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INTERNATIONAL NUCLEAR DATA COMMITTEE

Progress Report

on

Nuclear Data Activities in Romania for 1983

S. Rapeanu, I.A. Dorobantu
Central Institute of Physics
Bucharest, Romania

July 1984

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F O R E W O R D

This progress report contains the main nuclear data work performed during the year 1983 in the institutes of the Central Institute of Physics from Romania. It has been prepared to promote exchange of nuclear data information between the Socialist Republic of Romania and the other member states of IAEA. The emphasis in the works here reported has been on measurement, codes and evaluation of application nuclear data, such as those relevant to fission and fusion reactor technologies. The individual reports are not intented to be complete or formal. Consequently they should not be quoted and reproduced without the permission of the authors.

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CROSS SECTIONS OF SOME REACTIONS INDUCED BY 14.8 MeV NEUTRONS

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The cross sections have been measured by using a TEXAS-9900 neutron generator of Central Institute of Physics. The main parameters of TEXAS generator operation are, for these measurements, as follows :

- high voltage : 120 kV
- current : about 450 μA
- neutron intensity : about 10^{10} n/s.

The energy of neutrons incident on the targets has been 14.80 MeV, with a dispersion lower than 65 keV. The neutron flux has been monitored by a system of 3 absolutely calibrated fission chambers /1/.

The activation cross sections for ^{58}Ni(n,p), ^{58}Ni(n,2n), ^{59}Co(n,2n), ^{59}Co(n,α), ^{48}Ti(n,p), ^{27}Al(n,p) and ^{98}Mo(n,p) reactions have been obtained from reaction rates measured by high resolution gamma spectrometry (Ge-Li). The Ge-Li crystal has been calibrated in the absolute efficiency /2/. The cross section of ^{235}U(n,f) reaction has been takes as reference. The results concerning cross section measurements are given in Table 1.

The associated errors of the cross section values are as follows : statistics errors 0.4 - 1.2%; error in absolute efficiency calibration 1.5 - 2.1% ; background substration error 0.5 - 0.9%; error in absolute flux determination 2.0 - 2.3%.

Table 1

Reaction	Measured cross sections (mb)	Cross sections at 14.5 MeV/3/ (mb)	Cross sections at 14.8 MeV (mb)
$^{27}Al(n,p)^{27}Mg$	79.2 ± 4.0	75 ± 4	
$^{59}Co(n,2n)^{58}Co$	828.0 ± 60.0	720 ± 50	
$^{59}Co(n,\alpha)^{56}Mn$	35.0 ± 2.0	30 ± 2	
$^{58}Ni(n,2n)^{57}Ni$	40.3 ± 2.0	35 ± 3	39.94±0.67 /4/
$^{58}Ni(n,p)^{58}Co$	392.0 ± 20.0	375 ± 22	
$^{98}Mo(n,p)^{98}Nb$	5.4 ± 0.4	2.6 ± 0.7	5.2 ± 0.6 /5/
$^{48}Ti(n,p)^{48}Sc$	73.0 ± 3.5*	53 ± 6	71.7 ± 2.6 /6/

*This value includes that for $T^{49}Ti(n,n',p)$ reaction too.

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MEASUREMENTS CONCERNING THE REFERENCE SPECTRUM OF d(13)-Be AT U-120 CYCLOTRON

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ROMANIA

Neutron spectrum at U-120 cyclotron using d(13)-Be was determined in free air by time of flight technique /1/ and in irradiation space, shielded by boron paraffine, using multiple foil method /2/. For this has been used an irradiation head with a 166.5 mg/cm^2 Be-target, indirectly water-cooled, having an appropriate electron suppresion electrode and a Ta slit. TOF measurements with 13 MeV deuteron beam pulsed at 1.26 MHz frequency, have been performed. The two Ne102 scintillators were placed at 4.5 m flight distance (movable) and at 2 m (as monitor). The efficiency of Ne102 scintillators was computed by KURZ code. The neutron spectrum in free air, in the range 0.3-17.25 MeV was measured. The angular distribution measured between 0^{o} and 120^{o}, was strongly peaked forward.

