International Atomic Energy Agency

INDC(CSR)-1/G

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

Progress Report on Nuclear Data Activities in Czechoslovakia

Compiled by J. Roček
Nuclear Research Institute,
Řež, Czechoslovakia

September, 1978

IAEA NUCLEAR DATA SECTION, KÄRNTNER RING 11, A-1010 VIENNA

Progress Report on Nuclear Data Activities in Czechoslovakia

Compiled by J. Roček
Liaison Officer to the INDC for Czechoslovakia
Nuclear Research Institute, Řež, Czechoslovakia

This report contains the main works performed in the field of nuclear data and low energy nuclear research at the Institute of Nuclear Physics of the Czechoslovak Academy of Sciences.

MULTIPLE SCATTERING OF FAST CHARGED PARTICLES IN SILICON

J. Vincour, P. Bém

Nuclear Physics Institute, Czechosl. Acad. Sci.,

250 68 Řež u Prahy
Czechoslovakia

The angular distributions of 6.6 MeV protons, 12.5 MeV deuterons and 24 MeV alpha particles transmitted through 50 /um - 260 /um silicon targets were measured. The results are in fair agreement with calculations based on the Molière and approximate Nigam, Sundaresan, and Wu theories.

Computer program for calculation of the internal conversion coefficients

M. Ryšavý, M. Vinduška, O. Dragoun
Nuclear Physics Institute, Czech. Acad. Sci., 250 68 Řež
Czechoslovakia

The internal conversion coefficients (ISS) for the experimentalist's purposes are usually interpolated from the existing tables. The computer program NICC /1/ developed in our laboratory makes possible to calculate the ICC immediately for the transition energy in question. It works for all atomic shells.

Two versions of the program are available /2/, both written in the programming language PL/1. In the first one, the bound-electron wavefunction is calculated as a solution of the Dirac equation for a given potential (usually that of the relativistic Hartree-Fock-Slater atomic model). In the second version, this function is read as data, which enables one to use e.g. the wavefunction of the Hartree-Fock atomic model. The wavefunctions of the electrons in the continuum state are always generated from a potential. The static effect of the finite nuclear size is taken into account using the Fermi charge distribution (The internal conversion matrix elements are calculated in the usual way).

In order to test this new ICC program it was run for the Coulomb field and the results were compared with these of the code AICC /3/, which is based on analytic solution of the problem for the pure Coulomb potential. This test has proved the numerical reliability of the code NICC to be about 0.5% /1/.

References:

/1/ M. Ryšavý, O. Dragoun, M. Vinduška: Czech. J. Phys. B27 (1977) 538

/2/ O. Dragoun, V. Brabec, M. Ryšavý, A. Špalek: Z. Physik A281 (1977) 347

/3/ O. Dragoun, G. Heuser: Computer Phys. Commun, 2 (1977) 427

Internal conversion coefficients in the Hartree-Fock atomic model.

O. Dragoun, V. Brabec, M. Ryšavý
Nuclear Physics Institute, Czech. Acad. Sci., 250 68 Řež, Czechoslovakia

The calculation of the internal conversion coefficients (ICC) requires knowledge of the electron wavefunctions for both bound and continuum states. All previous authors generated those functions from an overall atomic potential, usually the Hartree-Fock-Slater (HFS) one. We have adapted the computer code NICC [1] to read the bound - electron wavefunction as a data. By means of that code we evaluated ICC for three transitions in ^{199}Hg using the wavefunctions [2] of the Hartree-Fock model.

Simultaneously, we measured [3] the precise conversion line intensities of these transitions.

The calculations proved that the ICC of the HFS model are systematically higher than those of the HF model, the deviations range from less than 1% for the K shell up to about 30% for the P_1 subshell. Our measurements of relative line intensities are in accord with both sets of theoretical results. We conclude that the interpretation of the current nuclear spectroscopy measurements does not require the ICC calculated in the HF atomic model. Nevertheless, this need not necessarily be true for the very precise absolute ICC measurements.

