International Atomic Energy Agency

INDC(CCP)-112/LN

INDC

INTERNATIONAL NUCLEAR DATA COMMITTEE

REVIEW OF EXPERIMENTAL WORK BY SOVIET SCIENTISTS IN THE FIELD OF NUCLEAR DATA ACQUISITION

V.M. Kulakov

Translated by the IAEA

June 1977

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

Reproduced by the IAEA in Austria
June 1977

77-5382

INDC(CCP)-112/LN

REVIEW OF EXPERIMENTAL WORK BY SOVIET SCIENTISTS IN THE FIELD OF NUCLEAR DATA ACQUISITION

V.M. Kulakov

Translated by the IAEA

June 1977

77-4333
Translated from Russian

REVIEW OF EXPERIMENTAL WORK BY SOVIET SCIENTISTS IN THE FIELD OF NUCLEAR DATA ACQUISITION

V.M. Kulakov

I. Neutron data

A cascade accelerator has been used as a basis on which to construct a correlation spectrometer designed for time-of-flight measurement of spectra and angular distributions of inelastically-scattered neutrons with 14 MeV energy [1]. Together with klystron bunching, the spectrometer makes use of the modulation of an ion beam by a pseudorandom signal. The resolving power of the spectrometer is determined by the width of the bunched pulses, while modulation by the pseudorandom signal makes it possible to reduce the effect of the non-coherent background on the statistical accuracy. The duration of the neutron pulse from the target is 2.5 nsec, and the length of the pseudorandom pulse code is 15.

The correlation spectrometer has been used to measure secondary neutron spectra in plutonium-239 at an initial neutron energy of 14.3 MeV [2]. To obtain the neutrons use was made of the reaction $T(d,n)^4He$. Resolution of the spectrometer over the elastically-scattered neutron peak width is 4.5 nsec for a path length of 3 m. The sum spectra for neutrons from the reactions (n,f), (n,n'), (n,2n) and (n,3n) have been measured over the energy range 100 keV-14 MeV at angles of 30, 60, 90, 120 and 150°. A set of algorithm-based programs has been worked out for processing data obtained with the correlation spectrometer.

Experiments have been carried out with an evacuated model of a pulsed neutron generator with a laser deuteron source [3]. As the laser targets use was made of LiD and TiD, i.e. the reaction $D(d,n)^3He$ was used to obtain the neutrons. The neutrons were recorded by being slowed down to thermal velocities, followed by counting with a boron counter. A yield of $\sim 10^6$ n/pulse was obtained at an accelerating voltage of 150 keV. Evaluations of the neutron yield under various generator conditions and for different life times of the laser target have been made.

A multiseries macroscopic fast-neutron spectrometer has been constructed for the study of fission neutron spectra [4]. It consists of a rectangular block made of eight polyethylene slabs 5 cm thick, with channels drilled through them for BF_3 or ^3He counters. Each series of counters is connected to a single recording channel. This spectrometer has been used to measure [5] the intermediate energy ratios for neutrons emitted during the fission of uranium-233, uranium-235 and plutonium-239, and during spontaneous fission of califronium-252 (0.967 ± 0.003):(0.946 ± 0.003):(0.983 ± 0.002):1.

The time-of-flight method has been used to measure prompt neutron spectra for the fission of uranium-233, uranium-235 and plutonium-239 by thermal neutrons over the range 0.01-4 MeV, and for spontaneous fission of californium-252 over the range 0.01-10 MeV [6]. The measurements were made with a thermal neutron beam in the SM-2 reactor, using non-threshold neutron detectors with a uranium-235 base.

Cross-sections for fast-neutron fission of uranium-233, uranium-238, plutonium-239, plutonium-240, plutonium-241 and plutonium-242 with respect to the fission cross-section for uranium-235 have been measured over a wide range of neutron energies [7]. The work was carried out in electrostatic accelerators, using the reactions Li(p,n), T(p,n) and D(d,n) as the neutron sources. A back-to-back ionization chamber served as the fission fragment detector.

The spectra for secondary neutrons produced by the bombardment of uranium-238 by 9.1 ± 0.2 MeV neutrons have been measured at angles of 30, 60, 90, 120 and 150° by the time-of-flight method in the 150-cm FEI cyclotron [8]. There have been determinations of double differential interaction cross-sections for neutrons and uranium-238 nuclei. The integrated neutron spectrum for the reactions (n,n) and (n,2n) has been analysed within the framework of the pre-equilibrium model.

Neutron spectra at 5 angles for the reaction $^{27}Al(p,n)^{27}Si$, at a 10.3 ± 0.1 MeV proton energy, have been measured by the time-of-flight method in the FEI cyclotron (150 cm) [9]. The resolving power of the spectrometer was 1.4 nsec/m. The stability with which the spectrometer operated was checked by multiple measurement of the neutron spectrum of californium-252 spontaneous fission. The discrete neutron groups observed in the spectra tally well with the energy level diagram for ^{27}Si. The angular distribution of the neutron group corresponding to the ground state is 90° symmetric.

