International Atomic Energy Agency

INDC(CSR)-014/GJ

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

PRE-EQUILIBRIUM DECAY CALCULATIONS

BASED ON THE REALISTIC LEVEL SCHEME *,**

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* The work has been performed under IAEA CRP on "Methods for calculation of neutron nuclear data for structural materials" and research contract No. 4325/RB.

** The paper is based on the Diploma work of V.P.

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Reproduced by the IAEA in Austria
April 1988

88-01569

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Abstract:
Neutron and proton energy spectra are calculated within the pre-equilibrium model using the realistic level scheme. The emphasis is put on possible manifestation of the shell structure. To this aim, calculations are performed in the vicinity of closed shells near Ni, Sn, and Pb; as well as far of any shells, near $A \approx 160$. The value of the transition matrix element, treated as a parameter needed to fit the gross trend of the data, is to be about one order of magnitude below its conventional value.

The pre-equilibrium decay serves as a suitable tool for the analyses of low-energy nuclear reactions for nearly two decades. Already in the early years of the model, Blann et al. /1/ suggested the use of the so-called realistic densi-

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ties of states with specified exciton number. The word "realistic" means that it is based on the realistic single-particle levels (e.g. the Nilsson scheme) instead of the usual equidistant-spacing model.

Due to the enlarged requirements on both the computer time and its memory, five years elapsed till the first subsequent use of the approach suggested /2/. Recently, a tandem of papers on the topic by Blann and co-workers /3/ also appeared. We have benefitted from the code PEQGM, written by one of us /4/, and incorporated therein the realistic exciton level density subroutine kindly supplied by Lichman /5/. This subroutine enables to use an arbitrary scheme for the single-particle levels. In fact, up to three different schemes were used in the present work: Seeger-Howard /6/, Nilsson (taken from /7/), and for nuclei near $A \approx 60$ also the levels of Woods-Saxon potential (calculated by Antalík /8/).

We aimed at the following task: to study the influence of the so-called realistic level densities on the calculated nucleon spectra. To do that, we chosed four regions of nuclei: in the vicinity of the double-magic nucleus N=Z=58, near magic nucleus of Z=50 (tin), near double-magic nucleus of Z=82, N=126 (lead), and far of all closed shells, about $A \approx 160$.

In the first step, we calculated the exciton level density (for several exciton configurations) as a function of the excitation energy and compared it to the usual formula of Williams /9/. The second step included calculations of nucleon spectra and their comparison to the available experimental data.

Fig. 1 shows the comparison of the density of 3-exciton states as a function of the excitation energy, obtained within all three schemes of the single-particle levels used. The "realistic" exciton level density is compared to the prediction of the Williams formula /9/ with $g=3.3\ MeV^{-1}$ (a value, which yielded a reasonable agreement to the "realistic" calculations). Though the details are different for each one of the three single-particle schemes used, some features are common. Firstly, one observes a significant gap, especially for the doubly-magic ^{56}Ni, at low energies, which corresponds (mainly) to the pairing. Moreover, densities for this nucleus are generally lower at all the energy range than for the other nuclei in the region, though this effect is not so pronounced for the Nilsson scheme. Second nucleus,