[1] M.Ryšavý, O.Dragoun, M.Vinduška: Czech.J.Phys. B27(1977)538
[2] J.B.Mann: private communication
[3] O.Dragoun, V.Brabec, M.Ryšavý, A.Špalek: Z.Physik A281(1977)347

New method for efficiency calibration of Ge(Li) detectors.

V.Hnatowicz, M.Fišer
Nuclear Physics Institute
250 68 Řež near Prague, Czechoslovakia

The usual measurement of the gamma-ray intensities with Ge(Li) detectors relies upon knowledge the dependence of the full energy peak efficiency (FEPE) on the energy of radiation. The FEPE at specific energy values are usually determined with the help of standard sources with well known relative or absolute gamma-ray intensities. Some errors in the FEPE determined in this way can arise from the source-detector geometry variation due to large number of sources used. All methods presently in use give the FEPE only at specific energies depending on sources employed. The FEPE value for any other energy has to be approximated by fitting some suitable formula to experimental FEPE values.

In the view of the mentioned difficulties inherent to conventional methods the new procedure for FEPE determination is suggested employing the external bremsstrahlung (EB) radiation exited by electrons from radioactive beta-decay. EB is emited in collisions between moving electrons and Coulomb field of target atoms. The proposed method consists of following steps :

a) measurement of EB spectrum s (E) in the energy region of interest
b) determination of the relative FEPE values e (E_k) (k=1...n) in the same geometry, at few specific energy values E_k. This can be done using one suitable standard source e.g. ^{75}Se or ^{182}Ta.
c) calculation of the true EB spectrum s´(E_k) at the energies E_k using known relative FEPE values

$$s'(E_k) = s(E_k) / e(E_k)$$

d) approximation of the corrected EB spectrum s´(E) with some suitable analytical formula
e) determination of FEPE value at any point E as the ratio s(E)/s´(E)

By the proposed procedure a complicated fitting of the FEPE curve is replaced by a simple approximation of the EB spectra.

This method makes possible to determine the relative efficiency for any energy in the region of interest.The feasibility of this method was demonstrated by using external bremsstrahlung from ^{204}Tl and $^{90}Sr+^{90}Y$ sources. The FEPE values obtained using the EB radiation agree within 5% with those measured by usual method.

Levels in ^{172}Yb from the ^{172}Lu β-decay.

V.Hnatowicz, V.Zvolská, J.Zvolský, M.Fišer, J.Jursík

The high resolution measurement of ^{172}Lu and ^{172}Hf gamma-ray spectra has been made to obtain more precise values of gamma-ray intensities and energies. Various Ge(Li) detectors were used. The singles and coincidence spectra were studied.

Six weak transitions were observed for the first time and some of transitions reported previously were not confirmed. The energies most of transitions were determined with precision better than 100 eV. The structure of lower lying excited levels in ^{172}Yb is discussed in terms of the unified model.

The possible effect of Coriolis interaction on the structure of positive-parity bands with band heads at 1172 keV ($K^{\pi}=3^{+}$), 1465 keV ($K^{\pi} = 2^{+}$), 1608 keV ($K^{\pi} = 2^{+}$) and 1662 keV($K^{\pi} = 3^{+}$) is scrutinized.

Multiple scattering of fast particles in silicon (1)

J. Vincour, P. Bém
Department of Nuclear Reactions
Institute of Nuclear Physics

A ΔE - E solid state detector telescope with the corresponding particle identification system represents a valuable tool for accurate measurements of the neutron flux and of the (neutron, charged particle) reaction cross - sections. The angular spread of detected particle beam by multiple scattering in the transmission detector causes that the part of the beam can miss the stopping detector. For the calculation of the multiple scattering correction of the telescope efficiency the experimental verification of the multiple scattering theories is required. However no data exist up to date on the scattering of light particles on silicon.