Neutron spectra and angular distributions for the reactions $^{181}Ta(n,n')^{181}Ta$ at an initial neutron energy of 9.1 ± 0.2 MeV, and $^{181}Ta(p,n)^{181}W$ at Ep = 10.2 ± 0.2 MeV have been measured by the time-of-flight method in the FEI cyclotron at angles of 30, 60, 90, 120 and 150° [10]. The initial proton and neutron energies were selected so as to attain the same excitation energy interval. It turned out that for the same excitation energy the integrated inelastically-scattered neutron spectrum has a more rigid shape than the neutron spectrum for the reaction (p,n), while the angular distribution of the inelastically-scattered neutrons indicates the presence of an asymmetric component, more especially in the higher energy bands.

Neutron spectra and angular distributions for the reaction $^{115}In(p,n)^{115}Sn$ have been measured by the time-of-flight method for 5.6 and 7 MeV proton energies [11]. The spectrometer's time resolutions was 1.5 nsec/m, and the path length 2 m. For all the energy regions the angular distributions proved for practical purposes isotropic or symmetric with respect to the neutron emission angle $\vartheta = 90°$, which indicates that the reaction proceeds mainly through the compound nucleus. For all the measured spectra the high energy neutron yield proved less than was predicted by the Maxwell distribution.

Functions for passage through uranium-235 samples were measured in energy groups ranging between 2 eV and 20 keV [12]. Proportional ^{3}He counters and fast-response fission chambers with uranium-235 layers were used as the detectors. The measurements were made with the aid of a neutron time-of-flight spectrometer in the fast pulsed reactor (IBR) at the Joint Nuclear Research Institute (OIYAI). Data analysis provided evaluations of the factors for resonance blocking of the uranium-235 fission cross-section. Similar measurements are planned for 1977 with plutonium-239.

A device has been constructed for obtaining ion current pulses over the nanosecond and microsecond ranges with a broad pulse recurrence frequency band, using the EG-1 FEI electrostatic generator and applying the chopping and bunching method [13]. The device permits neutron spectrometry in the fast and resonance neutron regions and, more especially, enables the saturated resonance method to be used for an absolute measurement of the neutron radiative capture cross-sections.

A neutron time-of-flight spectrometer with a resolution of ~0.3 nsec/m has been constructed [14] on the basis of the pulsed electrostatic accelerator belonging to the Atomic Energy Institute (beam parameters: current pulse length 1.5 nsec; amplitude up to 3 mA and mean target current 8 μA, for a recurrence frequency of 2 MHz). The accelerator makes it possible to obtain the same data as when using underground nuclear explosions as the neutron source, but under more stable and controllable conditions, with considerably less expense, and with much smaller amounts of fissile material (reduction by a factor of 10^4-10^6).

The time-of-flight method has been used in the accelerator to measure differential elastic scattering cross-sections at 90°, and partial inelastic scattering for the 2^+, 4^+, 1^- and 3^- states of the uranium-238 nucleus [15]. The efficiency of the detector (stilbene crystal and FEU-30 photomultiplier) was determined from the neutron spectrum for spontaneous fission of californium-252. A uranium sample in the form of a hollow cylinder 32 mm high, 36 mm in diameter and 4 mm in wall thickness served as the scatterer. The total energy resolution was ~40 keV for 1 MeV neutrons.

En (keV)	$\frac{d\sigma_{el}}{d\vartheta}_{90°}$ (barn/steradian)	σ_{ind} (barn) 45 keV	148 keV	680 keV	730 keV
1200	0.169 ± 0.010	0.84 ± 0.14	0.51 ± 0.04	0.30 ± 0.06	
1350	0.161 ± 0.014	0.62 ± 0.21	0.48 ± 0.04	0.24 ± 0.03	0.17 ± 0.03
1400	0.161 ± 0.014	0.58 ± 0.35	0.43 ± 0.03	0.19 ± 0.02	0.17 ± 0.03

A facility has been constructed, following a feasibility study, for the measurement of the spectrum for the multiplicity of neutrons and gamma quanta emitted by excited nuclei, and for simultaneous spectrometry of neutrons exciting the nucleus [16]. The facility includes a 12-section 4π NaI(Tl) detector with ~90% efficiency in recording the capture event; an (n,γ) converter, electronic instruments for shaping the detector pulses, a multi-input time interval measuring device, and a minicomputer. Two detectors with crystal volumes of 17 and 26 litres were used for the work. The spontaneous fission multiplicities for californium-252 and ^{133}Cd + n have been measured, and neutron resonance spins have been determined for cadmium-133. The capture cross-section (σ_γ) for uranium-238 in the neutron energy range $0.1 \leq En \leq 30$ keV has been measured. The statistical error in $<\sigma_\gamma>$ is less than 2% [17]. Over the same neutron energy region there have been measurements of the absolute value of α, the fission cross-section and capture cross-section for uranium-235 [18]. The statistical error in $<\alpha>$ is less than 2%, and the error in $<\sigma_f>$ not more than 2-3% (disregarding the calibration error).

