COMITATO NAZIONALE ENERGIA NUCLEARE
DIPARTIMENTO RICERCA TECNOLOGICA DI BASE ED AVANZATA

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN ITALY

for the period from January to December 1979

RELAZIONE TECNICA INTERNA

RIT/FIS/LDN(80)4
NEANDC(E)212 vol. 7
INDC(ITY)5/G

NOT FOR PUBLICATION

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN ITALY

for the period from January to December 1979

Compiled by
C. Coceva and E. Menapace

Comitato Nazionale Energia Nucleare
Bologna, Italy

RIT/FIS/LDN(80)4
NEANDC(E)212 vol. 7
INDC(ITY)5/G

CONTENTS

1. C.N.E.N. - DIVISIONE DI FISICA - LABORATORIO DATI NUCLEARI - Via Mazzini, 2 - 40138 BOLOGNA (Italy)

1.1 Threshold Photoneutron Reactions

L. BIGNARDI, C. COCEVA, M. MAGNANI, A. MAURI

The time-of-flight spectra have been obtained of the neutron emitted at 90° and 135° with respect of the incident photons in the reaction $^{95}Mo(\gamma,n_o)^{94}Mo$. The target (100g of 96.5% enriched ^{95}Mo) was placed in a flux of bremsstrahlung photons with end energy 0.6 MeV above threshold for neutron emission. The data were taken with ^{6}Li glass detectors, up to 400 keV neutron energy.
The experimental data are now being analysed to obtain the cross-section of the observed reaction, and to extract information on the characteristics of the excited levels and on the gamma transition probabilities.

1.2 Total Neutron Cross Section Measurement in ^{96}Zr (ref./a/)

C. COCEVA, P. GIACOBBE, M. MAGNANI

Time-of-flight neutron transmission measurements on Zr O_2 enriched samples, performed with high resolution, allowed evaluation of energy, spin, parity and neutron width of fourteen ^{96}Zr resonances below 40 keV. Acuurate analysis was acrried out, as the measurement was intended to resolve the considerable discrepancies present in the literature. These are particularly inconvenient for an element as Zirconium, which is of great importance for reactor technology, and of considerable interest as it lies near the minimum of the s-wave strength function and the 3p-maximum of the p-wave strength function, as predicted by the optical model.
A contribution to reliable determination of ^{91}Zr parameters was given in a previous work /b/.
The experiment was performed at the Geel electron linac, within the frame of a CNEN-Euratom cooperation programme.
Transmission spectra were analyzed with the shape-analysis computer programme described in ref./b/, using single level formalism.
All contributions to the resolution function were accurately taken into account.

The results are shown in Table I. Comparison of these results with the values reported in the literature must be made essentially with reference to the most recent work by Musgrove et al./c/.
While energy values and parity assignments are almost coincident and few new spin assignments could be made, for neutron widths the estimates of the present work are systematically higher than those of ref./c/ and by a large amount.
The small number of s-wave resonances did not allow a meaningful estimate of the strength function. For p-wave obtained

$$S_1 = (11.6^{+9.5}_{-3.7}) \times 10^{-4} \quad ,$$

to be compared with the value 7.4 of ref./c/. The S_1 value is much higher than predicted by conventional optical model calculations, but in good agreement with the results of an optical potential characterized by the introduction of an imaginary isospin term /d/.
This work was presented at the 1979 Knoxville Conference on "Neutron Cross Sections and Technology". (ref. /a/)

/a/ C. Coceva, P. Giacobbe, M. Magnani, "Resonance Parameters of ^{96}Zr below 40 keV", Proceedings of the Int. Conf. on Nuclear Cross Sections and Technology, Knoxville (USA) October 1979.

/b/ A. Brusegan, F. Corvi, G. Rohr, C. Coceva, P. Giacobbe and M. Magnani, "Proceedings of the International Conference on Neutron Physics and Nuclear Data for Reactors and other Applied Purposes", Harwell, Sept. 1978, p. 706.

/c/ A.R. de L. Musgrove et al., AAEC/E415 (1977).

/d/ H. Tellier and C.M. Newstead, "Proceedings of the Third Conference on Neutron Cross Sections and Technology", Knoxville 1971, p. 680.

1.3 Shape Analysis of Neutron Transmission Resonances

P. GIACOBBE, M. MAGNANI

A new programme /a/ has been written for analysing time-of-flight neutron transmission spectra of non-fissile nuclei in the region of resolved resonances by means of an iterative least-square procedure. It was conceived with the following characteristics.

1) The structure of the programme is partly independent of the particular formalism used or cross-section description. The only limitation is that Doppler broadening may be treated by means of the well-known Ψ and Φ functions.
2) Resolution functions of any shape can be taken into account, in particular shew shapes such as those arising from the moderation of the fast neutron burst produced by a charged-particle accelerator.
3) The programme can exploit "a priori" information on the parameters, introduced as constraints in the fitting process.
4) Tle least-square procedure is able to obtain information on the fitted parameters taking into account simultaneously several transmission spectra of the same resonances corresponding to different sample thicknesses or isotopic enrichments.

/a/ P. Giacobbe, M. Magnani, "Shape Analysis of Neutron Transmission Spectra - A Computer Code", CNEN Rep. RT/FI(79)17 and NEANDC(E)208"L".

1.4 ^{100}Ru and ^{102}Ru Spectroscopy by means of Low-Energy γ-Rays from Resonance Neutron Capture

C. COCEVA, P. GIACOBBE, G. VALLONE(°)

A measurement of resonance gamma spectra in the low-energy gamma range (from 390 to 1900 keV) obtained from resonance neutron capture in a natural Ru sample was performed on the 13 m flight path

(°) Istituto di Fisica dell'Università di Bologna

of the Geel linear accelerator, with the aim of obtaining spectroscopic information on the low-excitation spectrum of the ^{100}Ru and ^{103}Ru isotopes, and in particular on the spin values. The method used is described in ref./a/.

The excitation spectra of these nuclei display a typical vibrational pattern. Existing spectroscopic information are mainly based on β-decay studies and on thermal neutron capture experiments, but some pieces of information come also from high - and low-energy gamma ray studies from resonant neutron capture by Rimawi et al./b/.

The selected time-of-flight intervals correspond to the 10.05, 25.22, 57.11 and 81.62 eV ^{99}Ru resonances and to the 15.9, 42.28, 52.13, 61.81, 66.82, 112.5 eV ^{101}Ru resonances, besides the peak at 198 eV due to overlapping of two resonances of the two isotopes. The resonance spin assignments given in the literature were easily confirmed by observing the relative intensities of some typical gamma peaks in the single spectra.

Subsidiary measurements of the gamma-activity peaks of ^{137}Cs and ^{60}Co were used for energy calibration and pile-up determination. The spectra and the complete results of the analysis are expected within few months.

/a/ C. Coceva, P. Giacobbe, F. Corvi and M. Stefanon, "Nucl. Phys. A218(1974)61

/b/ K. Rimawi et al., Phys. Rev. C9(1974)1978

1.5 Statistical Analysis of Neutron Resonance Parameters

M. STEFANON

A numerical method was worked out /a/ exploiting the known statistical properties of resonance parameters to obtain estimates of level density and average reduced neutron widths from an experimental set of resonance parameters. Suggestions are given for applications to available data and for a correct use of the computer code CAVE (work in course of publication in Nucl. Inst. and Meth.).

A possible extension of the analysis, including the authomatic fitting of a "diffuse" observability yhreshold, was also studied and the

corresponding Maximum Likelihood problem was stated.
However, for this kind of analysis, many limitations are foreseen in practical applications.
(M. Stefanon, Specialists' Meeting on Neutron Cross-Section of Fission Product Nuclei, NEANDC, Bologna 1979).

/a/ Proc. Spec. Meeting on Neutron Cross Sections of Fission Product Nuclei - Bologna, Dec. 12-14, 1979 - NEANDC(E)209"L".

1.6 Effect of Quasi-Conserved Quantum Numbers on Statistical Properties of Resonance Parameters

M. STEFANON

The effect of approximate symmetries on the statistical properties of resonance parameters was faced by Montecarlo diagonalisation of random matrices, making very simple assumptions about the coupling matrix elements. The main aim of this work is to describe how fast the usual statistical properties (Porter-Thomas law, Wigner repulsion etc..) are reached by increasing mixing and then to help in giving a physical meaning to experimental deviations from a complete statisstical behaviour. Very preliminary results were obtained. The work is in progress.

1.7 Investigation of Giant E3 Resonances by (N,Y) Reactions

F. FABBRI, R. GUIDOTTI(°), F. SAPORETTI

Effects related to the presence of giant E3 resonances are investigated by nucleon radiative capture according to the direct-semidirect model. The γ-ray angular distributions from the $^{208}Pb(N,\gamma_o)$ reactions are calculated in the energy region above the giant dipole resonance and the influence of the E1-E3 and E2-E3 interferences is discussed.

(°) Facoltà di Ingegneria dell'Università di Bologna

The results (see ref./a/) provide indications of an appreciable effect on the 90° photon emission when a collective isovector E3 excitation is present (see, e.g., fig. 1)

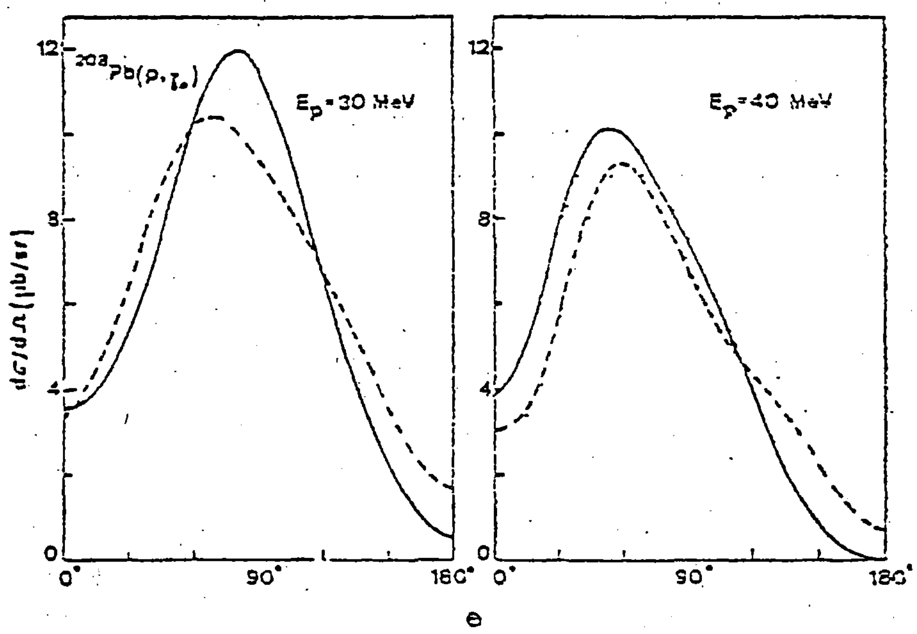


Fig. 1. Angular distributions of γ-rays emitted from capture of 30 MeV and 40 MeV protons to the $1h_{9/2}$ ground state of ^{209}Bi. E1 + E2 (dashed line), E1 + E2 + E3 (continuous line).

/a/ F. Saporetti et al., "Investigation of Giant E3 Resonances by (N,γ) Reactions", Nucl. Phys. A321(1979)354.

1.8 Polarized Nucleon Radiative Capture in Giant Multipole Resonance Study

F. FABBRI, R. GUIDOTTI(°), F. SAPORETTI

An extension of the direct-semidirect model to calculate the γ-ray angular distributions for polarized nucleon radiative capture, is presented. The analysing power for capture in lead-208 is investigated in the energy range above the giant dipole resonance. It is found that the polarized capture appears to be quite sensitive to radiation other than E1 (see, e.g. fig. 2). In particular, proton calculations indicate appreciable polarization effects on the γ-ray

---

(°) Facoltà di Ingegneria dell'Università di Bologna

emission at (90°, 20 MeV) and (120°, 30 MeV) arising from capture proceeding via giant isovector E2 and E3 resonance states, respectively. Some results of polarized neutron capture, which provide clearer information on the presence of the E2 and E3 collectivities, are also discussed in ref./a/.

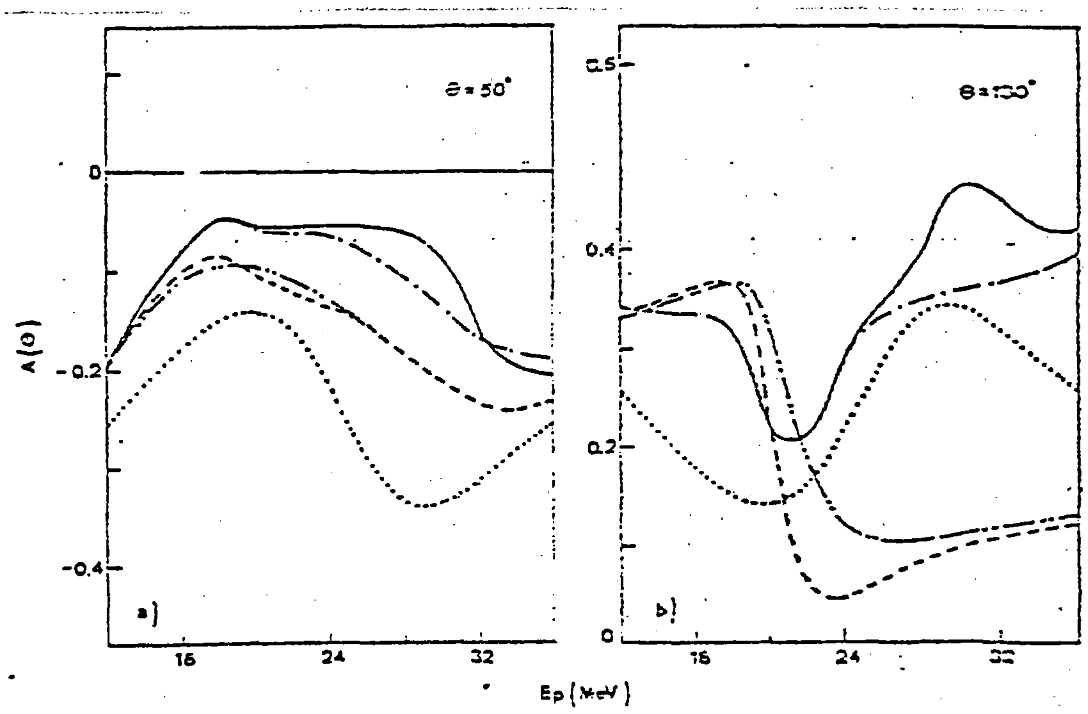


Fig. 2. Energy dependence of the analysing power at θ = 50° and θ = 130° for the ^{208}Pb($\vec{p}$, γ_1) reaction. E1 only (dotted line); E1 + E2^d (double-dot-dashed); E1 + E2 (dashed); E1 + E2 + E3^d (dot-dashed); E1 + E2 + E3 (continuous).

/a/ F. Saporetti and R. Guidotti, "Polarized Nucleon Radiative Capture in Giant Multipole Resonance Study",Nucl. Phys. A330 (1979)53.

