identical to the exciton state density $\rho_n(E)$. The second set of square brackets in Eq. (2) represents the fraction of the ν type particles at energy, which should undergo emission into the continuum, rather than making an intranuclear transition. The D_n represents the average fraction of the initial population surviving to the exciton number being treated. Early comparisons between experimental results, pre-compound exciton model calculations, and intranuclear cascade calculations indicated that the exciton model gave too few pre-compound particles and that these were too soft in spectral distribution for the expected initial exciton configurations. The intranuclear cascade calculations results indicated that the exciton model deficiency resulted from a failure to properly reproduce enhanced emission from the nuclear surface. In order to provide a first order correction for this deficiency the hybrid model was reformulated by Blann and Vonach (BLANN & VONACH 1983). In this way the diffuse surface properties sampled by the higher impact parameters were crudely incorporated into the pre-compound decay formalism, in the geometry dependent hybrid model (GDH). The differential emission spectrum is given in the GDH as

$$\frac{d\sigma_\upsilon(\varepsilon)}{d\varepsilon} = \pi \lambdabar^2 \sum_{l=0}^{\infty} (2l+1) T_l P_\upsilon(l,\varepsilon) \quad (3)$$

where $\lambdabar$ is reduced de Broglie wavelength of the projectile and T_l represents transmission coefficient for *l* th partial wave.

RESULTS AND DISCUSSIONS

The present paper describes new calculations on the excitation functions of ^{203}Tl(p,2n)^{202}Pb, ^{203}Tl(p,3n)^{201}Pb, ^{203}Tl(p,4n)^{200}Pb, ^{205}Tl(p,2n)^{204}Pb, ^{205}Tl(p,3n)^{203}Pb and ^{205}Tl(p,4n)^{202}Pb reactions carried out in the 5-70 MeV proton incident energy range. The pre-equilibrium calculations involve the hybrid model, the geometry dependent hybrid model and the cascade exciton model.

The pre-equilibrium calculations on the excitation functions were carried out with ALICE91 code (BLANN & BISPLINGHOFF 1982) for hybrid model and the geometry dependent hybrid model, and CEM95 code (MASHNIK 1980) for cascade exciton model.

In the calculations of pre-equilibrium model, the hybrid model and the geometry dependent hybrid model use the initial exciton number as n_0=3(1 proton, 1 neutron and 1 hole). This model requires the initial proton (p) and neutron (n) exciton numbers. A detailed description of the ALICE91 can be found in Ref. (BLANN & BISPLINGHOFF 1982).

The CEM95 code is intended for the Monte Carlo calculation of nuclear reactions in the framework of the Cascade-Exciton Model. The CEM95 code allows us to calculate reaction, elastic, fission and total cross sections; nuclear fissilities, excitation functions, nuclide distributions, energy and angular spectra, double differential cross sections, mean multiplicities, mean energies and production cross sections for ejectile yields. Different models are incorporated in the CEM95 to calculate the level density parameter. The cascade exciton model calculations have been made by using CEM95 code with the level density parameter, and a detailed description of the CEM95 can be found in Ref. (MASHNIK 1980).

CONCLUSIONS

The new calculations on the excitation functions of ^{203}Tl(p,2n)^{202}Pb, ^{203}Tl(p,3n)^{201}Pb, ^{203}Tl(p,4n)^{200}Pb, ^{205}Tl(p,2n)^{204}Pb, ^{205}Tl(p,3n)^{203}Pb and ^{205}Tl(p,4n)^{202}Pb reactions have been carried out using nuclear reaction models. The all experimental data of the measurements are in good agreement with each other for the ^{203}Tl and ^{205}Tl nuclei. These experimental data can be found in CSISRS and ENSDF Experimental Nuclear Data File (http://www.nndc.bnl.gov). In general, the used all model codes are well in agreement with the measurements data on target nuclei in Figs.1-6 (except the ^{203}Tl(p,2n)^{202}Pb reaction). The geometry dependent hybrid model, hybrid model and cascade exciton model calculations are in good harmony with the experimental data above the incident energy 20 MeV.