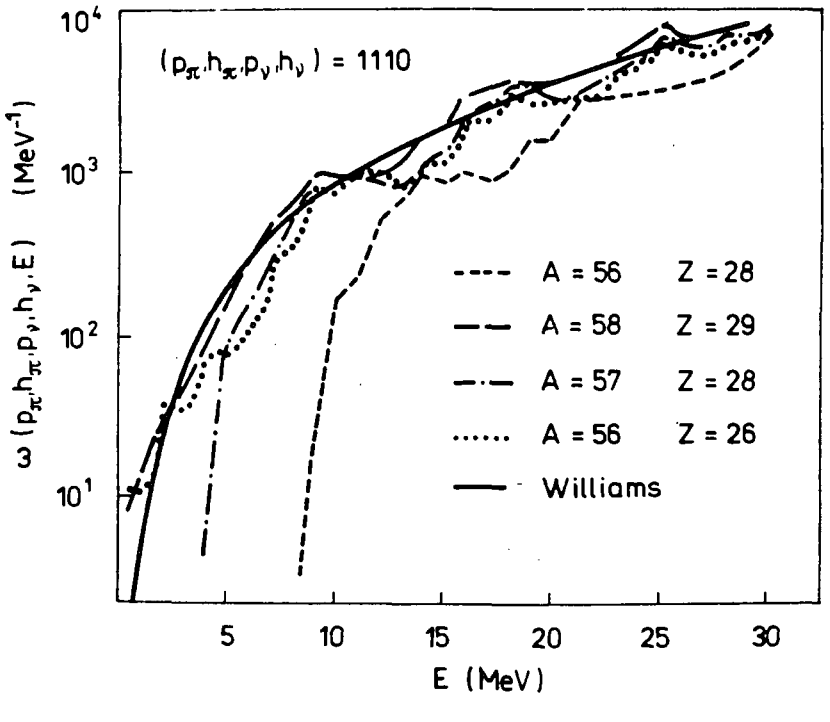

Fig. 1a) Comparison of the "realistic" level density of 3-exciton states versus the excitation energy in the vicinity of doubly-magic nucleus of N=Z=56, compared to the Williams formula. The "realistic" calculations are based on the Seeger-Howard scheme.

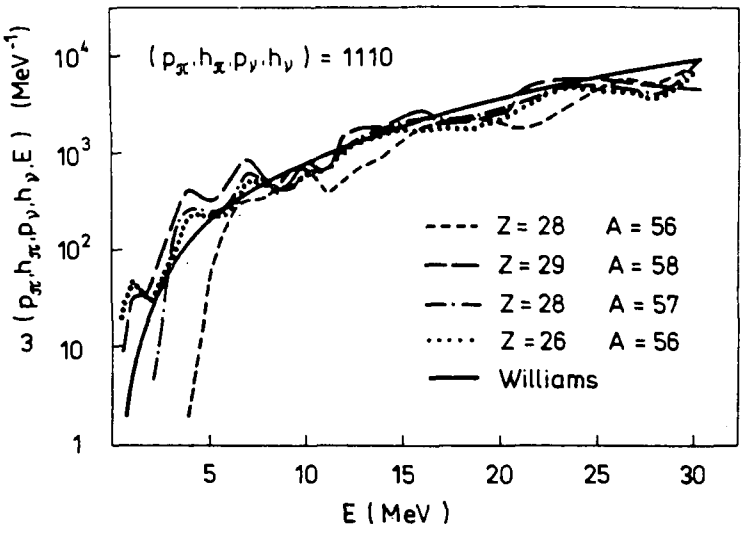

Fig. 1b) The same as in Fig. 1a), but for the Nilsson scheme.

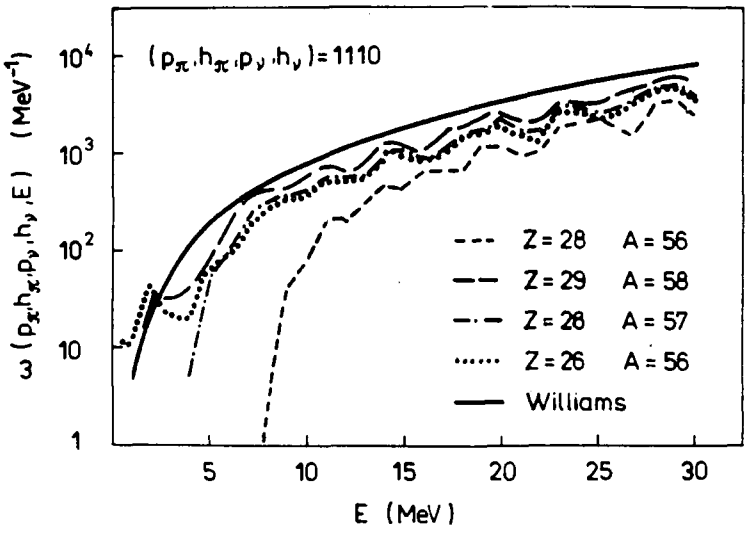

Fig. 1c) The same as in Fig. 1a), but for the levels of the Woods-Saxon potential.