1.9 Differential Cross-Sections for Radiative Capture of Energetic Protons by ^{110}Cd and ^{115}In

F. FABBRI, R. GUIDOTTI(°), G. LONGO, F. SAPORETTI

Spectra of high energy photons following the radiative capture of 8-22 MeV protons in ^{110}Cd and ^{111}In, are measured. The (p,γ) differential cross sections at 90° with respect to the beam axis is deduced from

(°) Facoltà di Ingegneria dell'Università di Bologna

the integration of measured spectra. The photon angular distribution is measured for the ^{110}Cd(p,γ_0) reaction, too, at 13 MeV incident energy. Satisfactory agreement between theory and experiment is obtained by using the direct-semidirect model for dipole and quadrupole fast nucleon radiative capture. (See, e.g., fig. 3). Results are published in /a/.

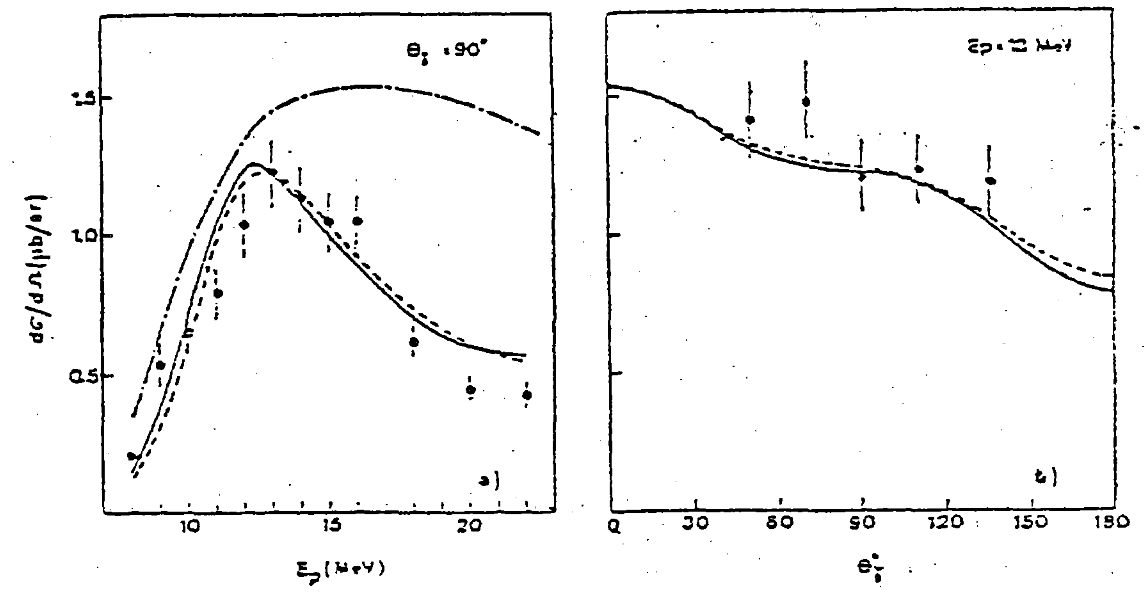


Fig.3 (a) Comparison between theory and experiment for the ^{110}Cd(p, γ_0) differential cross section at $\theta = 90°$. The dot-dashed curve is calculated for E2 capture going through the direct process alone ($S = 1$). (b) Comparison between theory and experiment for the ^{110}Cd(p, γ_0) differential cross section at $E_p = 13$ MeV. In (a) and (b) the solid and dashed curves correspond to a complex and real interaction respectively ($S = 0.5$) by taking into account direct as well as semidirect isoscalar and isovector E2 contributions.

/a/ F. Rigaud et al., "Differential Cross Sections for Radiative Capture of Energetic Protons by ^{110}Cd and ^{115}In", Nucl. Phys. A326(1979)26.

1.10 Angular Distributions in Photonucleon and Nucleon Radiative Capture Reactions

F. FABBRI, G. LONGO

Angular distributions in photonucleon and nucleon radiative capture reactions have been investigated by means of the direct-semidirect model. In ref./a/ two attempts have been made in order to bring theory into better agreement with experiment:

1) higher multipole contributions to the capture process have been taken into account; 2) the coupling interaction is given the same form and strengths as those of the optical potential adopted for calculating the incident wave functions. Diversely from what has been done up to now, no free parameters have been used to adjust calculated curves to angular-distribution experimental data. A comparison between experimental points and calculated curves for the $^{208}Pb(p,\gamma_o,\gamma_1)$ reaction (see fig. 4) shows that the inclusion of octupole contributions (continuous line in the figure) helps to come close to the data. Calculated curves for the $^{209}Bi(\gamma,n_o)$ reaction, plotted in fig. 5, satisfactorily reproduce the measured points. These results indicate that the introduction of higher-order multipoles and the choice of an appropriate coupling interaction allow reproduction of (p,γ) and (γ,n) experimental data for lead bismuth without recourse to free parameters.

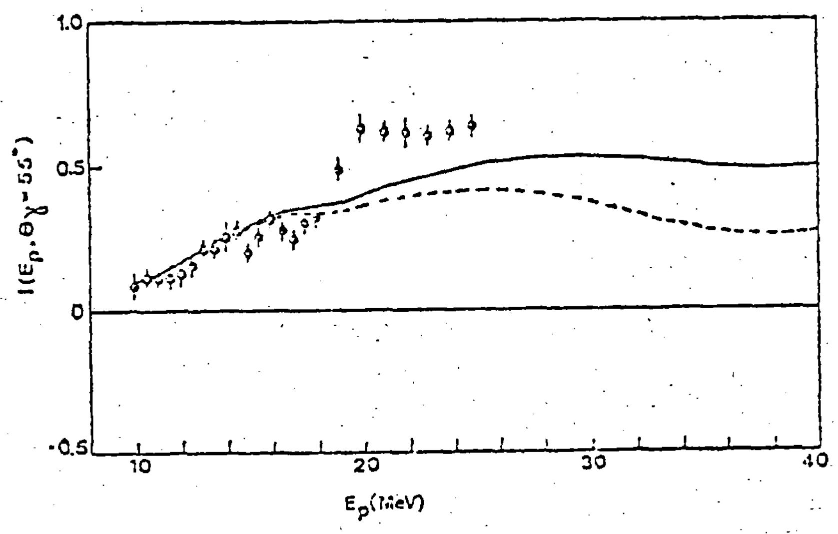


Fig. 4 - Comparison between experimental points and calculated curves for the $^{208}Pb(p,\gamma_o\gamma_1)$ reaction

/a/ G. Longo, F. Fabbri, "Angular Distributions in Photonucleon and Nucleon Radiative Capture Reactions" Phys. Lett. 84B (1979) 285.

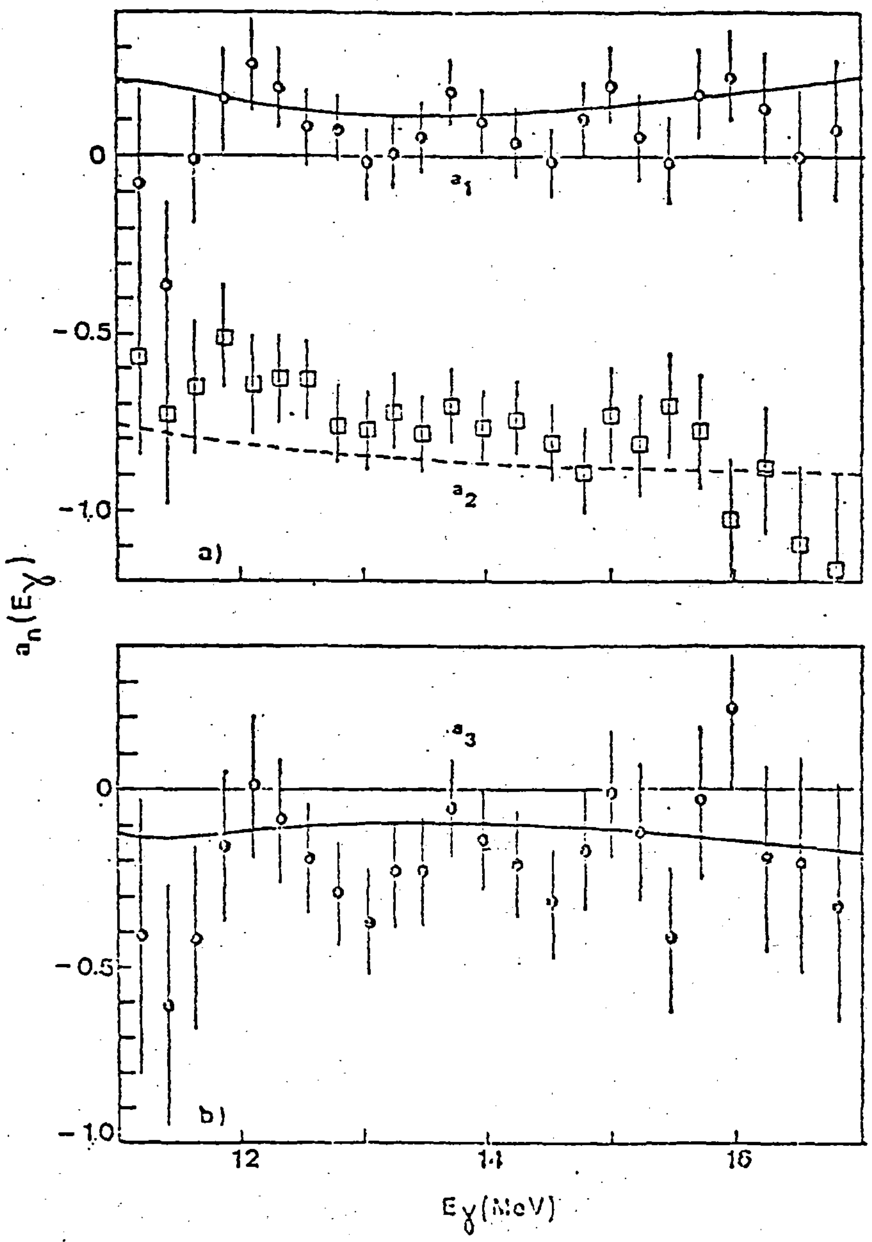


Fig. 5 – Comparison between experimental points and calculated curves for the $^{208}Pb(p,\gamma_o\gamma_1)$ reaction

1.11 Nuclear Level Densities and Average Radiative Widths

V. BENZI, G. MAINO(°), E. MENAPACE, A. VENTURA

An extensive investigation of s-wave neutron resonance spacings $\bar{D}$ and average radiative widths $\bar{\Gamma}_\gamma$ was carried out in the mass range 40<A<250. Empirical $\bar{D}$ values were obtained through "missing level estimator" method (G.A. Keyworth, M.S. Moore and J.D. Moses in NEANDC-US-199/L) and a "maximum likelihood" method (C. Coceva, M. Stefanon - Nucl. Ph. A135(1979) and M. Stefanon to be published on Nucl. Instr. Meth.). These results were reproduced by microscopic calculations in the frame of the superfluid model in BCS approximation, including collective effects and pairing interaction in approximated way. Thermodynamic temperature T values at excitation energy equal to the neutron binding energy obtained in these calculations were utilized in extimating average radiative widths $\bar{\Gamma}_\gamma$ though the "black-body" formula (by V. Benzi - 78 Harwell Conf. p. 288). The comparison between empirical and theoretical values is shown in figs. 6 and 7 and the detailed results in the mass range $40\leq A\leq 250$ were published in ref./a/ and /b/. A study for a more rigorous treatment of odd nucleon systems with a proper "blocking" procedure has been initiated.

(°) Guest researcher

/a/ V. Benzi, G. Maino, E. Menapace, A. Ventura, "BCS Level Density Calculations and Consistent Estimate of Radiative Widths by means of a Thermodynamic Model", Proc. Spec. Meet. on Neutron Cross Sections of Fission Product Nuclei, Bologna 1979, NEANDC(E)209"L".

/b/ G. Maino, E. Menapace, A. Ventura, "On the Level Spacing of Statically Deformed Nuclei", Nuovo Cimento 50A, 1 (1979).