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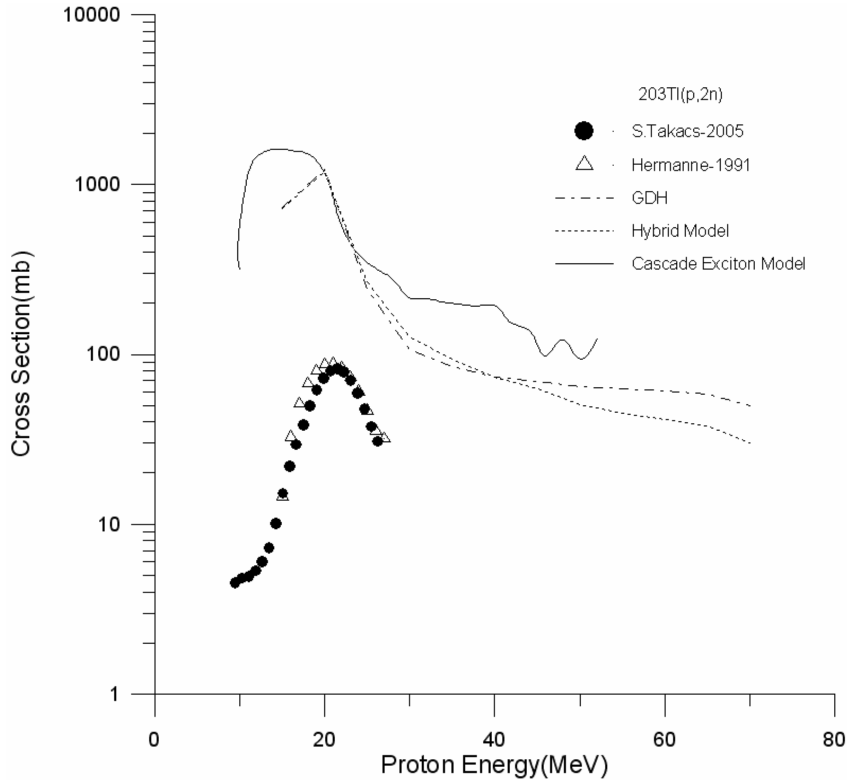

Figure 1. The comparison of calculated excitation functions of $^{203}Tl(p,2n)^{202}Pb$ reaction with the values reported in literature

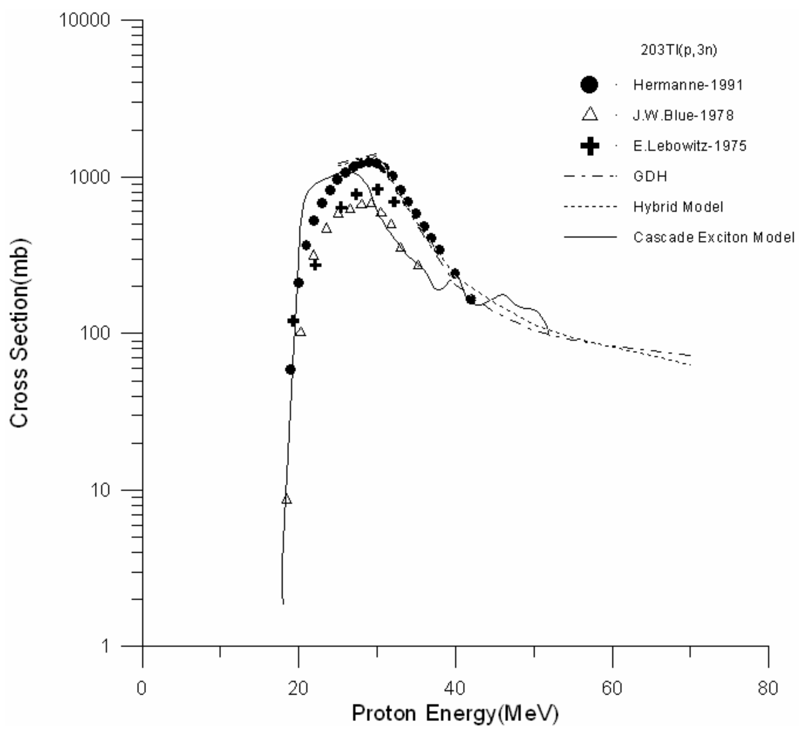

Figure 2. The comparison of calculated excitation functions of $^{203}Tl(p,3n)^{201}Pb$ reaction with the values reported in literature