In the present work the angular distributions due to multiple scattering of 6.5 MeV protons, 12.6 MeV deuterons and 24.0 MeV alpha particles in silicon (range from 50 /um to 264 /um) were measured in angular range from -10° to $+10^{\circ}$. To determine the correct maximum value fo distribution curves and the zero-angle of observed distributions a Gaussian was fitted to the experimental data. The measured angular distributions of particles have been compared with calculated ones, according to the well known theory of Molière (2) and its approximate treatment of Marion nad Zimmerman (3).

It may be concluded that the Molière theory as well as its approximate form describe well the multiple scattering of fast light nuclei in silicon, if the energy losses in the targets are small. Therefore they may be used for multiple scattering corrections of telescope detection efficiency and for the choice of telescope geometry with good reliability. However, in the case of large losses in silicon detectors the effect of energy changes should be taken into account.

---

(1) to be published in Nucl. Instr. and Meth.

(2) G. Molière, Z. Naturforsch. 2a (1947) 133: Z. Naturforsch. 3a (1948) 78

(3) J. B. Marion and B. A. Zimmerman, Nucl. Instr. and Meth. 51 (1967) 93

Determination of boron concentration profiles in silicon from $^{10}B(n,\alpha)^{7}Li$ reaction product spectra

J. Červená, V. Hnatowicz, J. Hoffmann, P. Kotas, J. Kvítek

Knowledge of the spatial boron distribution in silicon single crystals is of great importance in semiconductor component technology. At present the boron atoms are implanted or diffused. The boron atoms are introduced into silicon plates by means of implantation or diffusion. The usual boron densities and implantation depths vary from 10^{16} to 10^{19} atoms per cm^3 and from 0.1 to 1.5 μm respectively.

Determination of boron concentration profile is based on the fact, that the energy spectra of the $^{10}B(n,\alpha)^{7}Li$ reaction products depend directly on the boron depth distribution in the sample. The detected number of reaction products is proportional to the total boron content in the sample. Energy spectra of α-particles (or ^{7}Li nuclei) are measured using a simplified α-spectrometer with a silicon surface barrier semiconductor detector. All the measurements are performed on a thermal neutron beam from a VVR-S nuclear reactor [1] . The energy resolution of the spectrometer is 16.2 keV (for 1471 keV α-particles). In order to evaluate the true concentration profile from experimental spectra a deconvolution technique is used. All the procedure is highly automatized and makes it possible to analyze 100-150 samples per weak (assuming the average boron content of $\sim 10^{18}$ at/cm^2). Precision of the boron content determination is about 5 %. The spatial resolution in boron profile analysis is 350 Å and 270 Å for α-particles and ^{7}Li nuclei respectively. The sensitivity of the method is about 10^{13} at ^{10}B/cm^2 [2,3] .

The described method has also be employed for the study of anomalous boron diffusion along different crystalografic directions concentration profiles of boron implanted into Si, SiO_2 and photoresist and several other factores important for integrated circuit technology.

References:

[1] J. Kvítek, J. Hoffmann, Z. Kosina, Czech.J.Phys. B 25 (1975), 854.

[2] J. Kvítek, V. Hnatowicz, P. Kotas, Radiochem. Radioanal. Letters 24 (3) (1976), 205.

[3] P. Kotas, I. Obrusník, J. Kvítek, V. Hnatowicz, J. of Radioanalytical Chemistry 30 (1976), 475.