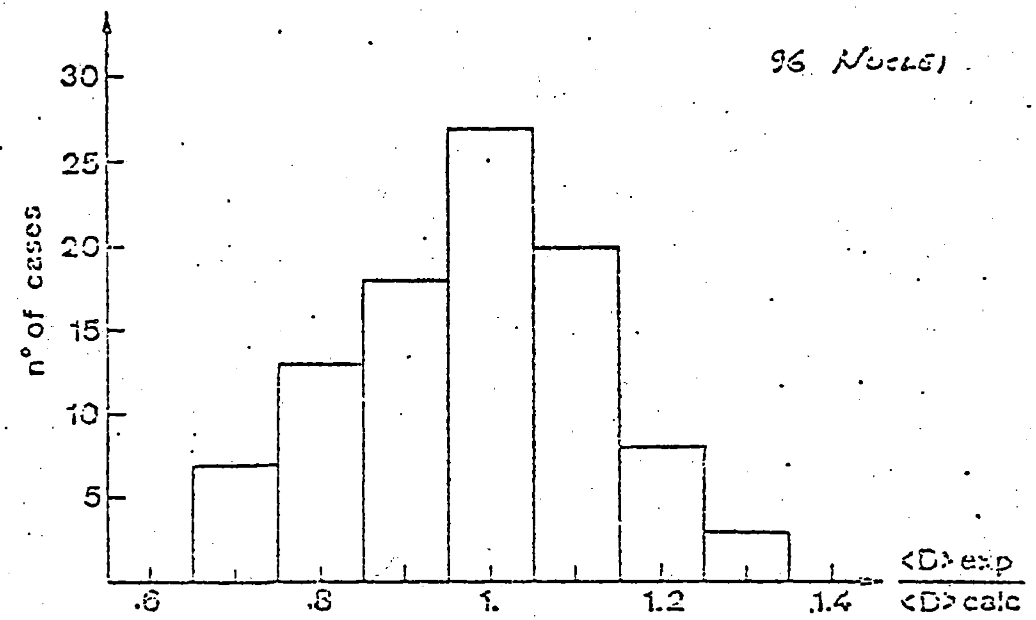

96 Nuclei.
n° of cases
30
25
20
15
10
5
.6
.8
1.
1.2
1.4
<D> exp
<D> calc

Fig. 6

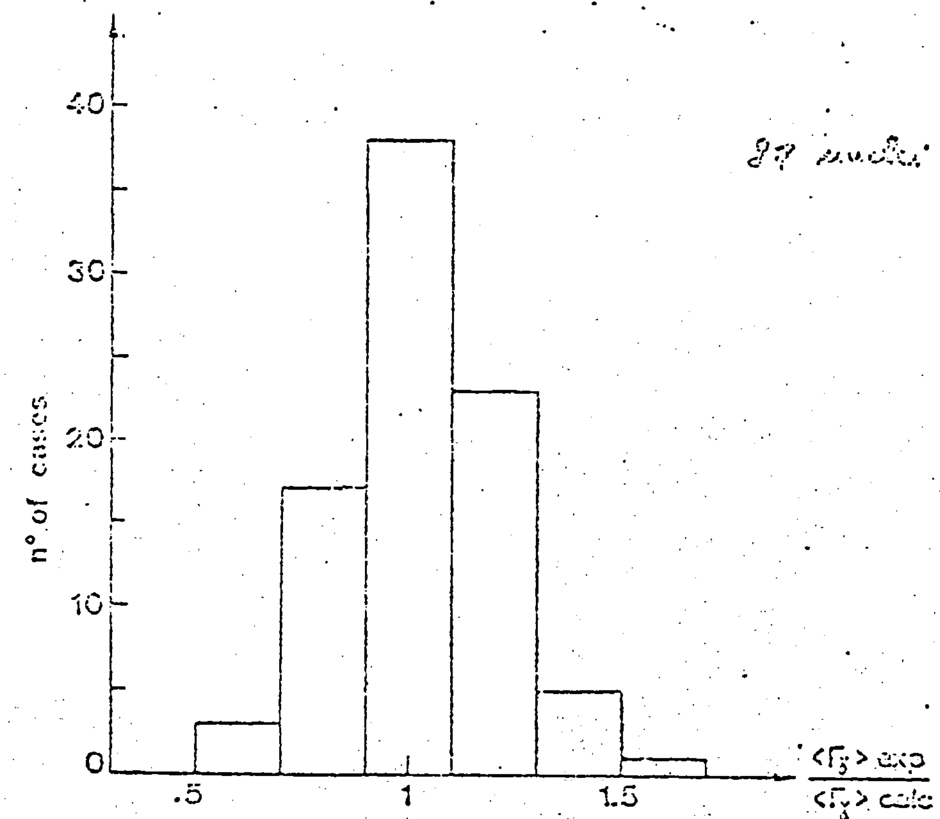

87 nuclei
n° of cases
40
30
20
10
0
.5
1
1.5
<Γγ> exp
<Γγ> calc

Fig. 7

1.12 Neutron Induced Fission: (n,f) and (n,n'f) Reactions

G. MAINO(°), E. MENAPACE, M. MOTTA, A. VENTURA

First and second chance contributions, (n,f) and (n,n'f), to neutron induced fission cross sections were studied up to E_n=13 MeV for the target nucleus ^{241}Am as an example of application. Extensive Hauser-Feshbach calculations, corrected for statistical width fluctuations by the method of Tepel, Hoffman and Weidenmüller, were performed to obtain the cross sections "via" compound nucleus for the first-chance fission and for the competing channels (radiative capture, elastic and total inelastic, for which the separate components (n,2n), (n,n'γ) and (n,n'f) were calculated).
The compound nucleus formation cross section was obtained consistently with optical and pre-equilibrium model calculations, performed by means of the JUPITOR(T. Tamura, Rev. Mod. Phys. 37, 679 (1965)) and ADAPE(F. Fabbri and L. Zuffi, CNEN Rep. RT/FI(1969)7) codes and of the PRODE code (E. Menapace and M. Vaccari) , respectively. In order to calculate $\sigma_{n,2n}$, $\sigma_{n'\gamma}$ and $\sigma_{n,n'f}$ for the compound nucleus ^{242}Am , the branching ratios P_n, P_γ and P_f for neutron emission, γ-decay and fission, were determined as functions of excitation energy, spin and parity of the decaying nucleus ^{241}Am. The so calculated P_f is shown in fig. 8, in comparison with the experimental values by Britt and coworkers (A. Gavron, H.C. Britt, E. Konecuy, J. Weber and J.B. Wilhelmy, Phys. Rev. C13, 2374(1976)) . Experimental and calculated fission cross sections of ^{241}Am are shown in fig. 9.
A simplified semiempirical approach to calculate first and second chance fission cross sections was also proposed and applied to ^{235}U and ^{239}Pu, giving results in qualitative agreement with the more general and complete procedure developed for ^{241}Am. To calculate the (n,2n) cross section, competing to (n,n'f) process, the pre-equilibrium component was estimated by the PRODE code and subtracted to the experimental data (see fig.10).
Results of this work were presented at the Knoxville Conference on Nuclear Cross Sections and Technology, in October 1979.

(°) Guest Researcher

/a/ G. Maino, E. Menapace, M. Motta, A. Ventura, "First and Second Chance Fission Calculations for Actinides and Related Topics", Contribution to the Conference on Neutron Cross Sections and Technology, Knoxville, October 1979 (abstract published in Bull. Am. Phys. Soc., 24, 876 (1979).

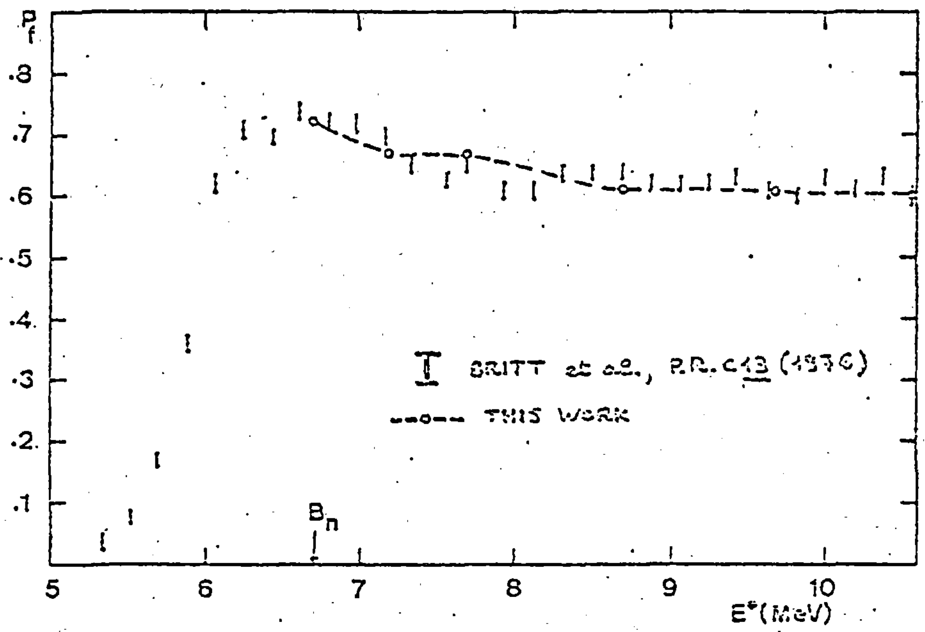


fig. 8

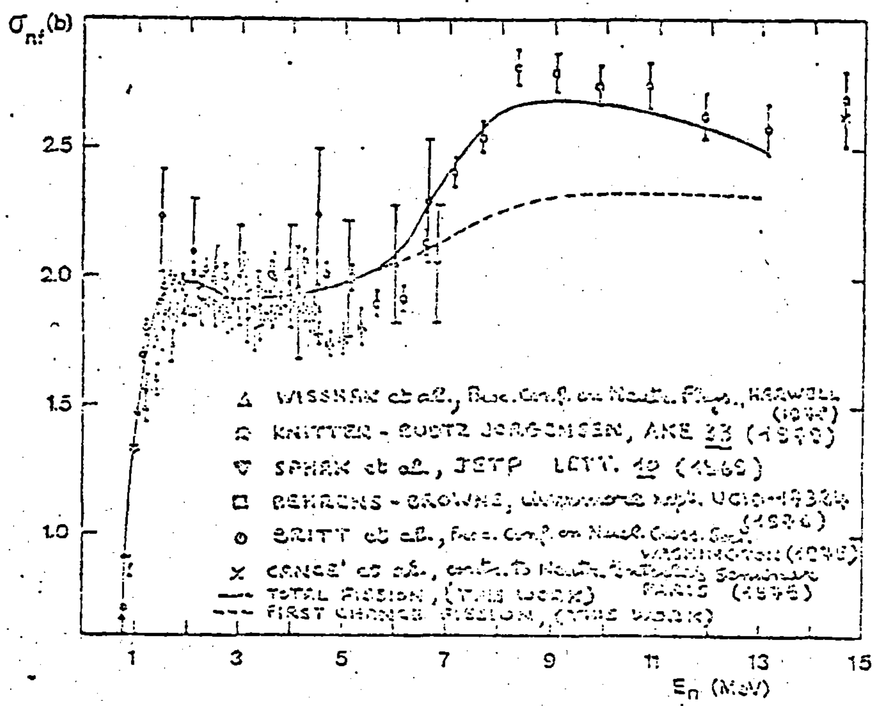


fig. 9

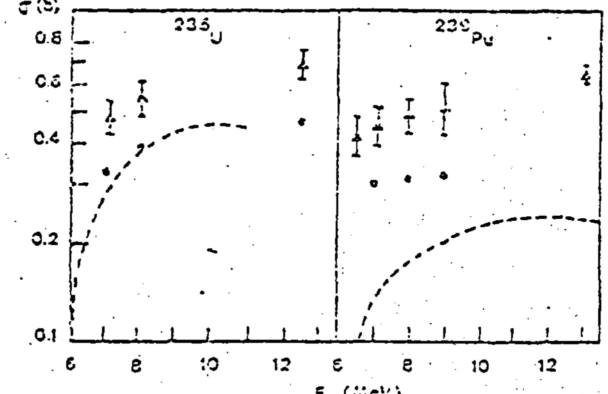


fig. 10

σ_{n2n}:
MATHER et al., rep. AWRE-0-82/72, ALDERMASTON (1972)
--- ENDF/B IV
o THIS WORK

1.13 Formalisms for Fission Cross Section Calculations in Resolved Resonance Region

T. MARTINELLI, E. MENAPACE, M. MOTTA

The application of the nuclear data to reactor calculations requires the most reliable group cross sections, obtained with the correct temperature dependence in the resolved resonance region, and the proper formalism for the fission reaction with 2-3 open channels. Both problems were studied: for the first one, a program was set up, which performs temperature Doppler broadening through Kapur-Peierls parameters, obtained by transformation of Reich-Moore parameters, more usually measured (in cooperation with N. Davidovitch, CNEN - Casaccia) .

About the second problem, a general equivalence between a multilevel many-channels formalism and Reich-Moore formulae was attempted. This work is still in progress.

1.14 Equilibrium and Preequilibrium Reaction Mechanisms (ref./a/)

J.M. AKKERMANS(°), H. GRUPPELAAR(°), G. REFFO

An alternative mathematical formulation is presented for the generalized master equation of the excitation model, introduced by Mantzouranis et al. to describe preequilibrium effects in angular distributions of emitted particles in nuclear reactions. The exciton model proposed in this paper includes internal transition with An=2, 0, -2, and describes both the preequilibrium and the equilibrium stage of the reaction process.
A simple, but exact formula is given to calculate mean lifetimes of exciton states and their Legendre coefficients, from which double differential cross sections can be easily calculated.
These mathematical improvements of the generalized exciton model greatly facilitate a systematical comparison with experimental data. In this paper the neutron inelastic scattering data for 34 elements measured by Hermsdorf et al. at 14.6 MeV were used for such inter-comparison. The results show underestimation of angular distributions at backward angles. However, a good overall fit of all angular distributions is obtained by adjustment of only two global parameters. It is concluded that further study with regard to the physics of the model is required. Some local variations in the angular distribution coefficients as a function of the mass number might be ascribed to level-density effects. Altrhough it appeared that the presently adopted formulae and parameters in exciton model calculation are not adequate to give detailed predictions of the energy and angular distributions, meaningful improvements were obtained by variation of final-state parameters. Finally, some attention was devoted to the unification of the exciton and Hauser-Feshbach models. By introducing a proper definition of "equilibrium" emission it is shown that consistent results are obtained for neutron emission spectra calculated with the two models.

(°) Netherlands Energy Research Foundation (ECN), Petten (The Netherlands)

/a/ J.M. Akkermans, H. Gruppelaar, G. Reffo, "Angular Distributions in Preequilibrium Neutron Emission", accepted by Phys. Rev. C.

1.15 Nuclear Model Code Development

F. FABBRI, G. REFFO

A code "PENELOPE" has been developed for multiple cascading emission calculations.
Compound nucleus and collective direct reaction mechanisms are considered.
Optical model transmission coefficients for particles which participate into the compound nucleus processes only are internally calculated according to a local spherical optical model. In addition coupled channels calculations can be optionally required in order to account for the direct coupling of entrance channels to target levels; the output is a consistent set of collective direct and compound nucleus contributions. Angular momenta, parity and width fluctuation correction are correctly introduced.
Temporarily, where necessary, the fission competition is simulated by means of Newton's iterative procedure starting from the theoretical or experimental knowledge of $\sigma_{n,f}(E)$.
Integrated cross section and energy spectra for any particle and/or γ-ray emitted in the cascade can be obtained as well as the complete γ-ray spectra following incident particle absorption or concluding a multiple particle emission.
The cross-section for isomeric state excitation can be calculated.
Any involved parameter can be inputted or taken from internal libraries. In fact, in order to reduce the input procedure and to avoid error possibilities standard data sets for all involved parameters have been previously determined based on experimental information and on careful model systematics. Namely:

- Optical model parameters can be chosen from a wide internal library by means of acronism.
- Level density parameter stored are taken from local systematics based on recent resonance scheme analysis.
- Photo absorpion giant resonance parameters are internally calculated according to the hydrodinamical model as given in CNEN Report 78(11)RT/FI.
- Level schemes are taken from an internal library of evaluated level schemes. Knowledge of the experimental branching ratios of the levels is very important in the calculation of isomeric state

excitation and γ-ray spectra. Where branching ratios are not available Brink-Axel model for the determination γ-ray transition probability is used.
The code "POLIFEMO" is a special reduced version of "PENELOPE" code to be used for binary reactions only. The difference with respect to PENELOPE is that in addition to spectra it can give also the angular distribution of the emitted particles according to each of the reaction mechanisms considered.

1.16 Cross Sections Calculations
F. FABBRI, G. REFFO

1) Neutron Capture Cross Sections of Kr, Se, Br, isotopes
B. LEUGERS(°), F. KAEPPELER(°), F. FABBRI, G. REFFO

A joint project for keV neutron capture measurements (performed at KFK Karlsruhe) and model calculation (performed at CNEN Bologna) is underway.
The following isotopes have been considered Kr-78, Kr-80, Kr-81, Kr-82, Kr-83, Kr-84, Kr-85, Se-76, Se-78, Se-79, Se-80, Br-79, Br-81.

2) S-Process Branch at Se-79
B. LEUGERS, F. KAEPPELER(°)., F. FABBRI, G. REFFO

From the careful measurements and model calculations in the region around Se-79, the determination of the s-process temperature has been attempted through certain peculiarities of the s-process branch at Se-79.

(°) Kernforschungszentrum Karlsruhe GmbH, Institut für Angewandte Kernphysik - Karlsruhe F.R. Germany.

3) Measurements and Model Calculations for (n,γ) and $(n,2n)$ Cross Sections of the Isotopes

F. FABBRI, G. REFFO, M. HERMAN(°), A. MARCINKOWSKI(°)

The cross section for $(n,2n)$ and (n,γ) processes in Ir-191 and Ir-193 have been measured in the energy range $(13\div18)$ MeV and $(.5\div1.3)$ MeV respectively. Cross section calculations have been done in the range 2 keV, 20 MeV. Important preequilibrium contributions appear at incident energies above 15 MeV.

1.17 Model Parameterization (refs./a/ and /b/)

F. FABBRI, G. REFFO

1) Level Density Parameters

The problem of level density has been considered from the application point of view. A phenomenological approach starting from the work of Gilbert and Cameron has been developed where all involved parameters are known to behave according to rather well determined systematic trends which lend themselves to interpolation where experimental information is not available.