The SM-2 reactor (NIIAR Institute, Dimitrovgrad) has been used to measure cross-sections for fission of uranium-233 by 0.0253 eV, 2, 24, 55 and 144 keV neutrons [19]. A double fission chamber was used. The fission cross-section of uranium-235 measured earlier with an accuracy of 2% was used as the standard. For the given neutron energies the following fission cross-sections have been obtained: 528.6 ± 8.0; 8.93 ± 0.22; 2.94 ± 0.08; 2.45 ± 0.06 and 2.16 ± 0.05 barn.

Absolute measurements of the fission cross-sections for uranium-233, neptunium-237 and plutonium-239 have been made with 14.8 MeV energy neutrons [20]. The neutron source was a neutron generator based on the reaction $^3H(d,n)^4He$. The method used was to record the coincidence of fission in the target with particles accompanying the neutrons. Measurement accuracy was better than 2%.

Fission cross-sections

	σ_f (barn)
^{233}U	2.350 ± 0.042
^{237}Np	2.430 ± 0.047
^{239}Pu	2.620 ± 0.046

For the same isotopes there have been measurements of the neutron fission cross-sections for the fission spectrum of californium-252 [21]. The error in measurement is 1.6%.

	σ_f (millibarn)
^{233}U	1947 ± 31
^{237}Np	1442 ± 23
^{239}Pu	1861 ± 30

The work was carried out with the support of the IAEA (Research Contract No. 1718/RB).

A study has been made of the fission of actinium-227 by neutrons and gamma rays [22]. The dependence of the photofission yield on the boundary bremsspectrum energy over the range 7.5-12.75 MeV has been measured. Neutron cross-sections have been used to determine fission barriers for $B_f(^{228}Ac) = 7.2 \pm 0.2$ MeV, and $B_f(^{227}Ac) = 7.0 \pm 0.5$ MeV, and they have also been determined from the photofission yields for $B_f(^{227}Ac) = 7.8 \pm 0.5$ MeV.

The time-of-flight method has been used in the SM-2 reactor to measure total neutron cross-sections for the isotopes curium-244, curium-245, curium-246 and curium-248 [23]. The time resolution was 70 nsec/m, and the statistical accuracy 0.5-1.5%. The resonance parameters were computed by the shape and area method on the basis of the Breit-Wigner single-level formula.

The neutron fission spectrum for californium-252 has been measured by the time-of-flight method over the energy range 0.01-10 MeV [24]. As neutron detector use was made of an ionization chamber with 12 uranium-235 oxide layers 10 cm in diameter, the total amount of material being 1.5 g. The efficiency attained in recording californium-252 fission fragments was 99%. A search has been made for the fine structure in the neutron spectrum for spontaneous fission of californium-252 in the 1-5 MeV range [25]. Irregularity in the spectrum within the bounds of the experimental errors (1.5-2.5%) was not observed.

At the Joint Institute for Nuclear Research (Dubna) a pulsed periodic reactor (IBR-2) is approaching completion [26]. The reactor will generate slow neutron pulses lasting 100 μsec and with a peak thermal neutron flux density of 10^{16}-10^{17} n/cm^{2}sec. The reactor is being fitted with experimental facilities for physical studies based on neutron time-of-flight spectroscopy.

II. Non-neutron data

The twenty-seventh conference on nuclear spectroscopy and structure of the atomic nucleus was held in Tashkent from 22 to 25 March. More than 700 papers were presented at the meeting. The collection of abstracts contains a wealth of reference material on nuclear data obtained by Soviet scientists in 1976. Suffice it to say that the energy level diagrams have been made more accurate or plotted afresh for more than 150 isotopes, and the discovery of 9 new isotopes (barium-177, lanthanum-123, lanthanum-124, lanthanum-125, cerium-124, cerium-125, cerium-126, cerium-127 and rhenium-173) was reported. The half-lives of a number of isotopes have been calculated more accurately or measured for the first time.

Let us take a brief look at some of the papers presented at the conference.