Neutron characterization in the range 10^{-10}-18 MeV have been performed by multiple foil method, using a large number of rates fission (determined by means of Saclay fission chambers, absolutely calibrated /3/) and activation (measured by gamma high-resolution spectrometry Ge-Li). Neutron flux-spectrum by unfolding method /4/, using SANDII code and ENDF/B-V library - Dosimetry file, have been obtained. The input spectrum is measured by TOF above 0.3 MeV and derived by theoretical methods below this energetical threshold.The incertitudes in the spectral shape are in the range 5-30%.

Average energy of the spectrum within the range of 0.3-17.25 MeV measured by TOF method (in free air) is of 5.24 MeV and the one obtained by multiple foil method (for irradiation space) in the range of o.3-18 MeV is 5.33 MeV. The neutron spectrum includes a low energy component (below 0.3 MeV) of 5% due to the shielding materials of the irradiation system. In order to decrease this low energy component will be performed modifications at the irradiation system and new measurements. This spectrum will be used as neutron field for the neutron cross section testing.

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DETERMINATION OF NEUTRON FLUX-SPECTRA AT PLASMA FOCUS INSTALLATIONS BY SSTR METHOD

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A procedure /1/ of measuring flux of fast neutrons emitted by plasma focus installations of Central Institute of Physics, by using the solid state track recorders (SSTR) has been suggested /2/. The method is based on the analysis of the tracks recorded in Makrofol KG, tracks due to the fission fragments appeared by neutron irradiations of fissionable deposits.

The absolute calibration of fissionable deposits performed in the reference spectrum ΣΣ-ITN and in the thermal standard spectrum (SST) /3/. The techniques of sample preparation and image analysis are given in /4/.

The absolutely measured fission rates serve to obtaining of the absolute values of neutron flux and to spectral characterization of the fields, being used as input data in the unfolding code SANDII /5/.

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/5/ W.N.McElroy et al., Nucl.Sci.Eng., vol.36, No.15 (1969)

NEUTRON MEASUREMENTS ON A PLASMA FOCUS DEVICE USING ACTIVATION TECHNIQUES

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The fluence of neutrons from two plasma focus Mather-type devices (IPF 2/20 and IPF 3/50 /1/) was measured by gamma-ray spectrometry of activated indium and silver targets.

The $^{109}Ag(n,\gamma)^{110}Ag$ reaction was used. 656 keV gamma-ray decay product of ^{110}Ag with 24 sec half-life was counted with NaI(Tl) detectors. Three 250 g silver targets were used. A 5cm thick high-density poliethylene moderator was located in front of each target.

The $^{115}In(n,\gamma)^{116m}In$ was also used. Total gamma-ray spectrum of ^{116m}In with 56 min half-life was counted with NaI(Tl) dedectors 10 min after the plasma bursts. Three 50 g indium targets and the same poliethylene moderators were used.

The gamma-ray counting detectors were calibrated with an Am-Be source of 1.1×10^7 ($\pm$ 5%) neutrons per second, because its neutron energy spectrum (average energy 2.35 MeV) is similar to neutron energy spectra of our plasma devices.

Total neutron yields of IPF 2/20 plasma focus device from 1.5×10^8 to 1.3×10^9 neutrons per burst have been measured by the silver gamma-ray counting method with an estimated uncertainty of 25%. Also, total neutron yields of IPF 3/50 plasma focus device from 3.5×10^8 to 4.5×10^9 neutrons per burst have been measured by the indium gamma-ray counting method with an estimated uncertainty of 20%.