2) Radiative Width Estimates

Radiative widths estimates according to Brink-Axel model have been shown to agree with experimental data provided correct values of level density and of the photo-absorption giant resonance parameters are available. In addition it has been shown that according to such a model no systematic behaviour should be expected for the radiative width of levels of given spin and parity.

(°) Institute for Nuclear Research - Ul. Hoza-Warsaw, Poland.

/a/ G. Reffo, "Phenomenological Approach to Level Density", Invited talk at the Int. Conf. on the Theory and Applications of Moment Methods in Many Fermion Systems", Ames Iowa, USA, September 10-14, 1979.

/b/ G. Reffo, "Phenomenological and Theoretical Basis for the Parameterization of Nuclear Models Used in Reactor Data Evaluation", Invited talk at the NEANDC Specialists' Meeting on Neutron Cross Sections of Fission Product Nuclei, Bologna, Italy, December 12-14, 1979.

1.18 Evaluation of Fission Product Nuclei (Neutron Data)

F. FABBRI, E. MENAPACE, M. MOTTA, G.C. PANINI, G. REFFO, M. VACCARI, A. VENTURA

The activity for the evaluation of fission products (FP) continued in 1979. The revised evaluation, in the framework of the CNEN-CEA agreement on Fast Reactor Project, of Pd-105, Nd-143, Sm-149, Sm-151 was extended to the unresolved and continuum regions. New experimental microscopic data from the literature were taken into account in addition to the indication arising from the analysis of integral experiments performed at Cadarache and Petten (STEAK). The revised evaluations are available in ENDF/B format and a description was published /a/.

/a/ M. Vaccari, "Tables of Neutron Resonance Parameters and Multigroup Cross Sections for Pd-105, Nd-143, Sm-149, Sm-151 (1979) Evaluation)", CNEN Report RT/FI(80)1.

1.19 Evaluation of Actinides (Neutron Data)

G. MAINO(°), T. MARTINELLI, E. MENAPACE, M. MOTTA, M. VACCARI, A. VENTURA

The evaluations started in 1978 within the framework of a CNEN-IAEA research agreement (^{241}Pu, ^{242}Pu, ^{243}Am and ^{242}Cm in the resonance region) and a CNEN-CEA-GFK collaboration (^{241}Am, from thermal neutron energies up to 13 MeV) were completed. The results are described in /a/, /b/, /c/, /d/.

^{241}Pu

Neutron cross section were evaluated from thermal energies up to 40 keV. The resolved resonances range from 0.26 to 104 eV, and were treated with the Reich-Moore formalism, taking into account the interferential effects among resonances and the presence of two open channels for fission reaction.
The unresolved resonance region, from 104 eV to 40 keV, was evaluated by means of a statistical model, with the average parameters of table 1.
Figs. 11 and 12 show the calculated capture and fission cross sections, respectively, in comparison with experimental values of L.W. Weston and J.H. Todd (N.S.E. 65, 454(1978)).

TABLE 1. Average Parameters for the Unresolved Region

Nuclide	^{241}Pu	^{242}Pu	^{242}Cm	^{241}Am
$\overline{D}$(eV)	0.83	15	16	0.58
S_0(10^{-4}units)	1.18	1.15	(0.64)	0.95
S_1(10^{-4}units)	2.2	2.7	2.3	2.5
S_2(10^{-4}units)	3.4	-	3.6	0.94
$<\Gamma_\gamma>$ (MeV)	36	25	38	44
$<\Gamma_f>$ (MeV)	391(ℓ=0)	(see text)	-	0.23(ℓ=0)

(°) Guest researcher

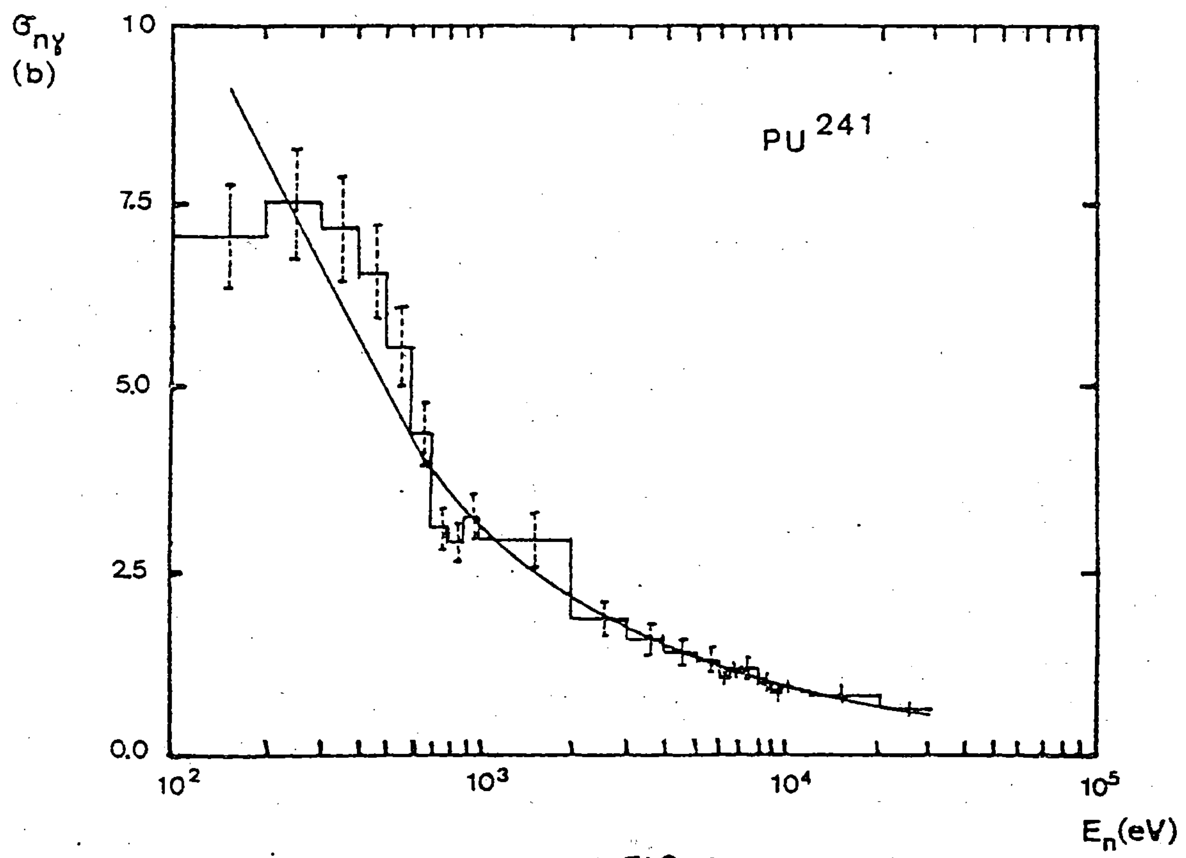

$\sigma_{n\gamma}$ (b)
10
7.5
5.0
2.5
0.0
PU 241
10^2
10^3
10^4
10^5
E_n(eV)

FIG. 11

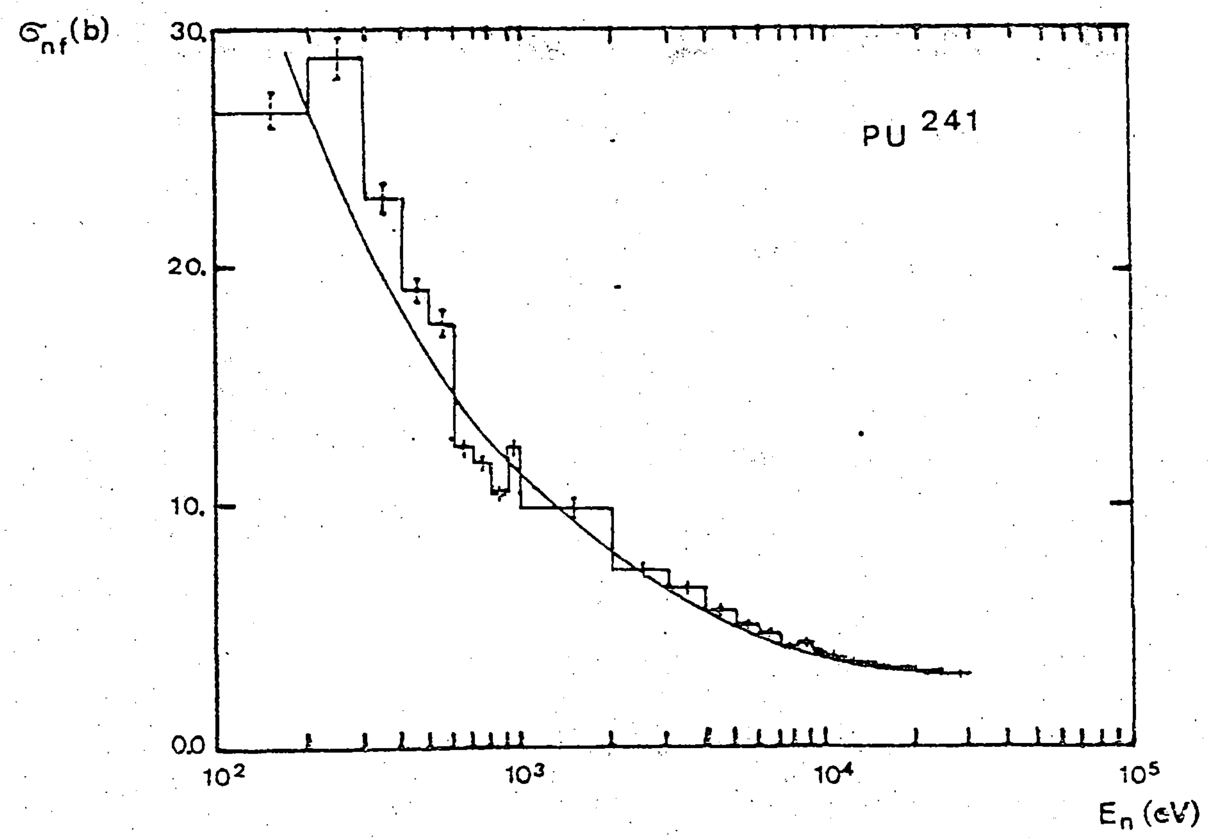

σ_{nf}(b)
30.
20.
10.
0.0
PU 241
10^2
10^3
10^4
10^5
E_n (eV)

FIG. 12

^{242}Pu

This evaluation covers an energy range from 0 to 1300 eV, where experimental resolved resonances are given. Average parameters for statistical calculations in the unresolved region were also deduced (see table 1) . In the studied energy range, the fission cross section exhibits two resonance clusters which are due to a weak coupling of class II states (i.e. in the 1st and 2nd well of a two-humped barrier). The state of data analysis is summarized in table II and discussed in ref./a/.

PU - 242 Table II

Fission Cluster Parameters and Deduced Barrier Heights

E_o (eV)	Γ_n (meV)	$\Gamma\uparrow$ (meV)	$\Gamma\downarrow$ (meV)	V_A (MeV)	V_B (MeV)	Ref.
475	0.4 ± 0.2	$(1.6\pm0.9)10^4$	1.4 ± 0.8	5.8	5.18	22
762	3.3 ± 1.5	$(1.2\pm0.7)10^4$	37 ± 22	5.8	5.18	22
				6.05 ± 0.2	5.6	4
475		1.4 ± 1	$(1.4\pm2)10^4$			13
762(a)		87 ± 5	$(1.5\pm.06)10^4$			13
762(b)		42 ± 3	$(1.57\pm.02)10^4$			13
				5.14	5.8	14

(a) Cross structure analysis

(b) Fine structure analysis

^{242}Cm

Neutron cross sections were evaluated up to the first excited level ($E_n \sim$ 45 keV); the resolved resonances range from 0 to 265 eV; above this energy a statistical description was given by means of average parameters (table I). As conclusion, new experiments are recommended, in order to determine unknown, or poorly known, microscopic data of fundamental importance for reactor applications, namely thermal fission and capture cross sections one in the statistical region, the subthreshold fission structure.

^{241}Am

The resolved resonance region ranges from thermal energy up to 150 eV, while the unresolved region from 150 eV to 10 keV. For the analysis of the last one, average parameters of table I were chosen. Fig. 13 shows the calculated neutron absorption cross section in the unresolved resonance region, in comparison with experimental data (a: L.W. Weston and J.H. Todd, NSE 61, 356(1976); b: D.B. Gayther and B.W. Thomas, Conf. on Neutron Phys., Kiev, 3, 3 (1977). A value $\bar{\nu}$ = 3.15 of the average number of neutrons per fission at thermal energy, was recommended.

/a/ E. Menapace, M. Motta, A. Ventura, "Pu-242 Evaluation in Resolved Resonance Region", "Proc. Spec. Meet. on Nucl. Data of Pu and Am Isot. for React. Appl.", Brookhaven, Nov. 20-21, 1978.

/b/ E. Menapace, A. Montaguti, M. Motta, A. Ventura, "Evaluation of Cm-242 in the Resonance Region", CNEN Report RT/FI(79)2.

/c/ E. Menapace, M. Motta, A. Ventura, "Evaluation of Pu-241 Neutron Cross Sections in the Resonance Region", CNEN Report RT/FI(79)5.

/d/ G. Maino, E. Menapace, M. Motta, A. Ventura, "Am-241 Neutron Cross Sections in the Resonance Region", CNEN Report RT/FI(79)6.