An analysis of experimental data obtained since 1945 has been made for 100 nuclides used in the national economy [27]. Evaluated data for all the nuclear-physical characteristics of the nuclides have been reported and the table covers the following nuclei:

^{3}H, ^{7}Be, ^{14}C, ^{22}Na, ^{24}Na, ^{32}P, ^{33}P, ^{35}S, ^{36}Cl, ^{37}Ar, ^{45}Ca, ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{59}Fe, ^{56}Co, ^{57}Co, ^{58}Co, ^{60}Co, ^{63}Ni, ^{65}Zn, ^{68}Ga, ^{68}Ge, ^{71}Ge, ^{74}As, ^{85}Kr, ^{85}Sr, ^{90}Sr, ^{88}Y, ^{90}Y, ^{91}Y, ^{95}Zr, ^{95}Nb, ^{93}Mo, ^{99}Tc, ^{103}Ru, ^{106}Ru, ^{103m}Rh, ^{106}Rh, ^{105}Ag, ^{109}Cd, ^{113m}In, ^{114m}In, ^{113}Sn, ^{122}Sb, ^{124}Sb, ^{125}Sb, ^{125m}Te, ^{125}I, ^{129}I, ^{131}I, ^{131m}Xe, ^{131}Cs, ^{134}Cs, ^{137}Cs, ^{133}Ba, ^{140}Ba, ^{140}La, ^{139}Ce, ^{141}Ce, ^{144}Ce, ^{144}Pr, ^{146}Pm, ^{147}Pm, ^{155}Eu, ^{153}Gd, ^{160}Tb, ^{165}Er, ^{170}Tm, ^{171}Tm, ^{169}Yb, ^{181}Hf, ^{181}W, ^{185}W, ^{185}Os, ^{192}Ir, ^{195}Au, ^{198}Au, ^{203}Hg, ^{204}Tl, ^{207}Bi, ^{210}Po, ^{234}U, ^{237}U, ^{237}Np, ^{239}Np, ^{236}Pu, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{242}Am, ^{242m}Am, ^{243}Am, ^{242}Cm, ^{244}Cm, ^{249}Cf, ^{252}Cf

A machine-based data bank on the properties of even-even nuclei with $150 \leqslant A \leqslant 196$ and $A \geqslant 220$ has been established [28].

At the Joint Nuclear Research Institute (Dubna) a procedure has been developed for high-precision gamma spectroscopy based on the use of semiconductor detectors [29]. A complete set of standards for energies and relative gamma ray intensities of radioactive nuclei has been put together. The summary data in the tables are the result of processing more than 3000 instrumental spectra.

A pair spectrometer for hard gamma radiation has been constructed with a view to studying (p,γ) reactions at low and medium proton energies [30]. The spectrometer is constructed on the basis of a germanium detector (DGDK-70A) and four NaI(Tl) crystals of diameter 120 x 120 mm. Its energy resolution for $E_\gamma \approx 10$ MeV is 35 keV, its efficiency compared with the single-crystal model is ~10%, and the Compton background attenuation is by a factor of 40.

A combined gamma-spectral absorption method has been developed for determining uranium, transuranic isotopes and fission products in solutions from the reprocessing of irradiated fuel elements [31]. A program for computer processing of the spectrometric data obtained has been written.

In 1976 the Atomic and Nuclear Data Centre operated by the State Committee on the Utilization of Atomic Energy was working on the software required for exchanges with foreign countries. At the present time the tapes prepared by the Centre are being read in all the centres to which they are dispatched.

An evaluation has been made of the radiation characteristics occurring during decay of nuclides with A = 95, and there has been re-evaluation of the half-life of tritium with allowance for the dependence of its half-life on the electron environment of the nucleus in the material.

Centres working with the above-mentioned Atomic and Nuclear Data Centre have been furnished with bibliographic material on Soviet nuclear-physical research and have received their first tape with numerical data from Soviet studies on cross-sections and radioisotope yields.

Over the last few years there has been a successful new development - the study of gamma spectra during inelastic scattering of fast reactor neutrons. Scientists at the Atomic Energy Institute, together with Iraqi physicists (Baghdad), have obtained a wealth of experimental material so far; some of it has been incorporated into the "Atlas of Gamma-Ray Spectra from Inelastic Scattering of Fast Reactor Neutrons; $Z \leqslant 42$" (the authors of which are A.M. Demidov, M.R. Akhmed, L.I. Govor et al.), which is ready for press.

References

1-26 References to papers presented at the IVth All-Union Conference on Neutron Physics held in Kiev, 18-22 April 1977.

27, 28 and 30, 31 References to papers in the proceedings of the XXVIIth Conference on Nuclear Spectroscopy and on the Structure of the Atomic Nucleus, held at Tashkent, 22-25 March 1977. Published by "Nanka", Leningrad 1977. (Ref. 27 - page 529, Ref. 28 - page 523, Ref. 30 - page 128, Ref. 31 - page 563)

29 Ts. Vylov. JINR (Dubna) preprint P6-10417, 1977.