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ENERGY SPECTRA AND ANGULAR DISTRIBUTION ANALYSIS OF ^{54}FE (N, D) REACTION

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ABSTRACT

The neutron induced charged particle emission in the pre-equilibrium and equilibrium stages have been considered in the present work using the Exciton model. An equidistant space model (ESM) includes different correction parameters is considered in calculating the energy spectra and double differential cross-sections of deutron emissions, that induced by neutron particle at energy range 15-96 MeV on^{54}Fe isotope. An evaluation of the present results with global code Talys *indicates an acceptable agreement in addition to experimental update data at interested region of study.*

Keywords: Cluster model, Statistical compound-nucleus reactions, Angular distribution, Emission spectra, Equidistant space model, Preequilibrium emission.

JEL Classification: C61, C67, C68.

1. INTRODUCTION

The particle-hole excitations caused by the nuclear reactions, which proceed through a number of nucleon-nucleon interactions, are described within the either semi classical models or the quantum-statistical theories of the preequilibrium emission (PE)**,** by means of the particle hole state densities.

The exciton model of preequilibrium nuclear reactions provides a simple way to describe the continuum energy and angular distributions of particles emitted during the energy equilibration in light particle induced reactions for example (n,d) at incident energies of around 15 to 96 MeV.

Because of its simplicity, its physical transparency, its utility, and its adaptability, the exciton model continues to be used in spite of the development of more microscopic and quantum mechanical models Fotina [1] , [2].

In this work the energy spectra and angular distribution of emitted particles are considered. Experimental results concerning light charged particle production in neutron induced reactions are available for iron at comparable incident neutron energies (28.5 MeV,62.7MeV and 96MeV). Our data together with those of experimental work and TALYS based evaluated nuclear data library Version 5 [3] provide a complementary information on nucleon induced light charged particle emission at the particular mass region and offer a larger base for testing the nuclear models of clustering in nuclei Bertrand and Peelle [4], Raeymackers, et al. [5], Ivascu, et al. [6].

2. THEORY

In exciton model [7-9] the primary pre-equilibrium differential cross section for the emission of a particle k with emission energy E_k can then be expressed in terms of lifetimes τ for various classes of states, the composite nucleus formation cross section σ^{CF}, and an emission rate W_k,

$$\frac{d\sigma_k^{pe}}{dE_K} = \sigma^{CF} \sum_{p_\pi = p_\pi^0}^{P\pi^{\max}} \sum_{p_\upsilon = p_\upsilon^0}^{p_\upsilon^{\max}} W_k(p_\pi, h_\pi, p_\upsilon, h_\upsilon, E_k)\tau(p_\pi, h_\pi, p_\upsilon, h_\upsilon) \times P(p_\pi, h_\pi, p_\upsilon, h_\upsilon)$$

where the factor P represents the part of the pre-equilibrium population that has survived emission. The basic feeding term for pre-equilibrium emission is the compound formation cross section σ^{cF}, which is given by:

$$\sigma^{CF} = \sigma_{reac} - \sigma_{direct}$$

where the reaction cross section σ_{reac} is directly obtained from the optical model .

The emission rate W_k has been derived by Cline and Blann [10] from the principle of micro reversibility, and can easily be generalized to a two-component version Betak and Dobes [11]. The emission rate for an ejectile k with relative mass μ_k and spin s_k is:

$$W_k(p, h, p, h, E_k) = \frac{2s_k + 1}{\pi^2 \hbar^3} \mu_k E_k \sigma_{k,inv}(E_k) \times \frac{\omega(p_\pi - Z_k, h_\pi, p_\upsilon - N_k, h_\upsilon, E^{tot} - E_k)}{\omega(p_\pi, h_\pi, p_\upsilon, h_\upsilon, E^{tot})}$$

where $\sigma_{k;inv}(E_k)$ is the inverse reaction cross section, again calculated with the optical model, Z_k $(N_k)$is the charge (neutron) number of the ejectile and E^{tot} is the total energy of the composite system.