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NEUTRONS PRODUCED BY DEUTERONS ON THICK Be-TARGET

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Energy spectra and yields of neutrons by d(13 MeV) - Be(166.5 mg/cm^2) were measured by time of flight method in an angular range between 0^o and 120^o. Thick beryllium target was placed at 20^o against the incident beam. The beam currents were no more than 5-15 nA, and the frequency of the beam pulses on the target was 1.26 MHz.

The neutrons were detected by two NE102 plastic scintillators (Ø 40 mm, ≠ 60 mm). One of them is placed at 2m at a fixed angle of 90^o as a monitor, and the moveable one at 4.5 m. The intrinsec efficiency of the detectors corresponding at 0.3 MeV threshold energy was computed by Kurz-code, using the most recent cross section data.

In a typical time of flight spectrum we observed a peak at 0.7 MeV neutron energy, that was explained by the decay of Be-states excited by inelastic reactions /1/.

The angular-distribution of d(13 MeV)-Be(thick) is peaked-forward and its maximum is not located at the angle of 0^o, in agreement with earlier measurements.

Also, we observed a low energy component, which reflects the contribution of many mechanisms to the emission of neutrons.

Neutron average energy is 5.2 MeV at 0^o.

Energy spectra, and yields the same angular range, for d(13 MeV)-Al(13.5 mg/cm^2) on Ta backing and d(13 MeV) - Ta(thick) were also measured, in order to extract the contribution of the aluminium impurities contained in the thick Beryllium target.

/1/ M.A.Lone, A.J.Ferguson, B.C.Robertson, N.I.M., 189, 515 (1981)

3 MeV ALPHA-PARTICLE INDUCED X AND PROMPT GAMMA-RAY EMISSION ANALYSIS

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An alpha-particle beam of a 3 MeV energy is used to excite the X-ray emission and a Ge(I) detector with an analog processor amplifier to detect the X-rays. In the 14 < Z < region, the sensitivity corresponding to the K_α X-rays of the trace elements is about 10^{-6} g/g in a carbon matrix (3 MeV alpha-particles is quite equivalent to 0.8 MeV protons). Biological and mineral samples (including National Bureau of Standards - USA rock-standards W1, BM, KH) have been analysed.

The 3 MeV alpha-particle beam also induces in samples prompt gamma-rays through nuclear reactions. Thus, we can analyse N, O, F, Na, Al, Si :

$^{14}Na(\alpha,p)^{17}O$, 871 KeV	$^{18}O(\alpha,n)^{21}Ne$, 350 KeV
$^{19}F(\alpha,\alpha'\gamma)^{19}F$, 110, 197 KeV	$^{23}Na(\alpha,p)^{26}Mg$, 1808 KeV
$^{27}Al(\alpha,\alpha'\gamma)^{27}Al$, 842,1013 KeV	$^{28}Si(\alpha,\alpha'\gamma)^{28}Si$, 1783 KeV

The sensitivity is between 0.2 and 5‰ .

We can use the same experimental set-up for alternative or simultaneous X and prompt-gamma-ray analysis.

NUCLEAR MODEL CALCULATIONS OF (n,p) AND (n,n'p) REACTIONS ON MOLYBDENUM ISOTOPES

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Cross sections for the (n,p) and (n,n'p) reactions on $^{92,94,95,96,97,98,100}Mo$ isotopes have been calculated in the energy range from threshold up to 20 MeV. The calculations have involved the spherical optical model (code SCAT2 /1/), the statistical model (Hauser-Feshbach STAPRE code /2/) and the preequilibrium decay exciton and hybrid models (incorporated in STAPRE).