where pairing is markant, is ^{57}Ni, and all the other nuclei around demonstrate only local fluctuations.

A similar comparison near $A \approx 160$ is presented in Fig. 2. The nucleus is far of the closed shells. As expected, no significant change of the exciton level density is achieved by changing the nucleus by several neutrons and/or protons.

Similarly, also the regions near Z=50 (Sn) and Z=82 (Pb) were studied, together with more complex exciton configura-

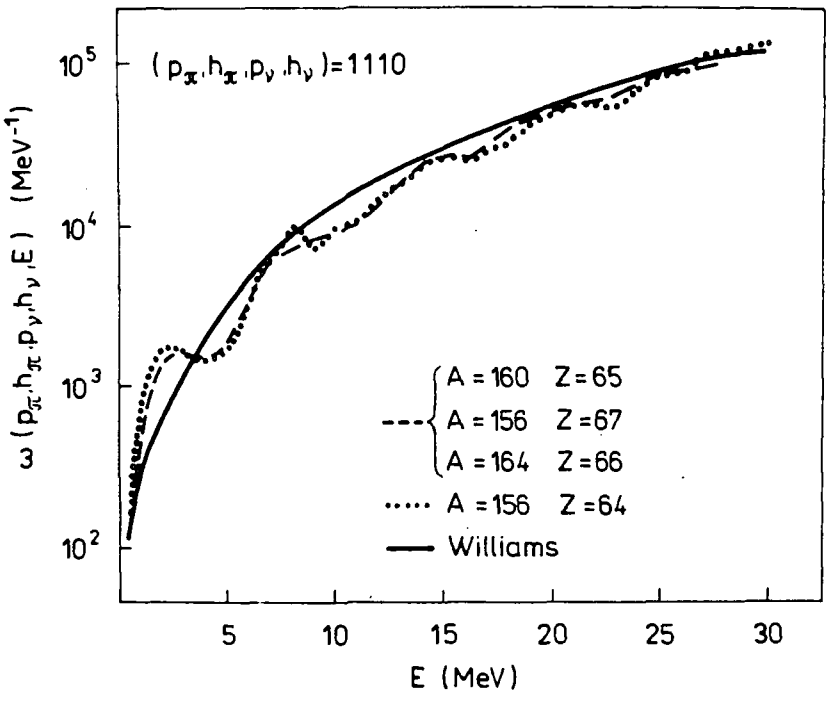

Fig. 2. Comparison of the "realistic" exciton level density, based on the Nilsson scheme, near $A \approx 160$ to the Williams formula with $g = 12.7$ MeV^{-1}. The differences among the three first nuclei are too small to be drawn in the scale.

tions for all four regions. As for the comparison of densities themselves, no principially new conclusions were obtained to the addition to the above presented ones.

A more interesting task is the comparison to the measured nucleon spectra. We have chosen several available published data and compared them to our calculations.

In all the cases, a special attention has to be paid to the transition matrix element used. Really, the transition rates are written in the form

$$\lambda^{\pm}(n, E) = \frac{2\pi}{\hbar} |M|^2 \rho_f , \qquad (1)$$

and the value of the matrix element was obtained from the fit to the analysed data, i.e. from the requirement to describe properly the competition between the particle escape and its

intranuclear transition. When one changes the densities, there is no wonder if also the value of the matrix element has to be changed. Generally, we used the form of $/M/^2$ dependent on the exciton number /10/, where a reasonable value for the matrix element constant, assuming the equidistant-spacing model, was $K' \approx 100$ MeV^3. Here, a significantly lower value was needed to come close to the data with "realistic" exciton level densities. Below, we present a typical picture of what was obtained.