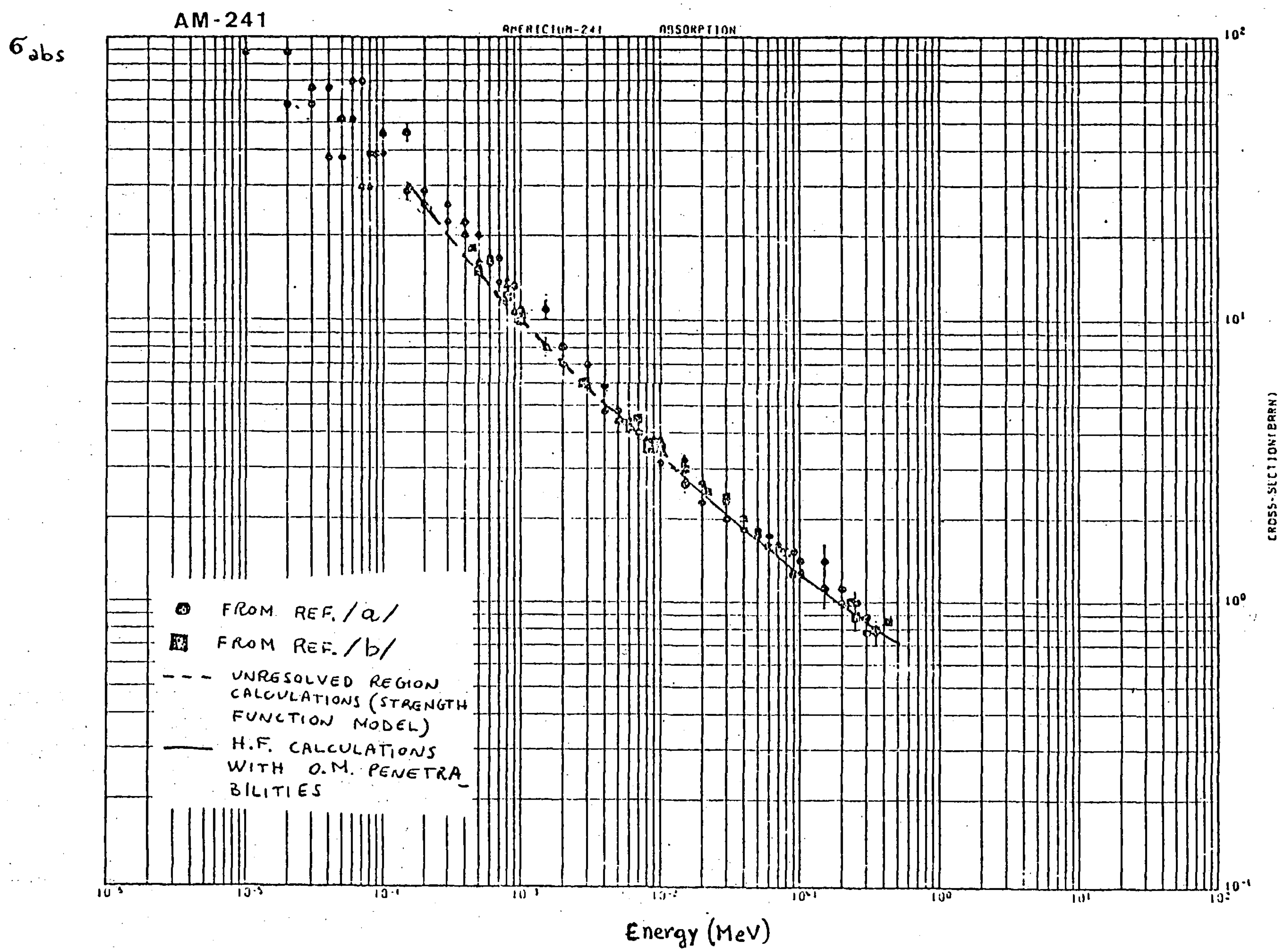

σ_{abs}
AM-241
AMERICIUM-241 ABSORPTION
CROSS-SECTION(BARN)
FROM REF. /a/
FROM REF. /b/
UNRESOLVED REGION CALCULATIONS (STRENGTH FUNCTION MODEL)
H.F. CALCULATIONS WITH O.M. PENETRABILITIES
Energy (MeV)

Fig. 13

1.21 Nuclear Data Library

G.C. PANINI, M. VACCARI

Within the framework of the Nuclear Data Library, an high level of automated handling has been reached.
New data acquired during 1979 include:

a) Neutron data of Fission Products originated at Petten in KEDAK format.
b) Evaluated data of Cm-242 and Cm-245 from JENDL in ENDF/B format.
c) A tape containing all resonance data listed in BNL-325.
d) The LLL ENDL-78 88 materials.
e) Neutron data evaluation of four Fission Products Pd-105, Nd-143, Sm-149, Sm-151 and resonance parameters of five actinides originated at Bologna.
f) A number of ENDF/B-V materials: H, ^{10}B, ^{12}C, ^{197}Au, plus Actinides(including ^{235}U), Standard,Dosimetry and FP files.

1.22 Multigroup Cross Sections

G.C. PANINI, M. VACCARI

The following multigroup set calculations were carried out:

a) Cross sections of four FP nuclides in Carnaval format in the CEA/CNEN agreement framework /a/.
b) Structural materials plus some actinides, also in Carnaval format, for flux calculation purposes.
c) A new MC-2 library through ETOE.
d) A 620-group SAND-2 scheme of some materials for activation calculations.

The multiformat multigroup calculation code FOURACES has been rewritten with:

1) dinamically allocated structure;
2) new algorithm in the resonance calculation;
3) increased precision in the computed results.

The modular System AMPX version 2 has been implemented in the computing facilities of CNEN. Two codes ISOTTA and CANCO, to be used as interface between MC-2/II and ANISN/CITATION) were also completed.

/a/ M. Vaccari, "Tables of Neutron Resonance Parameters and Multigroup Cross Sections from Bologna '79 Evaluation for Pd-105, Nd-143, Sm-149, Sm-151", CNEN Report RT/FI(80)1.

2. C.N.E.N. - DIVISIONE DI FISICA - LABORATORIO FISICA SPERIMENTALE DEI REATTORI - Via Mazzini, 2 - 40138 BOLOGNA (Italy)

2.1 Measurements of Structural Material Capture to U-235 Fission Rate Ratios in Intermediate Spectra (ref./a/)

P. AZZONI, A. SALOMONI
CNEN-Centro Studi e Ricerche "E. Clementel", Bologna, Italy
P.L. CHIODI, C. GIULIANI, R. MARVASI
AGIP NUCLEARE Nuclear Laboratories, Montecuccolino, Bologna, Italy

In order to contribute to improving knowledge on capture cross sections of Fe, Cr, Ni, Mo, Mn, Ti and Stainless Steel, an experimental program was undertaken by CNEN utilizing the RB2 Reactor at the AGIP Nucleare Montecuccolino Laboratories.
To obtain the integral capture cross sections of the structural materials two different techniques were used, nameli the "Null Reactivity Technique" and the "Reactivity Worth Technique".
By means of these, the structural material capture to U-235 fission rate ratios were evaluated and then compared with the theoretical results.
The measurements were carried out in an epithermal spectrum, in order to increase the neutron captures in the 1 keV - 100 keV energy range, where the uncertainties in the structural material capture cross sections are large.
By means of the "Null Reactivity Technique" one works in an infinite medium of near unit K_∞ and, consequently, the experimental results are more ready compared with theory. To achieve this the asymptotic spectrum of the medium was yielded in the central Test Zone of the Reactor. The difficulties related to heterogeneity effects were reduced by using quasi homogeneous media made up of materials in the form of microspheres ($\simeq$ 1 mm diameter) and the influence of the leakage was greatly reduced by flattening the neutron flux in the central Test Zone.
The "Reactivity Worth Technique" is a standard technique whose interpretation is difficult because of self shielding, elastic and non elastic scattering effects and few group one/two dimensional calculation method.

The measurements were carried out in two different configurations of the Fast Zone, without and with iron respectively, which give quite the same neutron spectrum at the Test Zone.
The comparison between experimental and theoretical results shows a systematic trend of ENDF/B IV calculated data to overestimate the experimental "Null Reactivity" results of some per cent (Table 1).
On the contrary, large discrepancies exist between experimental and the CARNAVAL IV calculated results with a systematic trend of the calculated data to underestimate the experimental results (Table 1).
The ENDF/B IV calculated values agree with the "Reactivity Worth" experimental results except for Mo and Cr (Table 2).

/a/ P. Azzoni et al., "Measurements of Structural Material Capture to U-235 Fission Rate Ratios in Intermediate and Fast Spectra", IAEA-SM-244/64, Aix-en-Provence, 24-28 September 1979.

TABLE I – Experimental and calculated values of the structural material capture cross section to U-235 fission cross section ratio $(\bar{\sigma}_c^i/\bar{\sigma}_f^{U5})_\infty$ (values multiplied by 10^3).

i	Atomic ratios of the infinite critical samples: N^C/N^{U-235}	N^i/N^C	Cross sections set	$\left(\frac{\bar{\sigma}_c^i}{\bar{\sigma}_f^{U5}}\right)_\infty = \frac{\int_E \sigma_c^i(E)\phi_\infty(E)dE}{\int_E \sigma_f^{U5}(E)\phi_\infty(E)dE}$ Fast zone without iron: exp.	Fast zone without iron: calc.	Fast zone without iron: (E-C)/C(%)	Fast zone with iron: exp.	Fast zone with iron: calc.	Fast zone with iron: (E-C)/C(%)
Iron	117.9	0.411	ENDF/B IV	3.60±0.32	3.78	-4.8±8.5	3.74±0.24	3.78	- 1.0±6.4
			CARNAVAL IV	3.46±0.32	2.62	32.1±12.2	3.56±0.24	2.62	35.9±9.3
	118.6	0.514	ENDF/B IV	3.62±0.27	3.65	-0.8±7.4	--	--	--
			CARNAVAL IV	3.59±0.27	2.54	41.3±10.6			
	112.0	0.823	ENDF/B IV	3.34±0.16	3.46	-3.5±4.6	--	--	--
			CARNAVAL IV	3.40±0.16	2.39	42.3±6.7			
Nickel	116.8	0.301	ENDF/B IV	6.93±0.41	7.34	-5.9±5.6	7.13±0.33	7.27	- 1.9±4.5
			CARNAVAL IV	7.28±0.40	6.31	15.4±6.3	7.39±0.33	6.34	16.6±5.1
Chromium	108.5	0.444	ENDF/B IV	4.54±0.33	5.07	-10.4±6.5	4.43±0.25	5.06	-12.4±4.9
			CARNAVAL IV	4.69±0.33	3.71	26.4±8.9	4.67±0.25	3.71	25.9±6.7
Stainless steel	118.1	0.308	ENDF/B IV	9.82±0.38	9.83	0.0±3.9	9.55±0.19	9.67	-1.2±2.0
	104.2	0.527	ENDF/B IV	9.15±0.25	9.34	-2.0±2.7	--	--	--

Table II - Experimental and calculated (ENDF/B IV) values of

$$\tilde{R}_i = \frac{\tilde{\sigma}_a^i}{\tilde{\sigma}_f^{U5}} = \frac{\int_E \sigma_a^i(E)\,\phi(E)\,\phi^t(E)\,dE}{\int_E \sigma_f^{U5}(E)\,\phi(E)\,\phi^t(E)\,dE}$$

	Fast Zone without Iron (+)		Fast Zone with Iron (++)	
i	Experim. x 10^3	$\frac{E-C}{C}$ (%)	Experim. x 10^3	$\frac{E-C}{C}$ (%)
B-10	2213±122	4.3±5.7	2173±87	0.9±4.0
Ti	5.97±0.64	-6.3±10.0	-	-
~~Cr~~	~~5.16±0.29~~	~~-10.2±5.0~~	-	-
Mn	41.8±2.5	4.6±6.2	41.2±3.4	1.6±8.4
Fe	4.39±0.26	2.5±6.1	3.96±0.14	-5.2±3.4
Ni	8.26±0.20	-0.5±2.4	-	-
~~Mo~~	~~82.4±6.5~~	~~-22.0±6.2~~	-	-
Stainless Steel	9.83±0.30	0.3±3.1	9.47±0.4	-0.2±4.2

3. ISTITUTO NAZIONALE DI FISICA NUCLEARE - SEZIONE DI PAVIA

Via Bassi, 6 - 27100 PAVIA (Italy)

3.1 Nuclear Fission (ref./a/ and /b/)

F. FOSSATI, T. PINELLI, P. TORRE

An analysis was performed of the data from measurements concerning the anisotropy of fragments and angular distributions (vs. energies) of α-particles emitted in the fission of U-235, induced by 40 MeV protons. The angular distribution with respect to the flight direction of the light fragment shows a peak at $(99\pm3)^\circ$, with a standard deviation $\sigma = (26\pm3)^\circ$.

The average energy of the α-particles exhibits small variations at different angles (the values are close to 13 MeV).

The angular distribution of the fragment , with respect to direction of incident protons, was well approximated by the function $d\sigma(\theta)/d\Omega = a+b\cos^2\theta$. From a fit, a value was obtained:

$$\left|\frac{d\sigma(0^\circ)}{d\Omega} \Big/ \frac{d\sigma(90^\circ)}{d\Omega}\right| = 1.85\pm0.1$$

From these experimental results, it was deduced that in the symmetric fission, the fragments are greatly deformed from the scission point (s.p.).

During 1979, a suitable equipment was arranged to measure the times of flight, in order to obtain the mass and energy distributions of the fragments, in coincidence with α-particles from U-233 ternary fission, induced by neutrons, and to calculate the nuclear structure at the s.p. Furthermore, a better calculation procedure was achieved to derive dynamical and geometrical conditions of the nucleus at the s.p., with the purpose to demonstrate that angular distributions of long range α-particles are not well reproduced without introducing remarkable values of fragment kinetic energy and nuclear elongation at the s.p. These parameters are crucial in the study of the fission process.

/a/ T. Pinelli, F. Fossati and P. Torre, "Cross-section anisotropy and long-range particle characteristics in the U-233 fission induced by 40.2 MeV protons", to be published in Nuovo Cimento.

/b/ T. Pinelli, F. Fossati, "An improved analysis in the evaluation of scission point configuration in Cf-252 spontaneous fission", to be published in Lettere al Nuovo Cimento.

3.2 Neutronics

F. FOSSATI, T. PINELLI, L. SACCHI, P. TORRE

An experimental apparatus was arranged for mapping the neutronic field generated by the Euracos converter (EURATOM), installed at the Triga Mark II reactor of the Pavia University, by means of proton recoil and ^{6}Li sandwich spectrometers for fast neutrons. These spectrometers, already settled by the group, are particularly suitable to discriminate background noise of any sort.

3.3 Small Angle Proton Scattering (ref./a/,/b/ and /c/)

G. BENDISCIOLI, E. LODI RIZZINI, A. ROTONDI, A. VENAGLIONI

Proton elastic scattering on ^{27}Al, $^{54,56,58}Fe$, $^{60,61,64}Ni$, $^{63,65}Cu$, has been measured at E_p=21 and 36.2 MeV in the angular range 0°-3°. Experimental distributions have been compared with those derived from current theories of multiple Coulomb scattering, modified so as to account for secondary effects dependent on ionization, kinematics and nuclear forces.

/a/ G. Bendiscioli, E. Lodi Rizzini, A. Rotondi, A. Venaglioni, "The Coulomb Multiple Scattering of Heavy Particles", submitted to Nucl. Phys.

/b/ G. Bendiscioli, "Coulomb-Nuclear Interference and Reaction Cross-Section in Charged Particle Scattering", J. Phys. G.: Nucl. Phys. 5(1979)L213.

/c/ G. Bendiscioli, "Physical Constraints on the Proton Scattering Amplitude", Lett. Nuovo Cim. 25(1979)343.

4. ISTITUTO NAZIONALE FISICA NUCLEARE - UNIVERSITA' DI TRIESTE - Via A. Valerio, 2 - 34127 TRIESTE (Italy)

4.1 A Study of the $^{59}Co(n,n'\gamma)^{59}Co$ Reaction (ref./a/)

U. ABBONDANNO, A. BOITI, F. DEMANINS, G. NARDELLI, C. TUNIZ

The $^{59}Co(n,n'\gamma)^{59}Co$ reaction has been studied for incident neutron energies ranging from 1.3 to 3.9 MeV. The pulsed-beam time-of-flight technique was employed to discriminate between the inelastically scattered neutrons and the de-excitation γ-rays, which were detected by means of a true-coaxial Ge(Li) detector.
The 77 observed γ-rays allowed us to determine the decay scheme. That scheme reproduces the energy range already studied in previous works ($E_x \lesssim 3000$ keV) fairly well and gives accurate energy positions and decay modes for some levels at higher energies.
Through a complete comparison between the experimental data and the compound nucleus statistical theory we confirm the spin values already determined in the energy range $E_x \lesssim 2000$ keV. The values reported in the literature in the energy range 2000 keV $\leq E_x \leq$ 3000 keV are discussed and possible spin values are finally proposed for the first time for the levels at E_x=2957 keV, E_x=3014 keV, E_x=3063 keV, E_x=3140 keV, E_x=3194 keV, E_x=3220 keV, E_x=3382 keV and E_x=3415 keV.