The input model parameters have been determined or checked analysing against the available experimental data the calculated neutron strength functions, potential scattering radius and total, differential shape elastic and inelastic scattering cross sections (SPRT method), the excitation function of the reaction $^{93}Nb(p,n)^{93}Mo$ at low energies, neutron resonance data and discrete levels at low excitation energies, neutron radiative capture cross sections on ^{93}Nb, $^{98,100}Mo$ target nuclei, the excitation function of the reaction $^{92}Mo(n,2n)^{91}Mo$ cross section and isomer ratio, and the proton-emission spectrum for 15 MeV neutron incident energy on ^{92}Mo target. The calculation of nuclear level density for excitation energies higher than $\simeq$ 23 MeV are more reliable done by means of the liquid drop model predictions for the back-shifted Fermi gas model parameters. That enable also to use in a unified way the average level density parameter $\bar{a} = A/8\ MeV^{-1}$ in both statistical and excitation models /3/.

The calculated (n,p) and (n,n'p) reaction cross sections have shown a general good agreement with the available experimental data. The isotope effect, confirmed by Molla and Qaim /4/ in the frame of their systematics of (n,p) reaction cross sections at 14 MeV, is illustrated in Figure 1 for Mo stable isotopes.

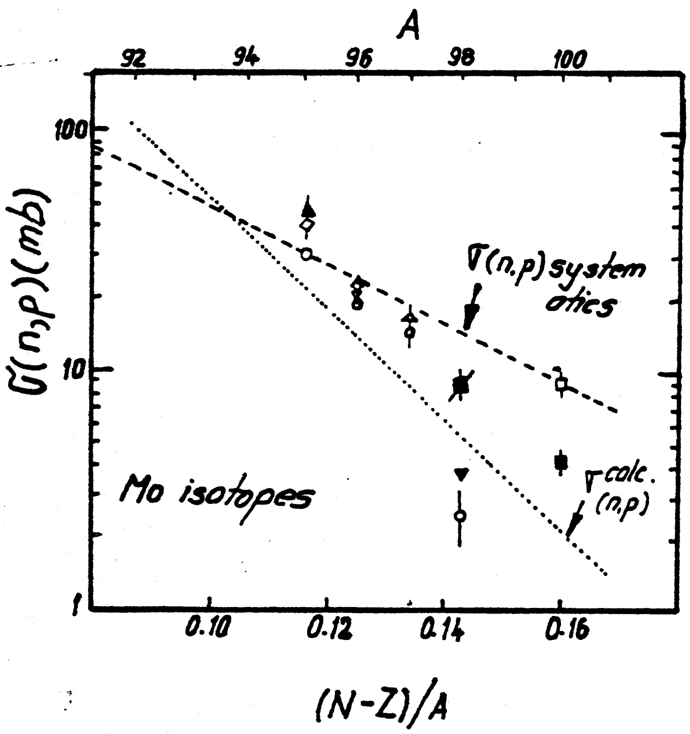

Fig.1

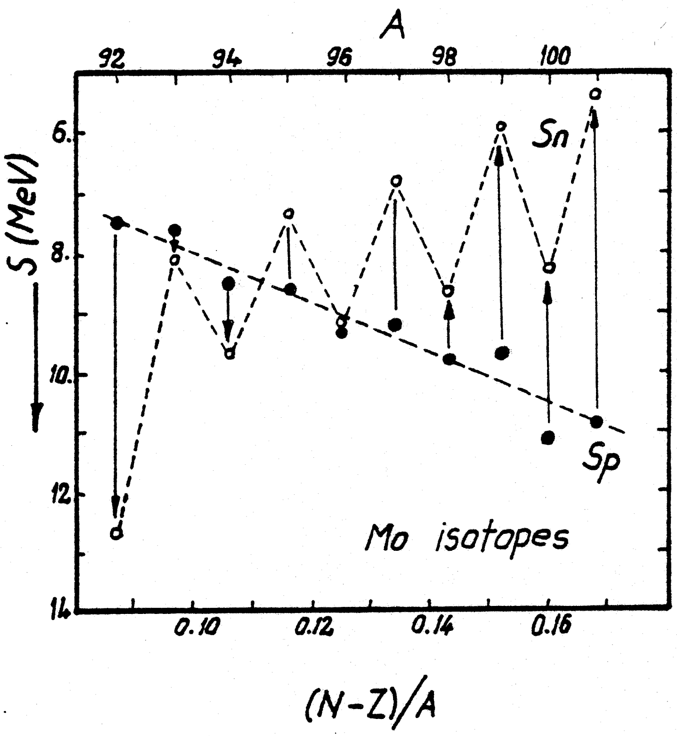

Fig.2

The isotopic cross section variations can be well correlated with nucleon binding energy trends depicted in Figure 2. The decrease in the (n,p) cross section with the increasing mass appears to be associated not only with the smooth increasing of the proton binding energies S_p but also with the oscillating values of the S_n-S_p difference. The higher cross sections for the ^{95,97}Mo isotopes, corresponding to smaller (negative) binding energy differences relative to the neighbour isotopes, seems to be well reproduced by the present calculations. Additional measurements for ^{100}Mo target could perhaps substantiate this conclusion.