For the particle-hole state density we use the expression of Betak and Dobes [11]. Their formula is based on the assumption of (ESM) and is corrected for the effect of the Pauli exclusion principle and for the Finite depth of the potential well. The two-component particle-hole state density is:

$$\omega(p,h,p,h,E)=\frac{g_{\pi}^{n_{\pi}}g_{\upsilon}^{n_{\upsilon}}}{p_{\pi}!h_{\pi}!p_{\upsilon}!h_{\upsilon}!(n-1)!}(U-A(p_{\pi},h_{\pi},p_{\upsilon},h_{\upsilon}))^{n-1}\times f(p,h,U,V)$$

where $g_{л}$ and $g_{л}$ are the single-particle state densities, A the Pauli correction, U = Ex - $P_{p;h}$ with $P_{p;h}$ Fu's pairing correction, Fu [12] ,for more detail about corrections see Kalbach [13], and f is finite well function which given in following expression:

$$f\,(p,h,E_x,V)=1+\sum_{i=1}^{h}(-1)^i\binom{h}{i}\left[\frac{E_x-iV}{E_X}\right]^{n-1}\Theta(E_x-iV)$$

3. SPECTRA AND ANGULAR DISTRIBUTIONS

Generally, the pre-equilibrium models ignore the influence of angular momentum. This is easily shown to be rather small for the nucleon emission, Betak [14] ,but is surely greater for clusters.

Here, the effect arises from two facts: (i) cluster emission is usually enhanced at higher angular momenta, which means increased role of the nuclear surface and consequently effective lowering of the Coulomb barrier, especially in the case of deformed nuclei (Blann [15] and Blann and Komoto [16]) and (ii) many of the quantities entering the pre-equilibrium reactions are spin-(or both spin- and energy-) dependent, and their simple contraction to one variable necessarily affects the results.

In nucleon-induced reactions, the original exciton (in fact, the incident neutron) is presumed to be the most energetic one for the most of the time and as such it keeps the notion of its direction Betak [17] , which is slowly smeared out in the course of the reaction. In the energy range of the pre equilibrium models, the nucleon-nucleon differential cross section is nearly isotropic in the c.m. system, so that in the laboratory system it is proportional to $\cos\theta$.

The emitted nucleon at the very early stage of the reaction is now just the leading particle, and the angular distribution is that which corresponds to the degree of smearing out the originally sharp value during the time interval from the creation of the composite system to the particle emission.
The original angular distribution formalism divides the cross section into two components, multi-step direct and multi-step compound, following the suggestion of Feshbach, et al. [18]. The multi-step direct (or MSD) part is defined as always having at least one unbound particle degree of freedom at each stage of the reaction, while in the multi-step compound (or MSC) part the system passes through at least one configuration where all of the particles are bound so that information about the original projectile's direction is largely lost. The MSD cross section is thus assumed to exhibit forward-peaked angular distributions, while the MSC cross section has angular distributions which are symmetric about 90^{o} in the center of mass Kalbach [13].

The basic formula for the double differential cross section for the included mechanisms in the reaction A(a, b)B can be written in the three equivalent forms

$$\frac{d^2\sigma}{d\Omega d\varepsilon_b} = \frac{1}{4\pi}\frac{d\sigma}{d\varepsilon_b}\frac{a_{ex}}{e^{a_{ex}} - e^{-a_{ex}}}\left(\left(1+f_{msd}\right)e^{a_{ex}\cos\theta} + (1-f_{msd})e^{-a_{ex}\cos\theta}\right)$$

where a_{ex} is the slope parameter associated with the exciton model and its related components .The quantity f_{msd} (ε_b) is the fraction of the cross section at the specified emission energy which is multi-step direct and it is replaced with the fraction that is preequilibrium. The angle θ is measured in the center-of-mass system. The general form of the slope parameter is:

$$a_{ex}(e_a, e_b) = 5.2(X_1) + 4.0(X_1)^3 + 1.9M_aM_b(X_3)^4$$

$$X_1 = \frac{e_b E_1(e_a)}{130MeVe_a}$$

$$X_3 = \frac{e_b E_3(e_a)}{35MeVe_a}$$

where e_a and e_b are given by the channel energies of the incoming and outgoing particles, ε_a and ε_b. The division of the cross section into the preequilibrium and equilibrium parts in order to generate is quite straight forward, though there is a separate value for each exit channel and emission energy. The ‘MSD’ or preequilibrium or forward-peaked component includes the exciton model preequilibrium components (both primary and secondary) as well as the cross sections from nucleon transfer, knockout and inelastic scattering involving cluster degrees of freedom. Collective excitations and elastic scattering are treated separately. Thus, for inelastic scattering:

$$\left[\frac{d\sigma}{d\varepsilon_b}\right]_{msd} = \left[\frac{d\sigma}{d\varepsilon_b}\right]_{pre,1} + \left[\frac{d\sigma}{d\varepsilon_b}\right]_{pre,2} + \left[\frac{d\sigma}{d\varepsilon_b}\right]_{NT} + \left[\frac{d\sigma}{d\varepsilon_b}\right]_{IN}$$

For other reaction channels (knockout) it is:

$$\left[\frac{d\sigma}{d\varepsilon_b}\right]_{msd} = \left[\frac{d\sigma}{d\varepsilon_b}\right]_{primary} + \left[\frac{d\sigma}{d\varepsilon_b}\right]_{\sec ondary} + \left[\frac{d\sigma}{d\varepsilon_b}\right]_{NT} + \left[\frac{d\sigma}{d\varepsilon_b}\right]_{KO}$$

where the knockout contribution occurs only for (N,α), (C,N) and (C,α) reactions, where N is a nucleon and C is a complex particle (d, t, 3He or α-particle).

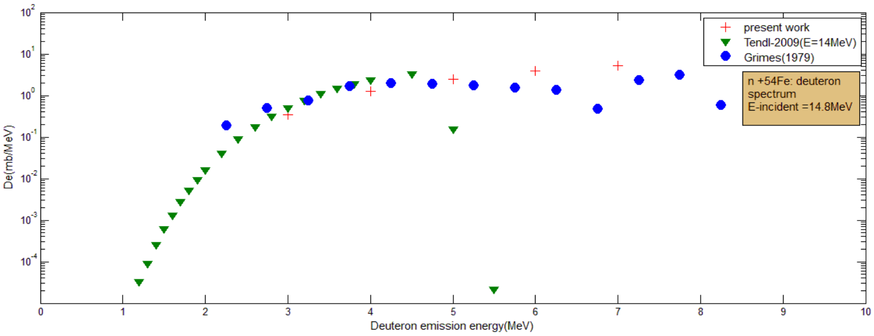
The corresponding equilibrium or symmetric component contains only the primary and secondary evaporation cross sections and is given by:

$$\left[\frac{d\sigma}{d\varepsilon_b}\right]_{msc} = \left[\frac{d\sigma}{d\varepsilon_b}\right]_{primary-eq.} + \left[\frac{d\sigma}{d\varepsilon_b}\right]_{\sec ondary-eq.}$$

4. RESULTS & DISCUSSIONS

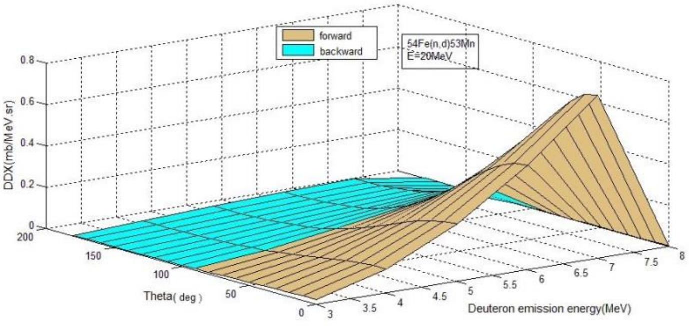
The results could be divided into multi-channel when projectile energy changed between 14 and100MeV. These results depend on the (ESM). Main results obtained from calculation of energy spectra and the double-differential cross-sections using the Kalbach systematics. Fig.1 present energy spectra for deuteron at 14.8 MeV incident neutron energy when the cross point indicate data from present work and full dote show experimental data of Grimes and Haight [19], with the triangles present data from the theoretical global code TALYS by Koning, et al. [20] . As seen in fig1.an acceptable agreement among the present work compared with and the experimental results within error bars from of Grimes and Haight [19].