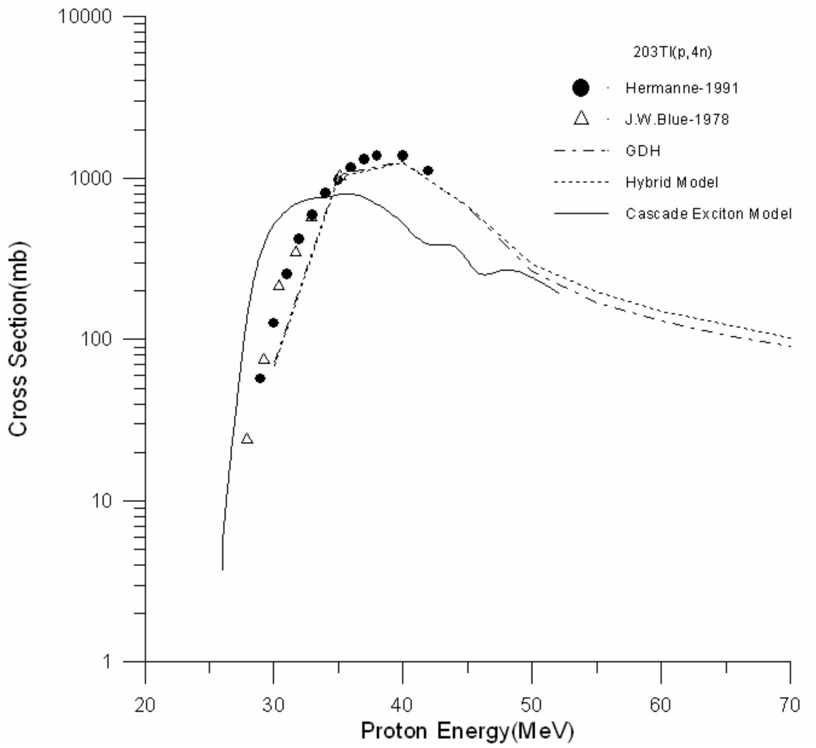

Figure 3. The comparison of calculated excitation functions of $^{203}Tl(p,4n)^{200}Pb$, reaction with the values reported in literature

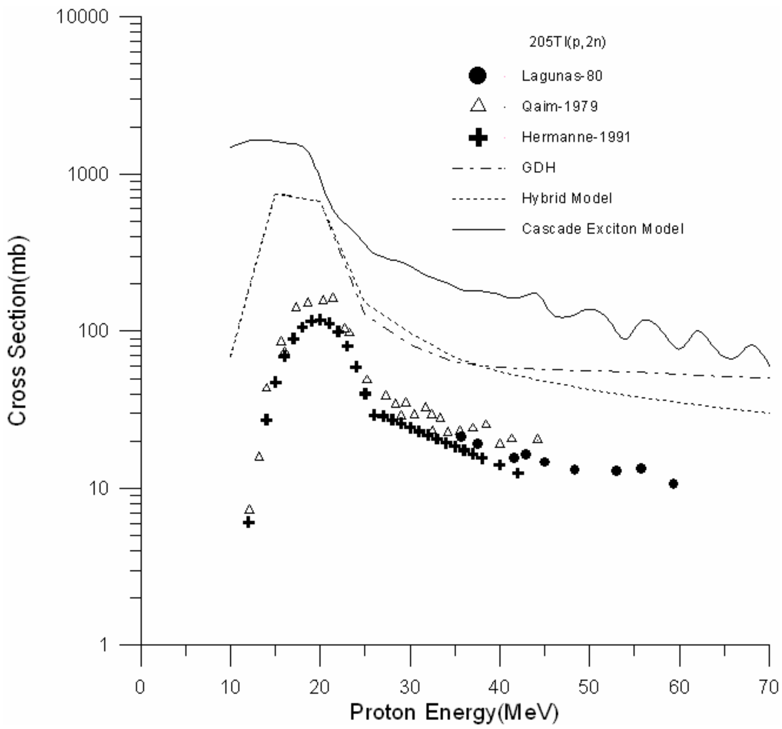

Figure 4. The comparison of calculated excitation functions of $^{205}Tl(p,2n)^{204}Pb$ reaction with the values reported in literature