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THE ENERGY DEPENDENCE OF THE INITIAL EXCITON STATE CONFIGURATIONS IN THE PREEQUILIBRIUM EMISSION MODEL

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Hauser-Feshbach and preequilibrium emission hybrid model calculations have been performed for the excitation functions of the (n,p) reactions on $^{46,47,48}Ti$ isotopes and the proton-emission spectra from $^{46,48}Ti$ isotopes at 15 MeV neutron energy, using the SCAT2 and STAPRE codes. Transmission coefficients for neutrons and protons were calculated from the global optical model potential (OMP) parameter sets of Wilmore and Hodgson /1/ and Perey et al. /2/, while for α particles the OMP of Bock et al. /3/ was involved. Level density parameters for the residual nuclei have been determined, in the frame of the back-shifted Fermi gas model, by using the most recently available s-wave neutron resonance spacings at the neutron binding energy and discrete levels at low excitation energies. γ-ray transmission coefficients were based on the absolute E1 gamma-ray strength functions generated by means of the adjusted /4/ energy-dependent Breit-Wigner (EDBW) model /5/.

The use of the preequilibrium hybrid model /6/ failed to reproduce the experimental excitation functions in the whole energy range. For the main constraint of this model - the initial exciton state configuration - the initial neutron number $p_o(n) = 1.2$ /6/ has been used. The agreement with the experimental data should be obtained if an energy dependence of the initial neutron number would be assumed. The representative results, obtained for the $^{48}Ti(n,p)^{48}Sc$ reaction using values of the initial neutron number $p_o(n)$ between 1 and 1.45 are shown in Figure 1. Further investigations are in progress to allow a final quantitative estimation of the presented energy dependence.