The (n,α) nuclear reaction investigation

J. Kvítek, J. Červená, J. Hoffmann, Yu.P. Popov

The (n,α) nuclear reaction induced by thermal neutrons is actually the alpha decay of highly excited nucleus. Its investigation can therefore render valuable information concerning the mechanism of alpha decay. A special alpha-particle spectrometer [1] has been build at a horizontal beam hole of a VVR-S thermal neutron reactor. The neutron beam ($\sim 10^8$ neutrons per $cm^{-2}s^{-1}$)passing through a silicon single crystal filter is collimated and directed to a target placed in a vacuum chamber. A charged particle telescope placed out of the neutron beam is used as an α-particle detector. The telescope consists of a dE/dX detector (a totally depleted gold surface barrier silicon diode of 100 mm^2 area and 11-15 μm thick) and a E detector (gold surface barrier silicon diode of 50-100 mm^2). The energy resolution of the alpha-particle spectrometers is 80 keV for ^{241}Am and 100-130 keV for alpha-particles from (n,α) reaction (rare earth isotope target thickness $\sim 100\ \mu g/cm^2$).

The measurements have been carried out with ^{149}Sm, ^{143}Nd and ^{180}Hf isotopes. For the ^{149}Sm nuclei the cross-sections of seven partial α-transitions were determined [2]. The $^{180}Hf(n,\alpha)$ reaction was investigated and upper limit of 0.15 mb for its cross-section was found [3]. Several cross-sections for partial α-transitions in $^{143}Nd(n,\alpha)$ reaction were also measured. Here an admixture of two-stop reaction $^{143}Nd(n,\gamma\alpha)$ was observed. Multipolarities of low energy γ-transitions between the high excited states in ^{144}Nd neutron binding energy region were determined.

References:

[1] J. Kvítek, J. Hoffmann, Z. Kosina, Czech.J.Phys. B 25 (1975), 854.

[2] J. Bischof, Z. Dlouhý, J. Kvítek, Czech.J.Phys. B 22 (1972), 9.

[3] J. Kvítek, J. Hoffmann, Z. Kosina, Yu.P. Popov, Czech.J.Phys. in press.

Thermal Neutron Capture in ^{130}Te.

K. Konečný, J. Honzátko and E.A. Eissa *

Neutron Physics Dept., Nuclear Physics Institute, Řež near Prague, ČSSR

The prompt gamma radiation following thermal neutron capture in ^{130}Te was investigated by irradiating a metalic powder sample enriched in ^{130}Te to 99 % at the horizontal experimental channel of the reactor VVR-S. A coaxial Ge(Li) detector of 17 ccm sensitive volume was used in measuring the gamma-ray spectrum in the energy range from 0.2 to 4.3 MeV. Energy calibration has been done by the use of the $^{14}N(n,gamma)^{15}N$ gamma-rays which are the main contributors to the observed background. On the basis of known intensity of the 1146.5 keV transition following the ^{130}Te ($T_{1/2}$ = 25 min) β-decay [1] absolute gamma-transition intensities in the $^{130}Te(n,gamma)^{131}Te$ reaction have been determined. Some discrepancies have been found between our results and those presented in ref. [2], which is the only work concerning the subject. Further analysis of the results is in progress.

1) S.V. Jackson, W.B. Walters and R.A. Meyer Phys.Rev. C 11, 1323 (1975)

2) E.A. Rudak, A.V. Soroka and V.N. Tadeush. Proc. 27th USSR Conf. on Nuclear Spectroscopy and Nuclear Structure, Tashkent, 1977.

* On leave from Egypt, E.A.R. Atomic Energy Establishment

Fission:

R. Bayer, Z. Dlouhý, J. Švanda.

In the field of polar alpha particle emission from the thermal neutron fission of ^{235}U energy distribution of alpha particles emitted in the direction of the fission axis in coincidence with fission fragments was measured. This distribution may be regarded as the superposition of two Gaussian distributions of average energies $\langle E_o^{(1)} \rangle = 22.9 \pm 0.2$ MeV and $\langle E_o^{(2)} \rangle = 26.7 \pm 0.5$MeV with standard deviations $\sigma^{(1)} = 1.55 \pm 0.2$ MeV and $\sigma^{(2)} = 2.1 \pm 0.5$ MeV respectively. There is some indication that these two groups of long range alpha particles be emitted in the flight direction of the light and heavy fragment respectively. This will be studied still further [1], [2].