/a/ U. Abbondanno, A. Boiti, F. Demanins, G. Nardelli, C. Tuniz (Istituto di Fisica, Università di Trieste and Istituto Nazionale di Fisica Nucleare I.N.F.N., Sezione di Trieste): Lettere al Nuovo Cimento, <u>24</u>, 437 (1979) and Nuclear Physics, to be published.

5. ISTITUTO DI FISICA DELL'UNIVERSITA' DI CATANIA - ISTITUTO NAZIONALE FISICA NUCLEARE - SEZIONE DI CATANIA - CENTRO SICILIANO DI FISICA NUCLEARE E STRUTTURA DELLA MATERIA - Corso Italia, 57 - 95129 CATANIA (Italy)

5.1 Fission Induced by Linearly Polarized Photons on Even-Even Nuclei

V. BELLINI, M. DI TORO, S. LO NIGRO, G.S. PAPPALARDO

The fragment angular distributions in the photofission of even-even nuclei at low energies induced by a linearly polarized photon beam are deduced. It is shown that, by using monochromatic and linearly polarized photons, measurements of azimuthal distributions added to the angular ones permit a detailed and careful analysis of the fission channels in the transition state nucleus.

5.2 Subthreshold Photofission of ^{238}U in the (3.6 ÷ 6.0) MeV Energy Range

R. ALBA, R.C. BARNA'(°), G. BELLIA, L. CALABRETTA, D. DE PASQUALE(°), A. DEL ZOPPO, E. MIGNECO, G. RUSSO

The (γ,f) reaction induced by intense bremsstrahlung beams allows the study of the fission process at very low excitation energy and it is especially useful because of its high selectivity in terms of parity and angular momentum. In the particular case of an even-even compound nucleus at low excitation energy the spin and parity quantum numbers are $J^{\pi}=1^{-}$ and $J^{\pi}=2^{+}$ corresponding to the absorption of the multipolarity E1 and E2, respectively. In this condition an investigation of the properties of deep subthreshold fission barriers can be made. We have performed photofission yield measurements of ^{238}U in the 3.6 ÷ 6.0 MeV energy range and angular distributions in the 5.1 ÷ 6.0 MeV range. As γ-source the bremsstrahlung beam from a microtron has been used. Because of the strong decrease of the photofission cross section with decreasing energy, two different experimental procedures have been used.

(°) Istituto di Fisica dell'Università di Messina;
Istituto Nazionale di Fisica Nucleare - Gruppo di Messina

A preliminary analysis of the data provides information about the transition states. Interesting features of the low energy total photofission yield are discussed.

5.3 Deep Subthreshold Photofission Yields Analysis

R.C. BARNA'(°), G. BELLIA, D. DE PASQUALE(°), E. MIGNECO, A. DEL ZOPPO

Photofission yield measurements on $^{232,236,238}U$, showing the "shelf effect", have been analyzed in terms of a double-humped fission barrier. From the characteristic of the shelf it was possible to evaluate the excitation energy E_{II} of the shape isomer.
In the framework of the double-humped barrier, with the competition between decay to the shape isomer and tunneling through the outer barrier of a compound state in the second well, it was possible to deduce fission branching ratios in agreement with those known in the literature. In particular for ^{232}Th a three-humped fission barrier is proposed, the second deep minimum causing the shelf effect and the third one the narrow resonances detected in this isotope.

5.4 $^{13}C(^{6}Li,t)\,^{16}O$ Reaction in the 20-32 MeV Incident Energy Range

A. CUNSOLO, A. FOTI, G. IMME', G. PAPPALARDO, G. RACITI, F. RIZZO, N. SAUNIER(°°)

The reaction $^{13}C(^{6}Li,t)\,^{16}O$ has been studied in the 20-32 MeV incident energy range. Angular distributions have been measured at $E_{^{6}Li}$=28 MeV; the data have been analyzed in terms of Hauser-Feshbach and exact finite range distorted-wave Born-approximation theories. The extracted relative ^{3}He spectroscopic strengths show a satisfactory indipendence from the optical model parameters.

(°) Istituto di Fisica dell'Università di Messina;
Istituto Nazionale di Fisica Nucleare - Gruppo di Messina
(°°) Départment de Physique Nucléaire - CEN Saclay, B.P.2, 91190 Gif-sur-Yvette, France

5.5 $^{12}C(^{6}Li,d)^{16}O + ^{12}C$ Reaction Mechanism by means of Angular Correlations Measurements

A. CUNSOLO, A. FOTI, G. IMME', G. PAPPALARDO, G. RACITI, N. SAUNIER(°)

The particle-particle angular correlation method is applied to the reaction $^{12}C(^{6}Li,d)^{16}O \rightarrow \alpha + ^{12}C$. Deuterons were detected at $\theta_d^{lab} = 10°$. Information on the reaction mechanism are obtained by analyzing the shape and the angular shift of the experimental data. A dominant direct transfer mechanism is found for the primary reaction. The ratios Γ_{α_o}/Γ and the α-reduced widths γ_{α_o} are deduced.

5.6 Spin-Isospin Dependent Potential Obtained from the $^{14}C(^{6}Li,^{6}He)$ ^{14}N Reaction

A. CUNSOLO, A. FOTI, G. IMME' B.T. KIM(°), G. PAPPALARDO, G. RECITI, N. SAUNIER(°)

We have measured and analyzed angular distributions of the charge-exchange reaction $^{14}C(^{6}Li,^{6}He)^{14}N$ leading to the 1^+ ground state and 3.95 MeV 1^+ and 5.10 MeV 2^- excited states at the 34 MeV incident beam energy. The 62 MeV data of Goodman et al. were also reanalyzed. The direct one-step charge exchange due to the spin-isospin dependent term in the two-body interaction can account well for the general trend of the data at both energies. The use of correct nuclear wave functions of nuclei involved seems to be critical to extract the consistent spin-isospin dependent potential.

5.7 Quasi-Free Reactions at Low Energy

S. BARBARINO, P.G. FALLICA, M. LATTUADA, F. RIGGI, C. SPITALERI, C.M. SUTERA, D. VINCIGUERRA

We have continued the experiments on quasi-free processes induced at low incident energy in high Q reactions. In particular the $^{9}Be(^{3}He,\alpha\alpha)$ reaction has been measured under several kinematical conditions, in

---

(°) Départment de Physique Nucléaire - CEN Saclay, B.P.2 91190 Gif-sur-Yvette, France order to evaluate the contribution of sequential processes and their influence on the quasi-free region of the spectra. From this analysis the conclusion has been drawn that the shape of the impulse distribution is not appreciably modified by the presence of sequential processes. Evidence for quasi-free contribution to the $^6Li(^3He,p\alpha)^4He$ reaction has been also obtained. The momentum distribution is narrower than expected; the shape of the distribution has been accounted for by putting a cut-off radius in the intercluster wave function of ^6Li.

A new analysis of $^6Li(p,pd)$ quasi-free reaction data, obtained by other authors at 590 MeV has been performed. We find that the data are compatible with the ^6Li impulse distribution which accounts for all other high energy quasi-free experiments, with a width of about 70 MeV/c, instead of the value of 120 MeV/c reported previously.

6. ISTITUTO DI FISICA DELL'UNIVERSITA' - ISTITUTO NAZIONALE DI FISICA NUCLEARE - SEZIONE DI FIRENZE - Largo E. Fermi, 2 - Arcetri - FIRENZE (Italy)

6.1 Level Structure of ^{49}Ti up to $E_x \approx 5.5$ MeV

P.A. MANDO', G. POGGI, P. SONA, N. TACCETTI

Levels in ^{49}Ti were populated via ^{49}Ti$(\alpha,\alpha'\gamma)^{49}$Ti, ^{49}Ti$(p,p'\gamma)^{49}$Ti and ^{48}Ti and ^{48}Ti$(d,p\gamma)^{49}$Ti reactions, using enriched targets of ^{49}Ti (1 mg/cm^2 thick) and natural targets of ^{48}Ti (40 μg/cm^2 thick). Levels at 1381 ($J^\pi = 3/2^-$) and 1542 keV (assumed to have $J^\pi = 11/2^-$ as reported in ref./a/ were Coulomb excited through the (α,α') reaction at beam energies ranging from 5.25 up to 5.8 MeV. The corresponding B(E2)↓ values were determined to be 33.5±4.5 e^2fm^4 respectively, having assumed as a calibration point the most precise value reported in the literature /b/ for the B(E2)↓ of the 983 keV transition in ^{48}Ti (namely B(E2)↓ = 138±12 e^2fm^4). No Coulomb excitation was observed of the 1586 keV level which, according to ref./a/ should have $J^\pi = 3/2^-$. This fact gives an upper limit of 11 e^2fm^4 for the corresponding B(E2)↓ .

The (p,p') and (d,p) reactions were carried out at 6 MeV beam energy. In both of them, $p'-\gamma$ coincidence measurements were performed with data acquisition in the standard three parameter mode. The information on the decay scheme of ^{49}Ti provided by the two reactions are somewhat complementary since the (d,p) reaction excites preferentially low spin states up to $E_x \approx 5.5$ MeV while the (p,p') reaction excites also high spin states up to $E_x \approx 3.5$ MeV. The figure summarizes the information obtained on the decay scheme. The $(p,p'\gamma)$ reaction was also used to measure lifetimes of various levels, by observing the shift of the γ-peak centroids as the Ge(Li) was rotated from +90° to -90° to the beam direction while leaving the Si detector fixed at +90°. Corrections to the small gain drifts were evaluated by reference to gamma calibration peaks from radioactive sources. In some cases it was possible to evaluate the Doppler shift by directly comparing the gamma peak centroids in the true-coincidence and in the corresponding chance-coincidence spectrum. In this way we could avoid the need of any correction. Lifetimes have been deduced from the observed Doppler shifts by means of the standard Blaugrund-type analysis, allowing for a ±15% uncertainty in the electronic energy loss. The preliminary values are reported in the table.

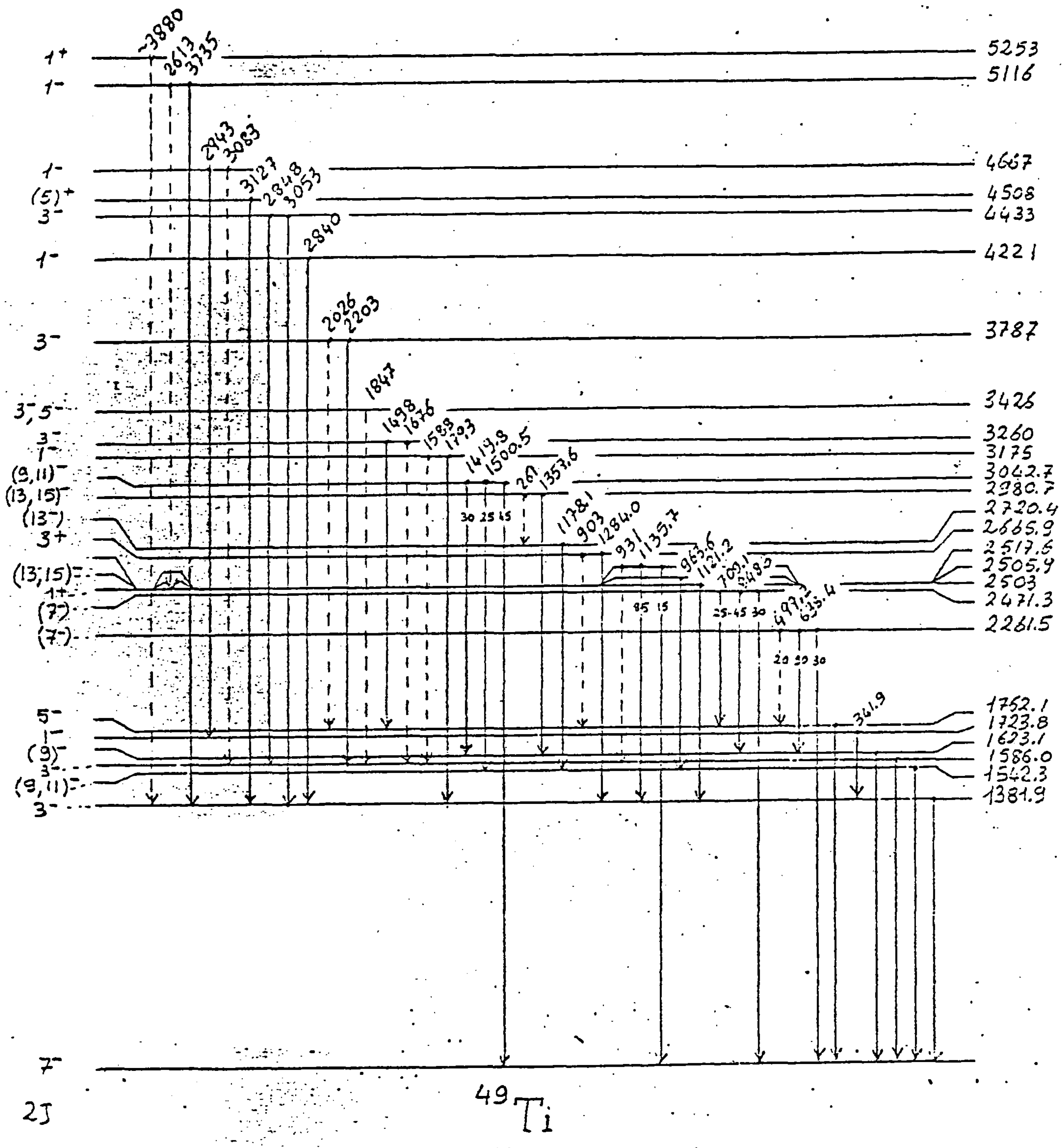
TABLE

Level energy (keV)	Lifetime (fs) Present work	ref. /c/
1381	>1200	
1623	44^{+8}_{-6}	55±7
1763	33^{+9}_{-8}	36±4.3
2262	136^{+33}_{-25}	
2517	>8000	
2663	> 210	
2720	49^{+39}_{-29}	
3040	< 15	

/a/ N.D. Sheets, 24, 175 (1978).

/b/ O. Hausser, D. Pelte, T.K. Alexander and H.C. Evans, Nucl. Phys. A150, 417 (1970).

/c/ V.K. Rasmussen, Phys. Rev. C13, 631 (1976).