Figure-1. energy spectra for deuteron at E(incident)=14.8MeV.



The main obtain data for double differential cross-sections in fig2. appear in forward case and render a sharp peak at certain values of emitted energy (7MeV) but DDX has approximately minor value in backward case. This can help with design of particle detector in laboratory systems and present a better prediction of favorite angle in experimental work in accelerations of particles.

Figure-2. DDX of E=20MeV ^{54}Fe (n, d)^{53}Mn when the sharp peak located at (7MeV).



The energy spectra of ^{54}Fe(n, d) in the range up to 25 MeV has been examined and compared with well define Grimes and Haight [19] .Indistinguishable points have been seen in fig.(3,4) from present results and Talys code data ,but we have some restriction on Talys code and this come from the cluster emission threshold energy which is approximately vanish in Talys data.

Figure-3. Energy spectra for deuteron at an incident energy of 28.5MeV.

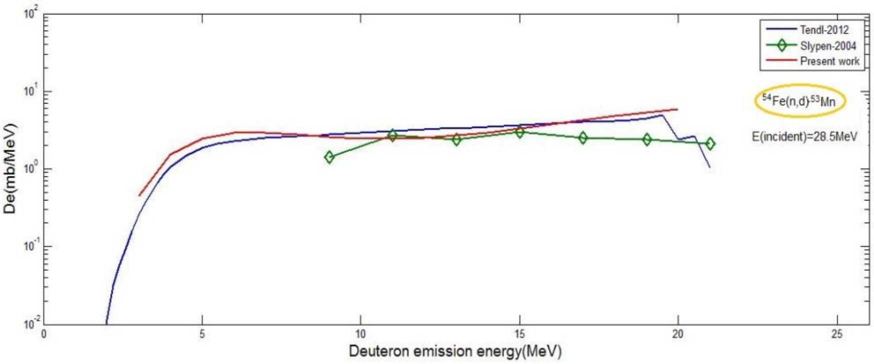
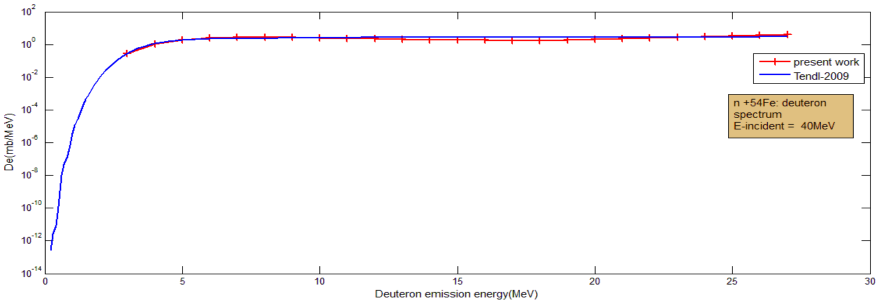
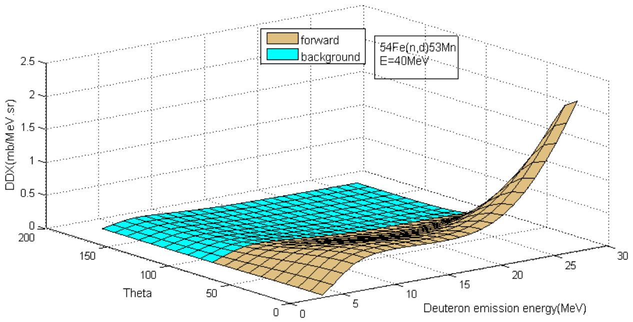


Figure-4. Energy spectra for deuteron at E(incident)=40MeV.



The double-differential cross-sections,fig.(5) show increasing in value with regard to energy until reach one value of emission deuteron energy and angle approximately (30MeV,45^0).