During the last year a method of studying the two-step reaction $^{235}U(n_{th}, \text{gamma-f})$ with the emission of pre-fission gamma rays by means of the detection of characteristic X ray radiation was analysed. From measurements at the reactor VVR-S the value of the cross-section for the emission of characteristic X ray radiation was deduced and an estimation of the $^{235}U(n_{th}, \text{gamma-f})$ reaction cross-section was given. This work was carried out in cooperation with that presented in ref. [3].

At present time an experimental set-up for simultaneous registration of up to six parameters of the fission process is being prepared. The apparatus is designed for studying the fission process of ^{252}Cf and the thermal neutron induced fission of heavy elements.

[1] R.Bayer, J.Čvanda, Z.Dlouhý, I.Wilhelm, Polar Alpha Particle emission from ^{235}U thermal neutron induced fission. Acta Physica Slovaca, 25(1975), No. 2-3, 199-202.

[2] I.Wilhelm, R.Bayer, J.Čvanda, Z.Dlouhý, Investigation of polar LRA particle accompanied fission of ^{235}U. Nuclear Physics, A 262(1976), 301-306.

[3] Z.Dlouhý, J.Krišťak, C.Pantělejev, Vychod rentgenovskich lučej i suščestvovanije (n, f) processa na jadre ^{235}U. Joint Institute for Nuclear Research Dubna, U.S.S.R., Report P3-9613, 1976.

Gamma-radiation from the ^{209}Bi (^{3}He,3nγ)^{209}At reaction

J.Adam, A.Kuklík, A.Špalek, D.Vénos, M.J.Kuznecova
Nuclear Physics Institute, Czech.Acad.Sci., 250 68 Řež u Prahy, Czechoslovakia

Gamma-radiation from the reactions of 28 MeV and 26 MeV ^{3}He-ions on ^{209}Bi target has been studied by means of Ge(Li) detectors. The γ-rays were detected at an angle of about 90° with respect to the beam. The results of previous studies of ^{209}At nucleus have been verified and completed. Two new levels at energies of 640 keV and 1270.5 keV have been introduced. For the 1270.5 keV state the $^{15}/_{2}^{-}$ characteristics have been proposed and this state has been interpreted as the number of $\pi(h_{\frac{9}{2}}^{3})$ $\nu(j^{-2})_{0+}$ multiplet.

The upper limits of the prompt γ-ray transitions half-lives (< 4 ns) have been determined. Time curves of some γ-ray transitions contained also components with long half-life (> 100 ns). These components could partly correspond to the decay of 680 ns isometic state in ^{209}At. Besides that, the delayed components of some transitions may indicate also existence of another isomeric state.

The experimental level energies have been compared with the theoretical values calculated by Paar in terms of three particle cluster - vibration model. For some lower spin levels rough agreement between calculated and experimental states has been found.

Additionally, 15 prompt γ - ray transitions have been observed, which could belong also to ^{209}At and which were not placed in the level scheme.

Due to the 9/2 target spin (^{209}Bi) it was posible to excite in ^{209}At the spins up to 29/2 in contrast to our previous works with 28 MeV ^{3}He ions bombarding targets with lower spins ^{89}Y (1/2), ^{159}Tb (3/2), ^{197}Au (3/2), where we have observed only the spins up to 25/

Reference

J. Adam et.al. to be published in Czech. J. Phys. B

Energy levels in ^{197}Tl populated in the ^{197}Au(^{3}He,3nγ)^{197}Tl reaction

D.Venos, J.Adam, J.Jursík, A.Kuklík, L.Malý, A.Špalek, L.Funke, P.Kemnitz

Nuclei from transitional region (A ~190) were the subject of several recent theoretical investigations [1,2] . It appeared desirable to have more complete experimental data about the nuclei in question and among others about ^{197}Tl [3] .