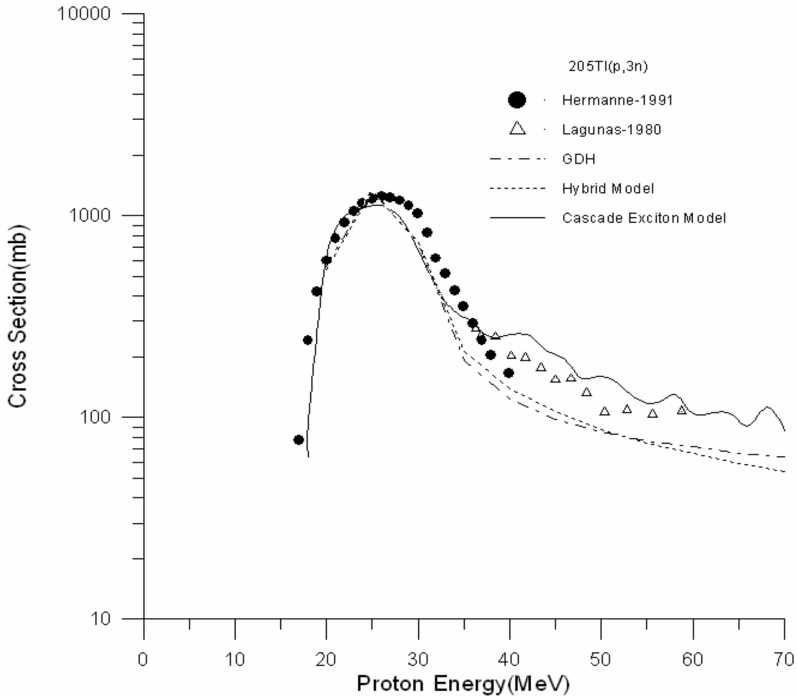

Figure 5. The comparison of calculated excitation functions of $^{205}Tl(p,3n)^{203}Pb$ reaction with the values reported in literature

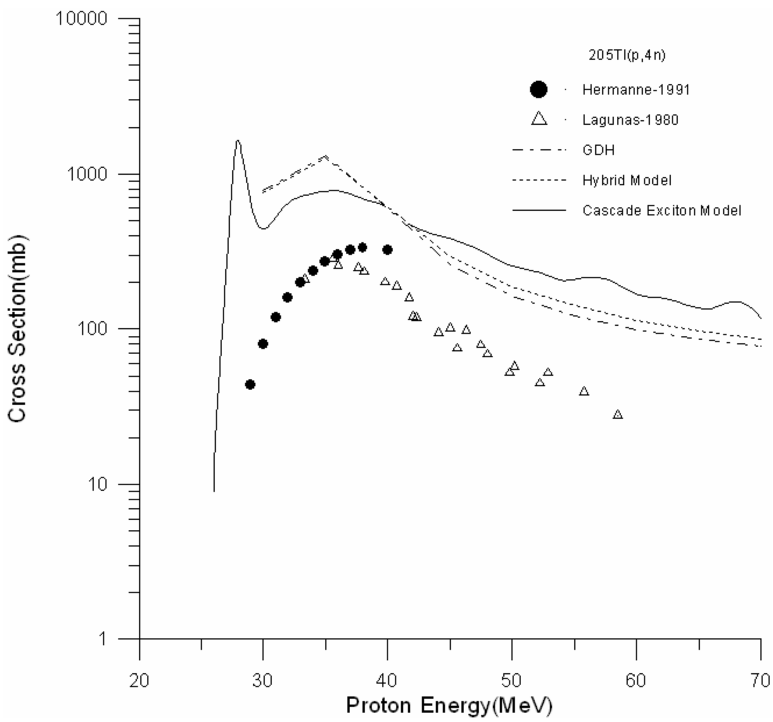

Figure 6. The comparison of calculated excitation functions of $^{205}Tl(p,4n)^{202}Pb$ reaction with the values reported in literature

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