1+
1-
1-
(5)+
3-
1-
3-
3-,5-
3-
1-
(9,11)-
(13,15)-
(13-)
3+
(13,15)-
1+
(7)-
(7-)
5-
1-
(9)-
3-
(9,11)-
3-
7-
2J
5253
5116
4667
4508
4433
4221
3787
3426
3260
3175
3042.7
2980.7
2720.4
2665.9
2517.6
2505.9
2503
2471.3
2261.5
1752.1
1723.8
1623.1
1586.0
1542.3
1381.9
~3880
2613
3735
2943
3083
3127
2848
3053
2840
2026
2203
1847
1498
1676
1588
1793
1419.8
1500.5
281
1357.6
1178.1
903
1284.0
931
1135.7
963.6
1121.2
709.1
549.5
497.7
635.4
341.9
30
25
45
95
15
25-45
30
20
20
30

^{49}Ti

6.2 Gamma-Decay of ^{85}Rb

T. FAZZINI, P.R. MAURENZIG, G. POGGI, N. TACCETTI

Excited levels of ^{85}Rb have been populated with the reaction $^{84}Kr(p,\gamma)$. The target, which consisted of natural Kr gas (purity 99.99%) at pressures ranging from 0.2 to 20 Atm., was bombarded with the proton beam of the 3 MV accelerator of the University of Florence. Due to the nickel window the maximum proton energy effective for the reaction was $\approx$ 2.8 MeV; the proton current was $\approx$ 400 nA.
Single spectra and γ-γ coincidence measurements allowed to obtain the γ-decay scheme of ^{85}Rb reported in fig. 1.
Lifetimes of some levels have been measured with the method of Doppler shift attenuation in gas, using the Kr gas as a target and stopper. The lifetime values have been extracted by using a best fit procedure to the experimental values of the attenuation factor, which was recorded as a function of the gas pressure. A typical example, referring to the 130 keV γ-ray (from the second excited state) is reported in fig. 2.

$^{84}Kr(p,\gamma)^{85}Rb$

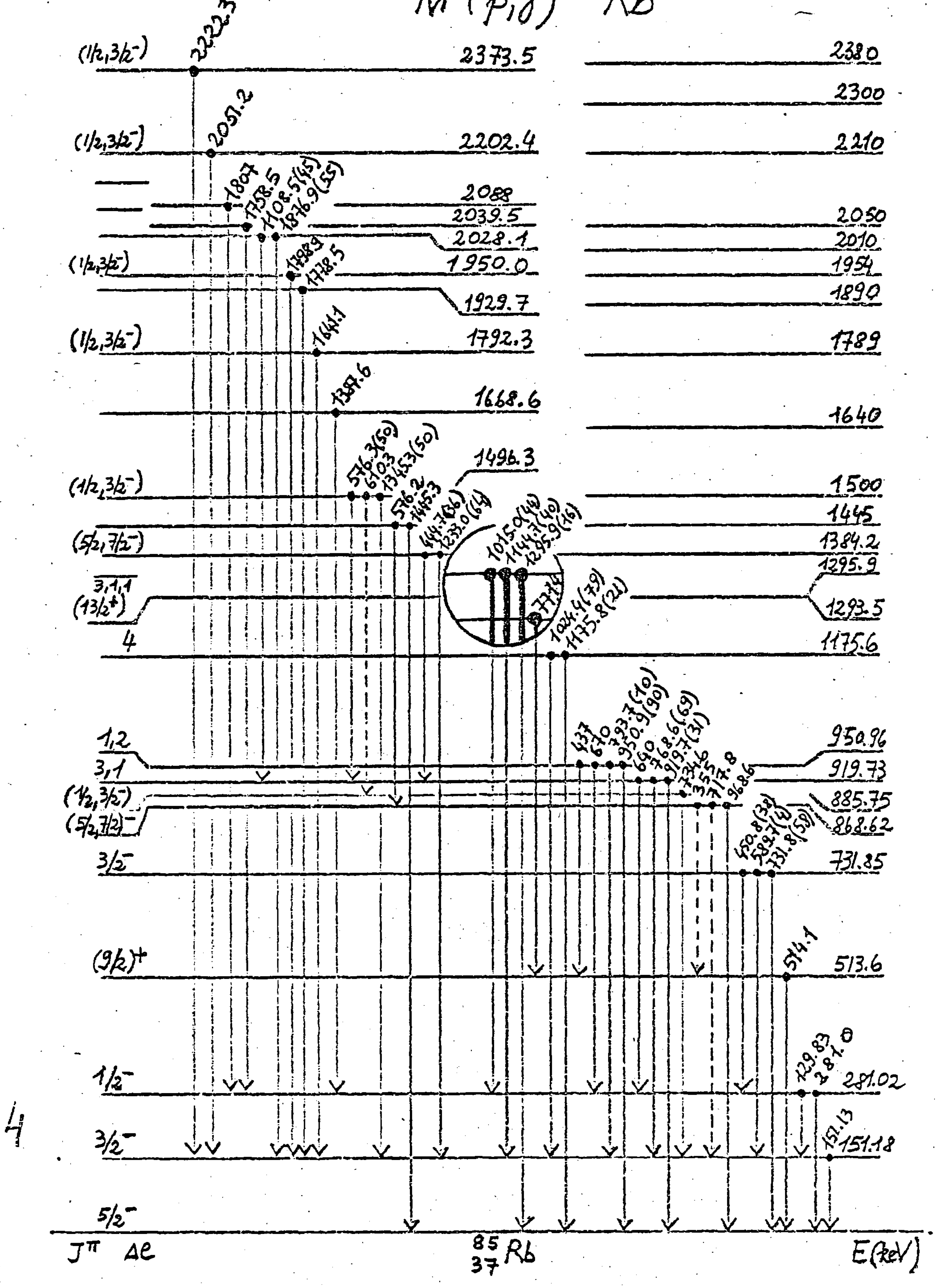


Fig. 1

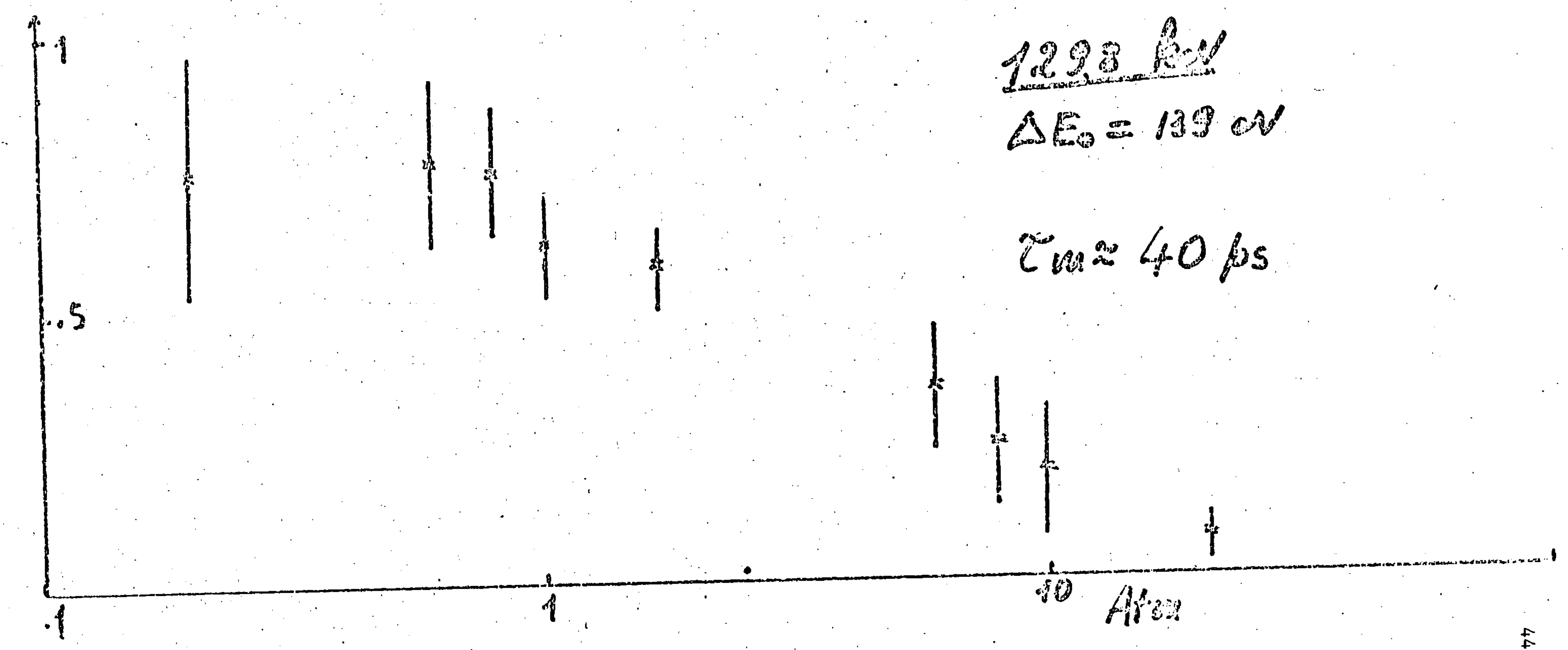


Fig. 2

7. ISTITUTO DI FISICA DELL'UNIVERSITA' DI NAPOLI - ISTITUTO NAZIONALE DI FISICA NUCLEARE - SEZIONE DI NAPOLI - Via A. Tari, 3 - 80138 NAPOLI (Italy)

7.1. Cluster Contribution to the Elastic Scattering of Protons by ^{12}C

R. BONETTI(°), L. COLLI-MILAZZO(°), A DE ROSA, G. INGLIMA, E. PERILLO, E. ROSATO, M. SANDOLI, G. SPADACCINI

Proton elastic scattering on ^{12}C has been measured in the energy range 3-40 MeV.
The analysis was carried out in the energy range 3-61.4 MeV using data available in the literature /a/.
The measurements were performed with the 7 MeV Van de Graaff of Laboratori Nazionali di Legnaro and the AVF cyclotron of the University of Milan.

/a/ R. Bonetti et al., "Investigation on Possible Cluster Contribution to the Elastic Scattering of Protons by ^{12}C at Different Energies", Nuovo Cim. A49, 433 (1979).

7.2 Direct Proton Capture in Light Nuclei

A. BRONDI, P. CUZZOCREA, G. LA RANA, R. MORO, M. ROMANO, F. TERRASI

The study of the proton direct capture on ^{28}Si for extracting spectroscopic factors of low-lying states in ^{29}P has been completed /a/.
Differential cross sections at 0° and 90° for the $^{28}Si(p,\gamma)^{29}P$ have been measured in the energy range 1.3-2.3 MeV. Spectroscopic factors deduced for the ground state and first excited state in ^{29}P are 0.36 ± 0.09 and 0.5 ± 0.13 respectively.

(°) Istituto di Fisica and Istituto Nazionale di Fisica Nucleare di Milano - Via Celoria, 16 - 20133 MILANO (Italy)

This work has been performed using the 2 MeV Van de Graaff accelerator of Laboratori Nazionali di Legnaro as well as the 3 MeV tandem of the University of Naples.

/a/ F. Terrasi et al., "Proton Resonant and Direct Capture on ^{28}Si", Nucl. Phys. A234 (1979) 1.

8. ISTITUTO DI FISICA DELL'UNIVERSITA' DI PADOVA - ISTITUTO NAZIONALE DI FISICA NUCLEARE - LABORATORI NAZIONALI DI LEGNARO - Via Marzolo, 8 - 35100 PADOVA (Italy)

8.1 On the Measurement of the Small Angle Scattering of Polarized Neutrons

V. GIORDANO, C. MANDUCHI, M.T. RUSSO-MANDUCHI, G.F. SEGATO

Our previous measurements /a/ on the scattering of 2.5 MeV polarized neutrons by heavy nuclei at angles from $\pm 2.1°$ to $\pm 9.1°$, have demonstrated that predictions based on the framework of the optical model were systematically lower than the observed cross sections. In an attempt to discover possible significant deviations from the theoretical predictions at very small angles, an apparatus was designed merely for the purpose of extending the measurements to scattering angles lower than 1°.
A shielded source configuration was achieved as a practical compromise of a good collimation and a correspondingly poor transmission probability. With a view to the possible use of the system as a neutron polarimeter, two detectors were arranged symmetrically with respect to the neutron beam direction in the horizontal plane. The characteristics of the detectors and associated optics were optimized in order to achieve both a small effective angular acceptance and a reasonable efficiency. The specific shape represented a further improvement in the signal-to-background ratio, owing to the directional detection properties.
In order to evaluate the validity of the apparatus for investigating small angle scattering, we measured the absolute values of the differential cross section of 2.50 MeV neutrons elastically scattered by Bi at 2° and 0.75°. As the apparatus was specifically designed for scattering angles lower than 1°, the measurement at 2° was intended only as a comparison test with respect to the previous data /a/. Although the experimental procedure was limited to an exemplification test, the statistical agreement between the experiment and the calculated data appaired fairly good.

/a/ V. Giordano, C. Manduchi, M.T. Russo-Manduchi, G.F. Segato, "Nucl. Phys. A302, 83 (1978).

8.2 The Spin-Spin Effect in the Total Neutron Cross Section of Polarized Neutrons on Polarized ^{165}Ho /a/

U. FASOLI, G. GALEAZZI, P. PAVAN, D. TONIOLO, G. ZAGO, R. ZANNONI

The spin-spin effect in the total neutron cross section of polarized neutron on polarized ^{165}Ho has been measured in the energy interval 0.4 to 2.5 MeV, in steps of 200 keV, in perpendicular geometry.
The ^{165}Ho oriented target was a polycrystalline holmium cylinder with the axis in vertical direction, in a magnetic field of 3T inside a cryostat which allows a minimum temperature of 0.36 K to be reached. The corresponding polarization vector, perpendicular to the beam direction, is $P_t=B_1/B_{1_{max}}=0.56$. The polarized neutron beam was obtained by the reaction $^7Li(p,n)^7Be$ on a LiF target about 100 keV thick, in direction of 50°. The neutrons passed between the poles of a processing magnet which allows the neutron spin to rotate by 180°.
The neutron time-of-flight technique and pulse-shape discrimination were used.
The experimental procedure consists in measuring the asymmetries $\varepsilon=2(N_{\uparrow\uparrow}-N_{\uparrow\downarrow})/(N_{\uparrow\uparrow}+N_{\uparrow\downarrow})$ where $N_{\uparrow\uparrow}$ and $N_{\uparrow\downarrow}$ are the transmitted neutron counts normalized by means of a neutron monitor, and obtained by swithing the magnetic field of the processing magnet alternatively on and off, with a period of a few minutes, in order to minimize the effect due to various instrumental drifts.
The corresponding spin-spin cross section σ_{ss} for the various incident neutron energies have been calculated from the measured asymmetries and reported in fig. 1, together with the theoretical results, represented by the curve, obtained by a coupled-channel calculation. It is found that σ_{ss} is approximately constant with a mean value $\sigma_{ss}=3.7\pm9.6$ mb.
Therefore the spin-spin effect for ^{165}Ho, in contrast to ^{59}Co, in the explored energy interval, is very small (not larger than about 0.1% of the total cross section), both in perpendicular and parallel geometry /b/.
The spin/spin interaction was theoretically calculated, up to 5 MeV, by a non-adiabatic coupled-channel calculation performed by taking into account the ^{165}Ho deformation and the coupling between the dynamical effects of the $I\cdot\sigma$ potential on the levels of the fundamental rotational band.

Our theoretical results agree substantially with those of ref./b/ (if one takes into account the different approximation degree of the two calculations), both in the order of magnitude and in the trend of the effect versus the incident neutron energy. Some difference is apparent in the low energy (< 2 MeV) parallel effect. From the comparison between our experimental and theoretical results a value $V_{ss}=9\pm77$ keV was obtained for the strength of the spin-spin potential.