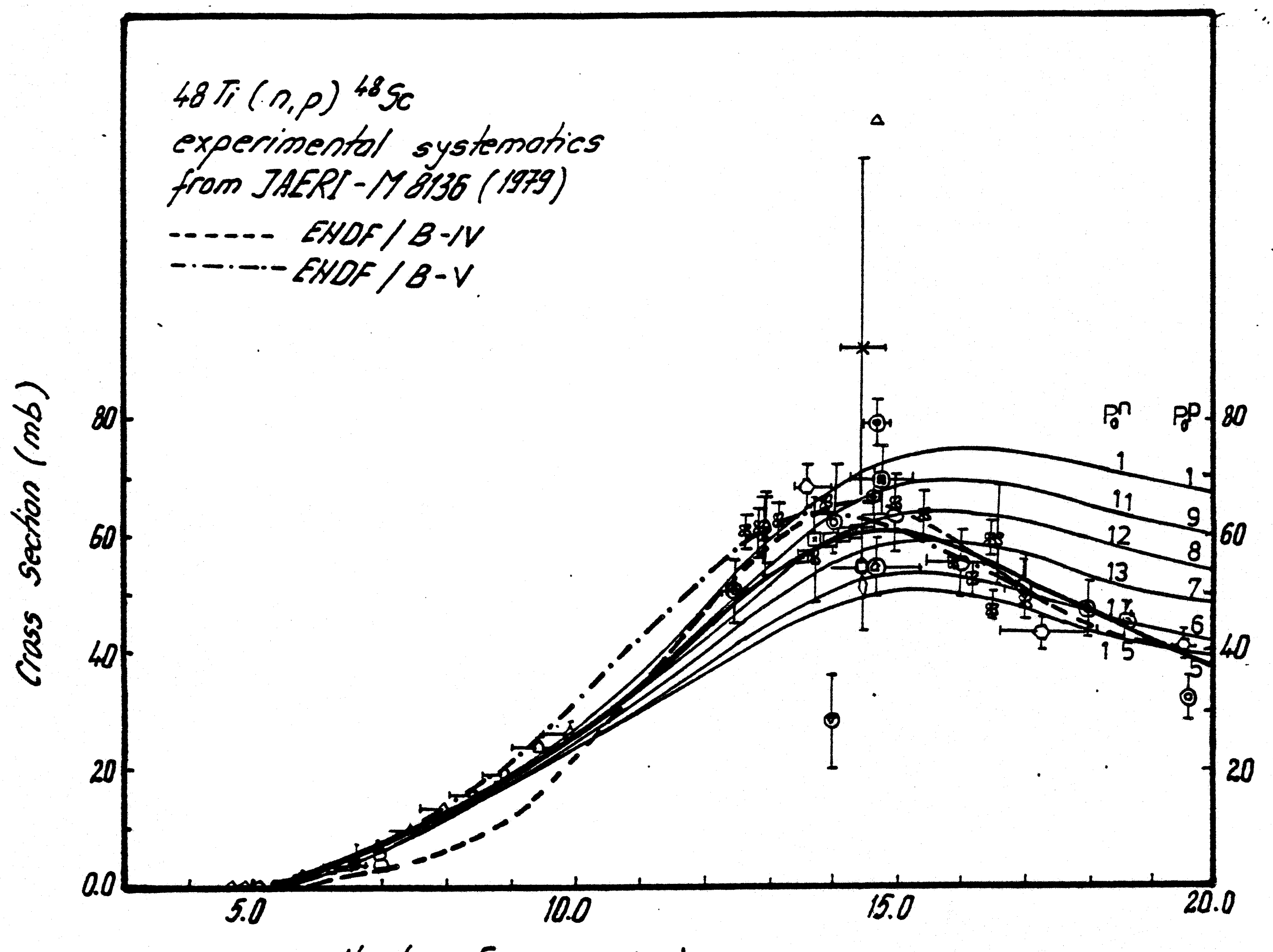

Fig. 1.

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ENERGY-DEPENDENT BREIT-WIGNER MODEL FOR GAMMA-RAY STRENGTH FUNCTIONS OF MEDIUM NUCLEI

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The giant dipole resonance (GDR) model, with a Lorentzian energy dependence, is commonly used to predict the E1 gamma-ray strength functions, $f_{E1}(E_\gamma)$. However, the more recently developed energy-dependent Breit-Wigner (EDBW) GDR shape /1/ has given much better results in reproducing the observed hardness in the capture gamma-ray spectra. On the other hand a useful single-peak approximation /2/ of this model, as well as the model itself (quite insensitive to nuclear deformation for β_2 values in the range 0.1-0.3), yield $f_{E1}(E_\gamma)$ values too large by about 30%, while the average trend with energy of the experimental data is better reproduced relative to the Lorentz shape. The last aspect, pointed out by Gardner /2/, has been also checked in this work by means of the available experimental $f_{E1}(E_\gamma)$ values for 11 nuclei from 51V to ^{90}Zr and the (n,γ) cross sections for ^{93}Nb, $^{98,100}Mo$ target nuclei.