The energy levels in ^{197}Tl were populated in ^{197}Au(^{3}He,3n) reaction and deexciting γ-radiations were measured by means of Ge(Li) detectors. The ^{3}He beam of 28 MeV particle energy was produced at the U-120 cyclotron of the Nuclear Physics Institute in Řež. The experiments were carried out at energies of 28 and 24 MeV, where the lower energy was achieved by introducing aluminium degrading foils into the ^{3}He beam. Metallic gold foil targets of various thicknesses were mounted in the target chamber.

Altogether it was measured singles and delayed spectra, coincidence relations and angular distributions of γ -rays emitted in the reaction mentioned above. Coincidence data obtained confirmed some known positive parity states and the position of the $9/2^-$ isomer at 608.6 keV. Previously tentative established perturbed rotational-like band based on $9/2^-$ isomeric state was also proved. Further new levels at 1554.9, 1868.3, 1954.8 and 2115.8 keV were established from the coincidence spectra. For several excited levels the values of spins and parities were also determined.

It occured that the triaxial-rotor-plus-particle model by Meyer-ter-Vehn [1] reproduces the experimental level order correctly. The overall extension of the theoretical spectrum may be due to the neglect of the softness of the nucleus.

References

[1] J.Meyer-ter-Vehn, Nucl.Phys. A249 (1975), 111, 141
[2] G.Leander, Nucl.Phys. A273 (1976), 286
[3] D.Venos, J.Adam et al., Nucl.Phys. A280 (1977), 125

Levels of ^{89}Nb populated in the ^{89}Y (^{3}He,3nγ) reaction.

A.Špalek, J.Adam, J.Jursík, A.Kuklík, L.Malý, D.Venos, P.Šimeček, G.Winter, L.Funke.

Nuclear Physics Institute, Czech.Akad.Sci., 250 68 Řež u Prahy, Czechoslovakia

The excited states of ^{89}Nb nucleus have been investigated by means of (^{3}He,3nγ) in-beam γ-ray spectroscopy. A metallic or oxidic yttrium target was bombarded with ^{3}He ions provided by the U-120 cyclotron of the Nuclear Physics Institute in Řež. The energy of ^{3}He particles could be decreased from the maximum energy of 28 MeV down to 20 MeV by introducing Al foils into the beam.

The γ-ray spectra were measured by means of coaxial Ge(Li) detectors with active volumes of 7 - 40 cm^3. The γ-γ coincidences, angular distributions and life-time characteristics were studied, too.

When analyzing the results we have observed number of reactions competing with the (^{3}He,3n) reaction studied, as e.g.: (^{3}He,2n),(^{3}He,pn),(^{3}He,p2n) and (^{3}He,^{3}He').

A level scheme of ^{89}Nb has been constructed containing eight new levels : 1003.4 ($^{13}/_{2}^{+}$), 1935.1 ($^{17}/_{2}^{+}$), 2150.8 ($^{21}/_{2}^{+}$ or $^{17}/_{2}^{-}$), 2192.3 ($^{21}/_{2}^{+}$ or $^{17}/_{2}^{-}$),2516.8, 2531.8, 2955.1 and 3402.3 keV. The 2192.3 keV level has been identified as a high-spin isomer with $T_{\frac{1}{2}}$ = 15±5 ns. The ^{89}Nb level structure has been compared with the even-mass neighbours (^{88}Zr and ^{90}Mo). The first excited states in ^{88}Zr, ^{90}Mo and ^{89}Nb are very close in energy which gives the basis for use of weak coupling model.

Alternatively the observed states of ^{89}Nb could be explained on the basis of the shell model. In that case the coupling of two neutron holes in $1g_{\frac{9}{2}}$ orbital to the known excitations of the proton system should be considered.

Reference :

A.Špalek et.al., Nucl.Phys. A280 (1977) 115