Reaction ^{56}Fe (n, n′) was measured at 14 MeV /11/ and 26 MeV /12/, and was the only one where we could employ all three schemes of single-particle levels. The comparison is in Fig. 3. Unfortunately, the data at 14 MeV are available only to about 8 MeV outgoing neutron energy, and the interesting region near the end of the spectrum is not covered.

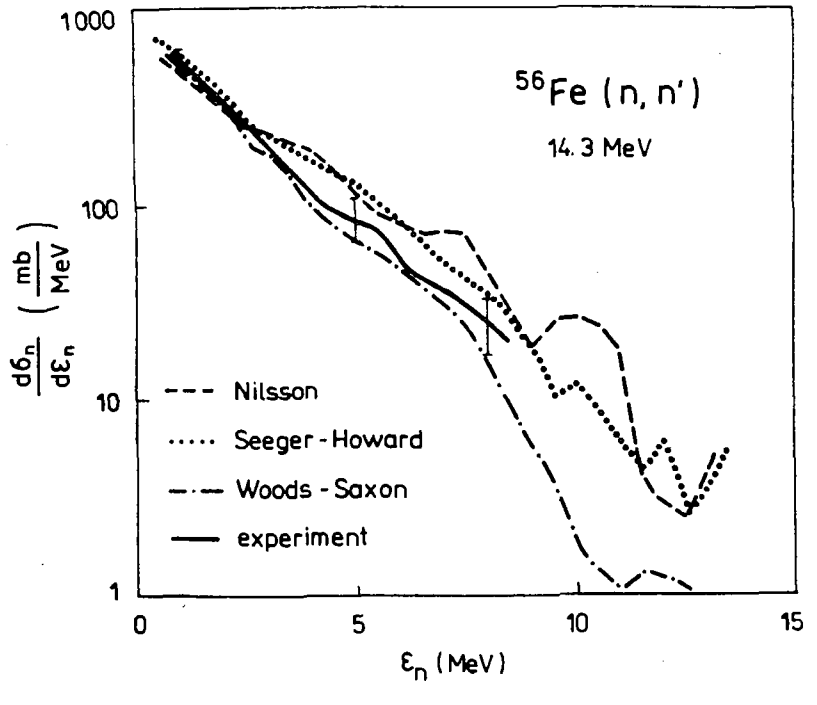

Fig. 3a) Neutron spectra calculated using three different "realistic" exciton level densities, compared to the data of ^{56}Fe (n, n′) at 14 MeV /11/. The matrix element constant used was $K' = 30$ MeV^3 for all three schemes.