By comparing the experimental results of Fisher et al./b/ at 0.41 and 0.98 MeV with our theoretical results, we found $V_{ss}=227\pm160$ keV, in agreement with our value.

By combining the two results for V_{ss} obtained with the two geometries one has $V_{ss}=50\pm69$ keV.

The contribution of the compound-nucleus spin-spin cross section, calculated by the method recently suggested by Thompson /c/, was found to be about +60 mb, but such a value is hardly acceptable if compared to the experimental data.

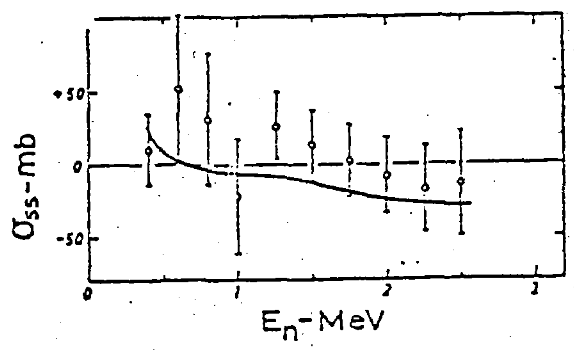


Fig. 1 - The spin-spin cross section in perpendicular geometry for ^{165}Ho as a function of the incident neutron energy. The curve represents the fit to the experimental data corresponding to the value $V_{ss}=9\pm77$ keV for the strength of the spin-spin potential.

/a/ U. Fasoli, G. Galeazzi, P. Pavan, D. Toniolo, G. Zago, R. Zannoni, Nucl. Phys. A311, 368 (1978).

/b/ T.R. Fisher, D.C. Healey, J.S. McCarthy, Nucl. Phys. A130, 609 (1969).

/c/ W.J. Thompson, Phys. Lett. 65B, 309 (1976).

8.3 The Deformation Effect in Fast Neutron Transmission through an Aligned ^{59}Co Target in the Energy Range 0.8-20 MeV /a/

U. FASOLI, G. GALEAZZI, P. PAVAN, D. TONIOLO, G. ZAGO, R. ZANNONI

The deformation effect in neutron transmission was measured on ^{59}Co in the energy interval varying continuosly from 0.8 up to 20 MeV. The orientation was obtained by cooling a cobalt monocrystal by means of a ^{3}He-^{4}He dilution refrigerator, built by the Cryogenic Laboratory /b/ of Legnaro. The monocrystals were grown at Padua using the Czochralski method /c/ and were cut from the boule in the form of truncated cones weighting about 45 g.
The average temperature of the target during the experiment was 18.5 mK, with variations not exceeding $\pm$1 mK, and the corresponding degree of nuclear alignment $B_2/B_{2_{max}}$ was 0.34$\pm$0.02.
The neutron beam was generated by means of reaction ^{7}Li(d,n)^{8}Be. Deuterons of 4.5 MeV impinging on a thick metal lithium target gave rise to a "white" neutron spectrum with energies ranging from 0.8 up to 20 MeV.
The measuring procedure consisted in comparing the neutron transmission through the monocrystal target with that of a second polycrystalline (not aligned) cobalt target with the same areal density, located laterally parallel and near to the first one.
The experimental apparatus permitted alternative exposure of the two targets to the same neutron beam, by moving the whole refrigerator laterally at intervals of a few minutes, in order to render negligible the temporal drifts of the electronics.
The neutron countings were performed by using the neutron time-of-flight technique.
The deformation effect $\Delta\sigma_{def}$, was calculated by the formula:

$$\Delta\sigma_{def} = \sigma_{al} - \sigma_{un} = \frac{1}{nt} \ln \frac{T_{un}}{T_{al}}$$

where n=0.896.10^{23} is the number per cm^3 of the cobalt nuclei in the target, t=2.370 cm its thickness and T_{al} and T_{un} the neutron transmission through the aligned and unaligned targets respectively.
In order to control the absence of spurious effects, two series of "warm" runs respectively at 77 K and 1 K (no alignment) were performed.

The experimental results are represented in fig. 1 where the continuous curve is a prevision of the effect performed by using the black-nucleus model and the nuclear Ramsauer effect /e/.

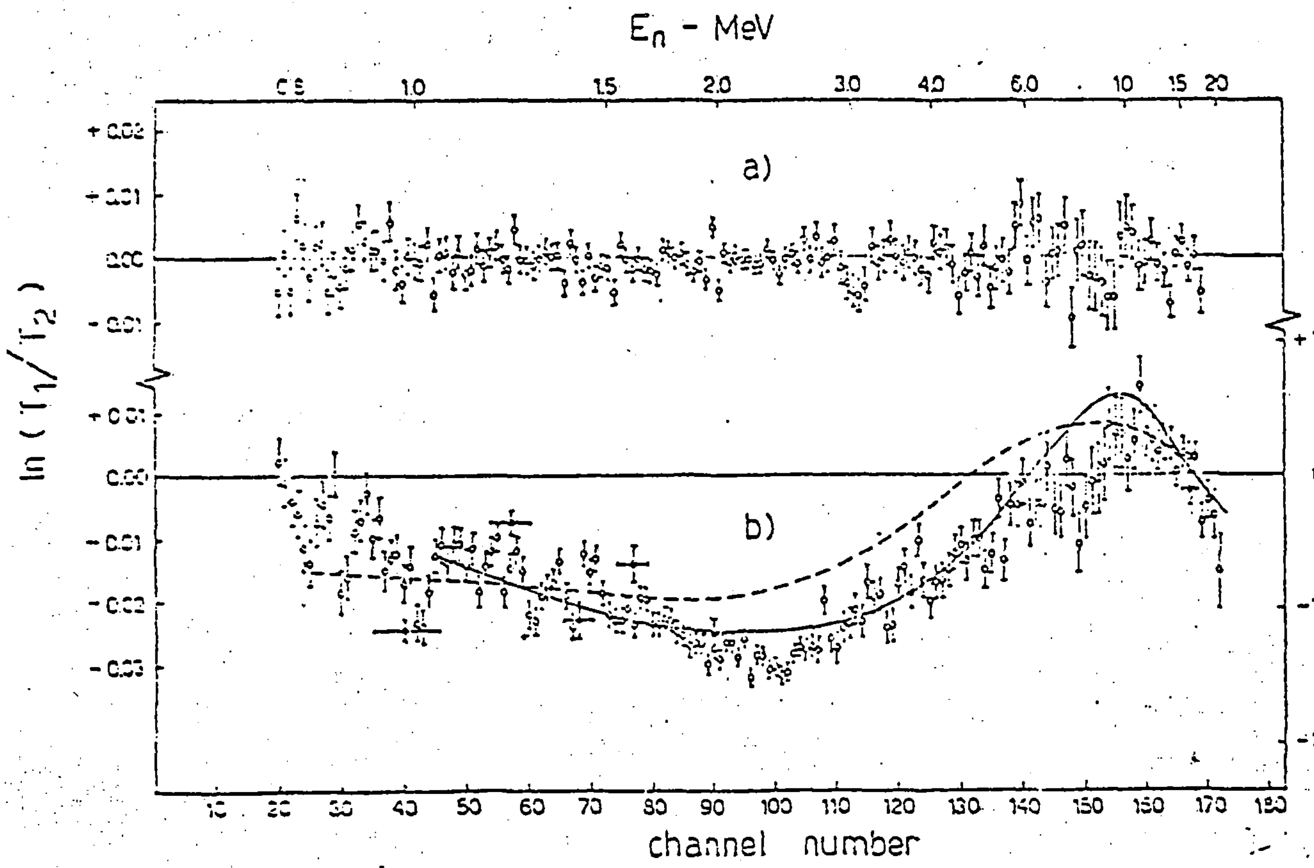


Fig. 1 a), b).

Fig. 1 a), b). The deformation effect $\Delta\sigma_{def}$ in the neutron transmission through a sample of aligned ^{59}Co, with an alignment degree $B_2/B_{2_{max}}$ =0.34 versus the incident neutron energy E_n.
The results in a) and b) are relative respectively to the "warm" runs with the two targets not aligned, and to the "cold" runs with the monocrystal target aligned. The full points are the results of Fisher et al./a/ normalized to our data. The dotted curve is the theoretical effect calculated by Fisher et al./a/ by a DWBA calculation.
The continuous curve is a theoretical prevision of the effect performed with the model of ref./e/.

/a/ Lett. N. Cim., in press.

/b/ U. Fasoli, G. Galeazzi, D. Toniolo, XV Congresso Internazionale del Freddo, Venezia, Settembre 1979.

/c/ U. Fasoli, P. Pavan, INFN, internal report, in press.

/d/ T.R. Fisher, A.R. Poletti, B.A. Watson, Phys. Rev. 8C, 1837 (1973).

/e/ H. Marshak, A. Langsdorf, T. Tamura, C.Y. Wong, Phys. Rev. 2C, 1862 (1971).

9. ISTITUTO DI FISICA DELL'UNIVERSITA' - ISTITUTO NAZIONALE DI FISICA NUCLEARE - SEZIONE DI BOLOGNA - Via Irnerio, 46 - 40126 BOLOGNA (Italy)

9.1 Blocking Measurements of Nuclear Decay Times

E. FUSCHINI, F. MALAGUTI, A. UGUZZONI, E. VERONDINI

Carrying on the programme of measuring the lifetimes of several isolated resonances in the $^{27}Al(p,\alpha)^{24}Mg$ reaction, during 1979 the lifetime of the 731-keV resonance was measured by means of the blocking method in Al single-crystals. A 250 nA proton beam from the 2-MeV Van de Graaff generator was impinging on a 2mm thick Al single-crystal whose axes <110> and <1$\bar{1}$0> were directed at 87 and 177 degrees respectively to the beam. The corresponding blocking dips were simultaneously recorded by LR-115 type I Kodak plastic detectors 6 μm thick covered by 3 μm Mylar foils to suppress α-particles coming from lower-energy resonances. Four measurements with four different single-crystals have been performed for a total 90000 μC proton charge.

To extract the mean displacement of the compound system ^{28}Si(12.291 MeV excitation energy) from the measured blocking dips, the procedure of Ref./a/ was followed, obtaining

$$v\tau = 10.1^{+2.8}_{-3.3} \ \text{pm} ,$$

hence the width of the 12.291 MeV level of ^{28}Si

$$\Gamma = 28^{+13}_{-6} \ \text{eV} .$$

This result is in good agreement with that obtained from yield measurements /b/, confirming that the procedure developed by the Bologna group to analyze blocking experiments is reliable and able to attain an accuracy better than "spectroscopic" methods.

/a/ F. Malaguti, A. Uguzzoni, E. Verondini, Phys. Rev. C19, 1606 (1979).

/b/ J.W. Maas et al., Nucl. Phys. A301, 213 (1978).

/c/ F. Malaguti, A. Uguzzoni, E. Verondini, Lettere N. Cimento 25, 65 (1979).

9.2 D(α,αp)n Reaction

M. BRUNO, M. D'AGOSTINO, F. CANNATA, M. LOMBARDI(°), G. VANNINI

In the reaction $\alpha + d \rightarrow \alpha + p + n$ at low energies sequential processes:

$$\alpha + d \rightarrow {}^5He(g.s.) + n \qquad (1)$$
$$|\rightarrow \alpha + p$$

$$\alpha + d \rightarrow {}^5Li(g.s.) + p \qquad (2)$$
$$|\rightarrow \alpha + n$$

were studied together with quasi-free scattering and p-n final state interaction. The measurements were carried out with the 7.5 MV Legnaro Van de Graaff using a doubly ionized ^4He beam to bombard a thin solid deuterated polystyrene target (about 30 $\mu g/cm^2$ thick). The measurements were performed at beam energies and at angles which favour the process (1) over the other channels. Absolute cross sections were determined by simultaneous measurements of the α-d elastic scattering (2) and properly normalizing the data.

9.3 D(α,α)D Elastic Scattering

M. BRUNO, F. CANNATA, M. D'AGOSTINO, M. LOMBARDI(°), C. MARONI

An experimental program involving the systematic investigation of the reactions:

(°) Laboratori Nazionali di Legnaro, I.N.F.N., Italy

$$\alpha + d \rightarrow \alpha + d$$

$$\alpha + d \rightarrow \alpha + p + n$$

was undertaken.
Systematic measurements of the cross sections of the elastic scattering:

$$\alpha + d \rightarrow \alpha + d$$

at several energies and kinematical configurations /a-b/ were performed.
The study of this process leads to direct information on the parameters of the excited states of ^{6}Li.
The experiment was performed at the 7.5 MV Legnaro Van de Graaff with the He^{++} beam in the energy range between 6 and 14 MeV. Since we required low statistical errors and a good angular definition ($\Delta\theta$=0.5°), solid polystyrene deuterated targets were used. These targets, in fact, have a relatively large number of deuterium centers and a very small thickness, which provide high counting rates, good angular resolution and a negligible energy loss /c/.
In order to reject spurious events from reactions in the target backing and from impurities in the beam, the recoiling deuterons in coincidence with the scattered α-particle have been recorded.
The angular distributions were measured from θ_{Lab}= 7° to 69° in steps of 2° .
The content of deuterium in the target during the measurements at the same energy, was continuously monitored by a ΔE-E system recording deuterons emitted at a fixed angle of 50°.
The experimental cross sections have been presented in /a-b/ together with excitation functions at four angles taken to match the data at different energies.

/a/ M. Bruno et al., INFN/BE-79/6.
/b/ M. Bruno et al., Lettere Nuovo Cimento (1980), to be published.
/c/ M. Bruno et al., Lettere Nuovo Cimento, <u>22</u>, 556 (1978).
/d/ R.A. Hardekopf et al., Nucl. Phys. <u>A287</u>, 237 (1977).

10. ISTITUTO DI INGEGNERIA NUCLEARE - CENTRO STUDI NUCLEARI ENRICO FERMI - CESNEF - Via Ponzio 34/3 - 20133 MILANO (Italy)

The use of fissile targets as neutron flux monitors is under study at CESNEF in the framework of a progress sponsored by ENEL.
Although the main object of the mentioned publications was the assay of these targets (mass determination and purity assessment), some of the developed methods can find application in nuclear material safeguard or in general in the control of the nuclear fuel cycle.
Non destructive γ-ray analysis, delayed neutron analysis following fission by thermal and fast neutron, and activation analysis by thermal neutrons have been investigated (ref. /a/ and /b/).
An evaluation about the consistency of the existing files of absolute γ-ray branching intensities, delayed neutron yields and neutron cross section data has been allowed by the comparison of experimental results.

/a/ A. Cesana, G. Sandrelli, V. Sangiust, M. Terrani, "Non destructive quantitative analysis of actinide samples", CESNEF,ENEL-CRTN-Milano; ESARDA 1st Symposium on Safeguards and Nuclear Material Management, Bruxelles, April 1979.

/b/ A. Cesana, G. Sandrelli, V. Sangiust, M. Terrani, "Gamma-ray spectra of ^{233}U, ^{237}Np, ^{238,239,240,241}Pu, and ^{241}Am samples", CESNEF, ENEL-CRTN-Milano; Energia Nucleare vol. 26, n. 11, novembre 1979.