In view of our interest in the medium mass nuclei, the main parameters of the EDBW model, the constants a and b entering in the expression of the apparent width of the two overlapping GDR peaks (eq. (9) of /1/) :

$$\Gamma_R = a \left[\frac{3E_R\ (F(\beta_2)-1)}{1+2F(\beta_2)}\right]^2 + 3/4\ \frac{b}{A^{1/3}}\ ,$$

have been further analysed. Gardner /1/ obtained the values a = 0.3974 and b = 29.699 by the least squares fitting of the above equation for the single-peak GDR widths compiled by Berman /3/ for 52 nuclides from Cu to Bi. The same single-peak GDR widths for nuclei from Rb to Sn have been refitted using the latest available experimental β_2 values. This smaller mass region fit has conducted to the parameter values

$$a = 0.887$$
$$b = 23.86 .$$

The smaller b constant has involved also a reduced width Γ_R^* of the EDBW single-peak approximation. The better agreement with the experimental data of both $f_{E1}(E_\gamma)$ strength functions and (n,γ) reaction cross sections seems to prove the significance of the systematic analyses in small mass regions also in the gamma-ray strength function field.

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A NON-UNIFORM "PICKET-FENCE" MODEL FOR TRUNCATED LEVELS CONTRIBUTION ESTIMATION IN THERMAL AND RESOLVED RESONANCE ENERGY RANGE FOR EVEN-EVEN ACTINIDES

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A non-uniform "picket-fence"-model to compute the contributions of the truncated levels to elastic scattering, capture and fission cross sections for even-even actinides in thermal and resolved resonance range is proposed. The recurrent algorithm developed, takes into account the exponential energy dependence of the level density and accepts variation of other resonance average parameters as well. BWSL and "s" wave resonance are considered. The proposed model, gives a better representation of neutron data in thermal and resolved resonance range for ENDF/B evaluations, as well as the possibility to obtain effective radii really constant. To obtain better results, a number of marginal resonances are recommended to be included into evaluated files, and the present

parameters for negative resonances as well as the effective radii are to be reconsidered. The new model has been developed and applied to 15 even-even actinide nuclei and can be considered an improved version of the uniform "picket-fence" model previously developed at ORNL for U-238 exclusively.

/1/ G.Vasiliu, Report unpublished (1984)

ELASTIC AND INELASTIC SCATTERING DATA FOR ^{92}Zr BETWEEN 1.5 MeV AND 5 MeV

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Using the program ELIESE /1/, based on optical and statistical models (Häuser-Feshbach-Wolfenstein), some scattering data have been computed for ^{92}Zr, in the energy range 1.5 MeV to 5 MeV: total, elastic, inelastic cross sections, angular distributions for elastic scattering of secondary neutrons, inelastic scattering data on excited levels, transmission coefficients, Legendre coefficients for angular distributions.

The incident energies choosen have been : 1.5, 1.8, 2.0, 2.2, 2.4, 2.5, 2.9, 3.0, 3.2, 3.4, 3.5, 4.0, 4.5, 5.0 MeV.

Three sets of optical model parameters have been taken : Bechetti - Greenless /2/, Guenther-Smith /3/, Finckh-Janke /4/.

The competitive (n,γ) reaction has been taken into account on this energy range.

The differential cross sections have been computed with and without Moldauer correction for the width fluctuations.

Up to 22 excited levels have been considered at 3.5 MeV, above this energy, the continuum has been considered, and the statistical parameters used.

The best fits with experimental data are obtained for the Finkh - Janke parameters, with Moldauer correction and Moldauer parameter Q = 0.0.

Some results are given in /5/.

Generally, a better agreement is obtained between experimental and calculated data using the Finkh parameters, than using the ENDF/B-IV data.

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A COMPARATIVE UNRESOLVED PARAMETERS EVALUATION FOR ^{233}U

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For the unresolved parameters evaluation, four resolved parameter sets have been taken into account : ENDF/B, JENDL-2 (with evaluated data), and BNL-325 (2), BNL-325 (3) (with experimental data).