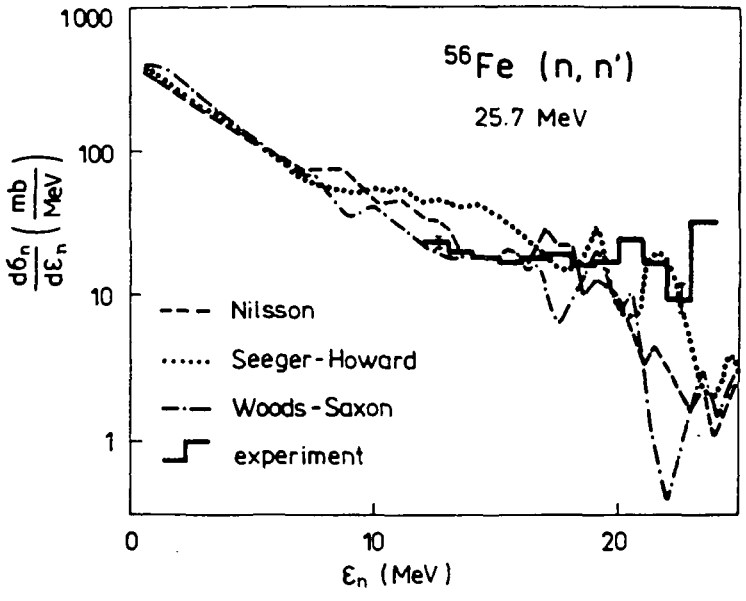

Fig. 3b) The same as in Fig. 3a), but at 26 MeV (data are of /12/). Matrix element constants: $K'=1C$ MeV^3 for the Nilsson and the Seeger-Howard schemes, whereas $K'=3C$ MeV^3 for the Woods-Saxon single-particle levels.

The data at 26 MeV manifest some structure, which reminds a structure in the calculated spectra. Nevertheless, its details (e.g. the positions of maxima) are not reproduced.

The next reaction chosen is ^{120}Sn (p, n) at 25 MeV and at 35 MeV /13/. Here, again some agreement can be found (c.f. Fig. 4), especially some about 15 MeV from the high-energy edge (i.e. near 10 MeV for the former, and .2C MeV for the latter one). The observed peak about 6-7 MeV below the high energy edge is not reproduced in either of the single-particle level schemes, what indicates it might be of a collective nature.

The last reaction chosen was ^{209}Bi (n, n') at 26 MeV (data of /12/), and the results are depicted in Fig. 5. As in the above reactions, also here some features are matched, especially, we succeeded to have a relatively flat spectrum up to about 22 MeV, followed by a steep decrease thereafter, just in the way observed.

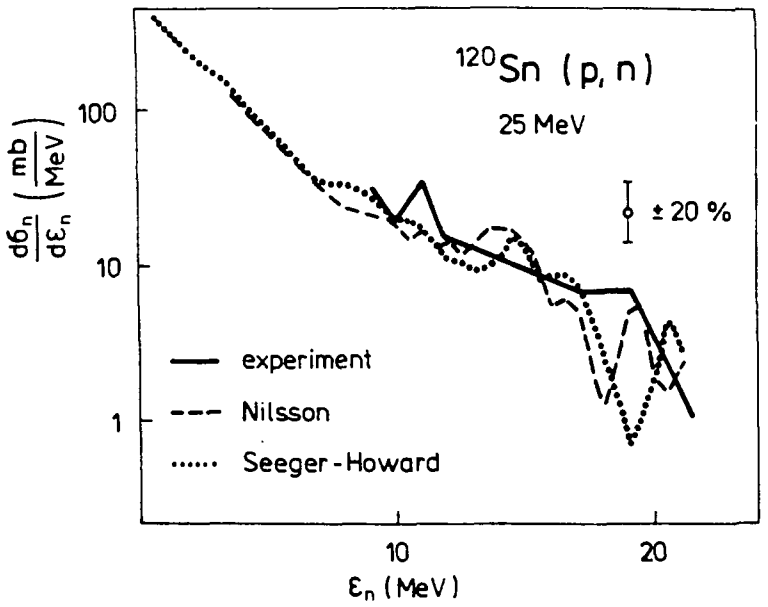

Fig. 4a) Calculated neutron spectrum compared to the experiment /13/ in ^{120}Sn (p, n) reaction at 25 MeV. The matrix element constant $K' = 10$ MeV^3.