Figure-5. DDX of E_{inc}=40MeV ^{54}Fe (n,d)^{53}Mn



A comparison has been done between present results and experimental data of Slypen, et al. [21]. in 53.5,62.7MeV incident neutron energy and fig.8 shows the divergence of energy spectra with respect of decrease the deuteron emission energy and vice versa.

Figure-6. energy spectra for deuteron at E(incident)=53.5MeV.

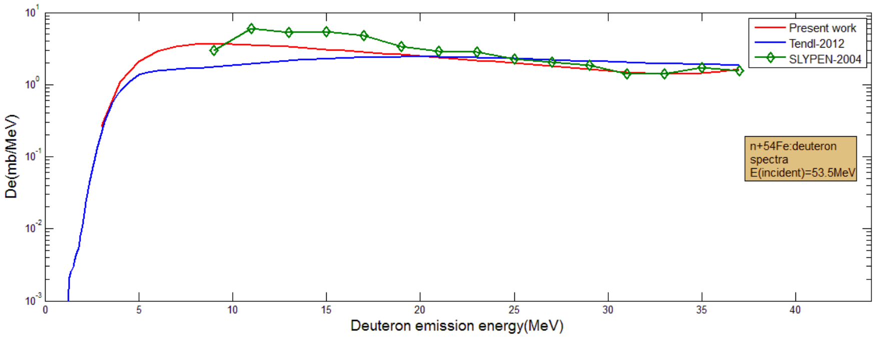


Figure-7. energy spectra for deuteron at E(incident)=60MeV.

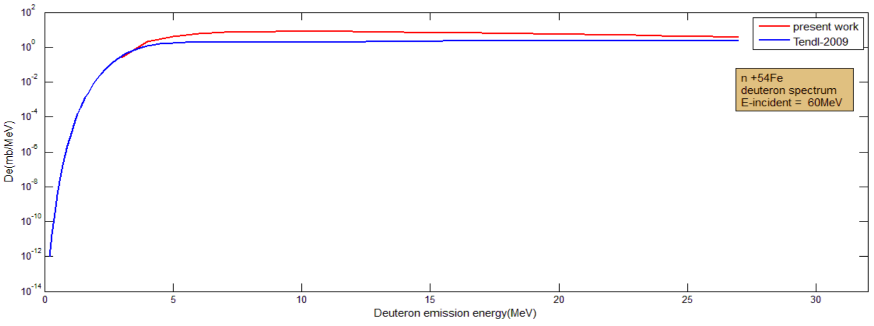
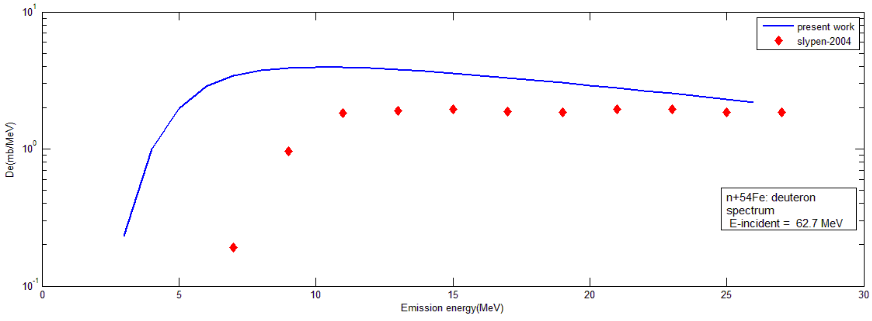


Figure-8. Energy spectra for deuteron at E (incident) =62. 7MeV.



In fig9. shows that at the present incident energy the DDX increase with E but at nearly 10MeV it takes a stably shape and this continues to another angle (less than 90), wile in backward the probability is very less than forward case

Figure-9. DDX of E_{inc}=60MeV ^{54}Fe (n, D).