The s-wave resonances (l=0) have been considered on the energy range 0.0 - 114 eV.

From the staircase plots (the comulative number of resonances function of energy), the cut-off energies and the observed level spacings have been derived.

The mean observed level spacing distributions were compared with Wigner distributions.

The reduced neutron widths were computed on the linear range of the staircase plots and were compared with the Porter-Thomas distributions.

Then, the strength functions and the associated errors were estimated. The values obtained for these from ENDF/B-IV and JENDL sets, are in good agreement with experimental values.

The average radiative and fission widths were obtained also (the fission widths are dependent on energy).

The results are presented in Table 1. The BNL-325(2) set gives discrepant results because only 30 resonances have been taken into account.

Using the program AVERAGE-3 /1/ the total, elastic, capture and fission cross sections have been computed, between 100 eV and 30 KeV, based on these four unresolved parameter sets. The best fit with experimental data was obtained for the ENDF/B-IV set.

/1/ M.R.Bhat, BNL-50296, 1971

TABLE 1. *The computed unresolved parameters for* ^{233}U

Reference with resolved resonances	l	J	Cutt-off energy (eV)	No.of resolved resonances	D(l,J) (eV)	Error for D(l,J)	$<\Gamma_n^0>$ (eV)	$<\Gamma_\gamma>$ (eV)	S(l,J) $\times 10^{-4}$	Error for S(l,J) $\times 10^{-4}$
ENDF/B-IV library	0	2.5	62.72	80	0.7939	0.0045	0.1362	44.05	1.7156	0.2712
JENDL-2 library	0	2.5	60.95	96	0.6219	0.0021	0.1076	44.15	1.7300	0.2497
BNL-325(3)	0	2.5	62.72	85	0.7379	0.0034	0.1640	45.28	2.2930	0.3517
BNL-325(2)	0	2.5	32.50	30	1.0766	0.0286	0.1792	48.25	1.7510	0.4536

CALCULATION OF TRANSITION PROBABILITIES LIFETIMES AND RADIATED POWER

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Using the theory of Rohrlich - Griem and Slater, Roothaan-Hartree-Fock and screened hydrogenic wavefunctions the transition probabilities and lifetimes for lithium atom /1/ and for multiply ionized ions of carbon are calculated.

Knowing the transition probabilities, the radiated power may be also calculated for collisions with excitation and for radiative unresonant change transfer between neutral rapid hydrogen atom and multiply ionized ions of carbon as impurities of interest in Tokamak researches.

/1/ L.Brânduş, Rev.Roum.Phys., 28, 595 (1983)

A FAST NUCLEAR METHOD FOR NITROGEN ANALYSIS

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We have developed a nuclear nondestructive method of protein analysis in cereals, which use proton activation for measuring total nitrogen content through the $^{14}N(p,n)^{14}O$ reaction.

A proton beam of 14.5 MeV energy and 100 $\pm$ 10 nA intensity is used. The ^{14}O activity ($T_{1/2}$ = 71 sec) is detected by means of its characteristic 2.312 keV gamma-rays (99.4%)with a NaI(Tl) detector.

The ratio of the number of gamma-rays to that of the incident particles for the sample, related to a similar ratio in adequate standards determines the nitrogen content in the sample.

For the complete automatisation of the measurement, we have constructed an electro-mechanical system based on a PDP-8 computer and a Nuclear Data multichannel analyser working in the MCS mode. Thus, we are able to analyse samples at a rate of one per minute.

If we protect the ambryo region during irradiation, the future germination of the analysed seeds will be quite normal (80-90% normal seedlings); thus we can directly select the richest protein content grains.

Several thousand samples of cereal grains (wheat, corn, barley, bean and soya-bean) were analysed with our nuclear method. Good correlation has been obtained between the results of the present method and the chemical Kjeldahl method values.