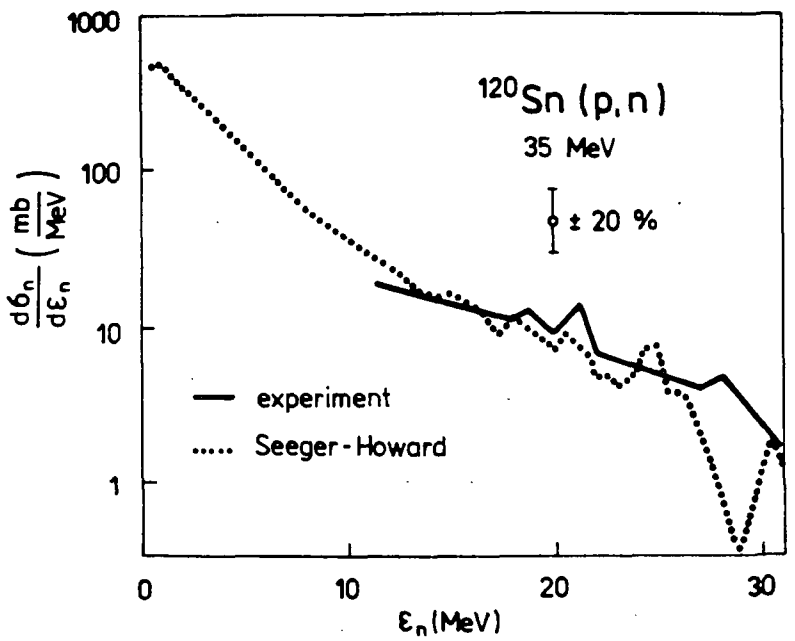

Fig. 4b) The same as in Fig. 4a), but at 35 MeV.

We have performed calculations based on the so-called realistic exciton level density for several nucleon spectra from reactions induced by nucleons of (14-35) MeV. The matrix element constant, treated as a parameter, had to be shifted by about 1 order of magnitude below its conventional (i.e.

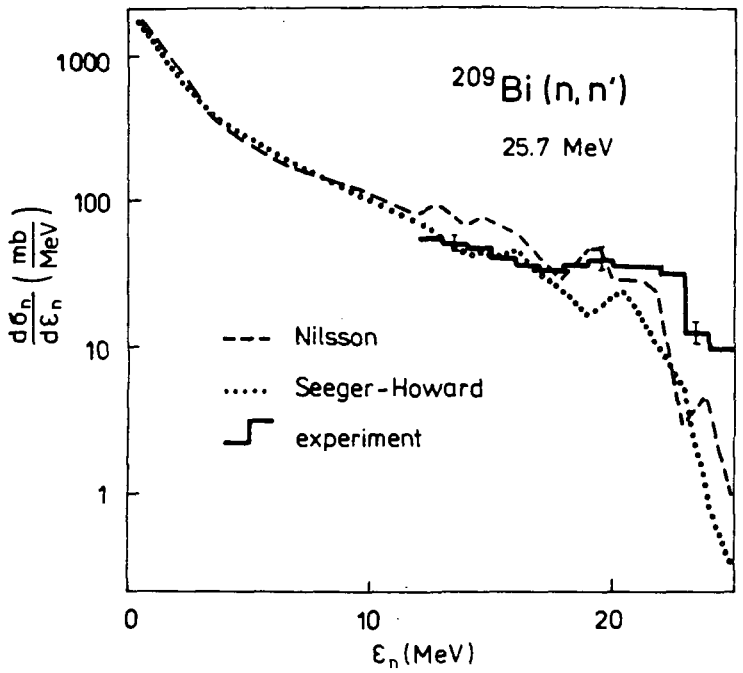

Fig. 5 Calculated neutron spectrum compared to the data /12/ in ^{209}Bi (n, n') at 26 MeV. Matrix element constant used was $K'=10$ MeV^3 for the Seeger-Howard scheme, and $K'=30$ MeV^3 for the Nilsson scheme.

based on the equidistant-spacing model) value. An improvement over the traditional picture is obtained; some of the structures observed in the data are reproduced by our calculations, but a part of them remains intact, what indicates they are probably not of the single-particle nature.

The authors are indebted to R. Antalík for calculation of Woods-Saxon energy levels, to V.A. Lichman for supplying his subroutine and for discussions, and also to E. Käbin for his interesting remarks.

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