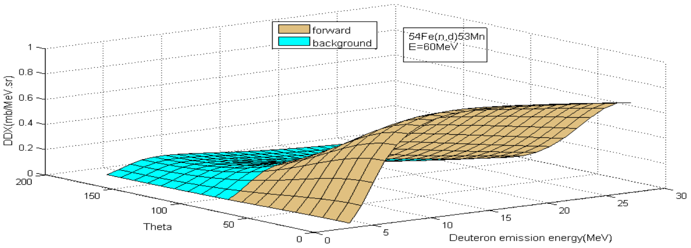


Figure-10. present DDX as a function of cluster energy for ^{54}Fe (n, D) at scattering angle=20(deg) and E(incident)=96MeV compared with experimental work Blideanu, et al. [22].

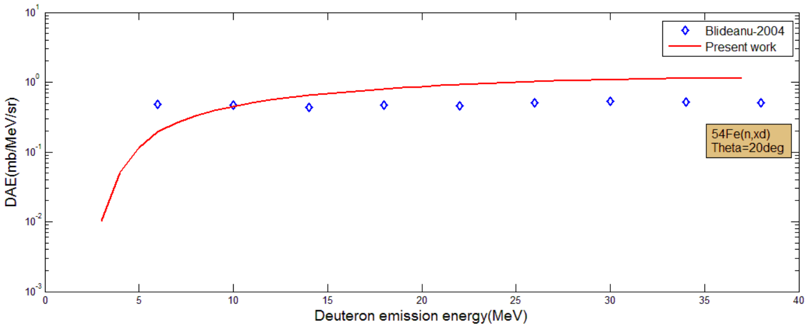


Figure-11. Present DDX as a function of cluster energy for ^{54}Fe (n, D) at scattering angle=160(deg) and E(incident)=96MeV compared with experimental work Blideanu, et al. [22].

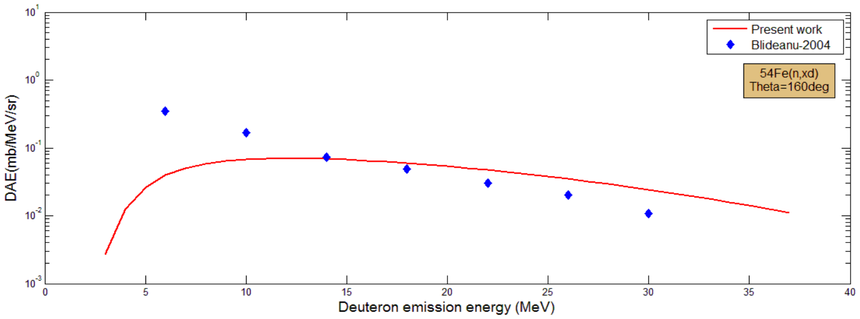


Fig.10,11 show similar behavior in DDX value with regard practical data at angle =20^0,160^0, the decreasing value of DDX in backward (160 deg) with an increase of E comes from the number of deuteron count in that region of energy.

5. CONCLUSION

A relatively naive and surely oversimplified view on the cluster emission can be found in the context of various pre-equilibrium model. The pre-equilibrium models may be completed by a presence of direct-type reactions, like the pickup and knockout, expressed for this purpose rather phenomenologically than microscopically. All these approaches, although simple, are rather useful to yield reliably the overall trends and also correctly predict the magnitude of cross-sections and related quantities. In this work theoretical energy spectra and double-differential cross-sections for deuteron production in (15-96) MeV neutron-induced reactions for iron-54 are reported based on the ESM model , which included all available corrections such as surface effect ,volume, spin dependent, isospin, Pauli blocking and pairing correction, bound-state and finite well depth , etc.

This allows energy differential cross-sections to be extracted and comparison with different model predictions to be performed. The comparison of the data to the other theoretical calculations and experimental done with nuclear-reaction code shows clearly that, despite the accept agreement obtained with the TALYS code improvements are still needed for a deep understanding of reaction mechanisms such as pickup and knockout which is play an important rule in cluster emission (^{2}D,^{3}T,α) .

By using the results of DDX for certain isotope in (n, d) reaction we can improve the facilities in labs and can get a right prediction of exact angle detection of emitted particle and it give us a reliably chance to test the cluster structure of nuclei which support the actual presence of clusters in nuclei.

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