ISINN-15

XV International Seminar
on Interaction of Neutrons with Nuclei

Neutron Spectroscopy, Nuclear Structure, Related Topics

Dubna, 2007

Abstracts

Joint Institute for Nuclear Research

NEUTRON SPECTROSCOPY, NUCLEAR STRUCTURE, RELATED TOPICS

XV International Seminar on Interaction of Neutrons with Nuclei

Dubna, May 16–19, 2007

Abstracts of the Seminar

Dubna 2007

УДК 539.125.5(042)
ББК 22.383.2я431+22.383.5я431+22.383.25я431
N50

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N50 **Neutron** Spectroscopy, Nuclear Structure, Related Topics: Abstr. of the XV Intern. Seminar on Interaction of Neutrons with Nuclei (Dubna, May 16–19, 2007). — Dubna: JINR, 2007. — 66 p.
ISBN 5-9530-0145-2

Нейтронная спектроскопия, структура ядра и связанные вопросы: Тез. докл. XV Междунар. семинара по взаимодействию нейтронов с ядрами (Дубна, 16–19 мая 2007 г.). — Дубна: ОИЯИ, 2007. — 66 с.
ISBN 5-9530-0145-2

УДК 539.125.5(042)
ББК 22.383.2я431+22.383.5я431+22.383.25я431

ISBN 5-9530-0145-2

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DYNAMICS OF TERNARY FISSION

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The model is proposed to calculate the trajectories of fission fragments in ternary fission. The motion starts from the scission point. The fragments of a ternary system at the scission point are considered as clusters [1]: three coaxial fragments, two heavy fragments and one light between them. The potential energy of the light charged particle (LCP) in the field of two heavy fragments is calculated at the scission point. Due to the use of the double-folding potential of nuclear interaction, the initial coordinates of the LCP are defined by the minimum of potential energy, and hence, are not the free parameters. The initial velocity of the LCP is defined by the height of the Coulomb barrier. Varying the direction of initial velocity of the LCP, we find the trajectories leading to emission of the LCP. Analyzing these trajectories, we obtain the energy and angular distributions of the LCPs. The results of trajectory calculations for the spontaneous ternary fission of ^{252}Cf accompanied by ^{4}He and ^{10}Be are compared with the experimental data.

1. A.V.Andreev *et al.*, Eur. Phys. J. **A** 30, 579 (2006).

ANALYTIC MODEL FOR GEOMETRIC PHASE EFFECT IN PARTICLE EDM SEARCHES

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It was shown in [1,2] that the geometrical phase effect resulting from the interaction of the well-known $\vec{v} \times \vec{E}$ field with magnetic field gradients yields a systematic error in the searches for particle electric dipole moments (EDM). This interaction produces a frequency shift linear in the electric field, mimicking an EDM. The frequency shift is determined by a velocity correlation function of the stored gas [3].

An analytic model for the velocity correlation function was proposed in [4]. It allows us not only to reproduce the results [2], obtained without gas collisions, but to predict as well the frequency shifts when collisions are taken into account. Averaging over velocity distributions of particles gives the temperature dependence of the effect.

1. E.D.Commins. Am. J. Phys. **59** 1077 (1991).
2. J.M.Pendlebury et al. Phys. Rev. A **70** 032102 (2004).
3. S.K.Lamoreaux, R.Golub. Phys. Rev. A **71** 032104 (2005).
4. A.L.Barabanov, S.K.Lamoreaux, R.Golub. Phys. Rev. A **74** 052115 (2006).

Neutron gamma irradiation method to measure neutron inelastic scattering cross section using very cold neutrons

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The method utilizes measurement with the help of a (HP)-Ge γ-ray detector by concurrent counting events of neutron capture and neutron up-scattering in the sample that is illuminated by a flux of VCN. The capture event is accompanied by prompt characteristic γ-rays with the well known energies of γ-quanta that correspond to isotopes that compose the sample. The up-scattering event transfers VCN into thermal neutron that flies away the sample and then being captured by a special ^{10}B-converter generating γ-ray with energy 477 keV of γ-quanta. Both kinds of events are proportional to corresponding (capture and inelastic scattering) cross sections. Thus the ratio of registered counts of both kinds of events does not depend on neither parameters of VCN flux nor sample geometry. Finally the required neutron inelastic scattering cross section is deduced from this ratio basing on known capture cross section for main isotopes of the sample.

THE STRUCTURE OF P-ODD AND P-EVEN CORRELATIONS WITH PARTICIPATION OF THE THIRD PARTICLE FOR TERNARY FISSION

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For the appearance of P-odd and P-even correlations in fission products angular distributions (AD) for fission of the compound nucleus formed by cold polarized neutron capture by inoriented nucleus-target it is necessary to fulfill two conditions [1–2]. Firstly, the fission mode must be connected with axially symmetrical and pear-like shape of fissile nucleus. Secondly, the fission fragments flight directions must be collinear to symmetry axis of fissile nucleus which allows to use Wigner functions $D^J_{MK}(\omega)$ connected with polarization effects for description of fission fragments AD. It is shown that these conditions are realized in spite of three body effects for ternary fission when the normalized third particles AD $P_3(\theta_{\mathbf{n}_3,\mathbf{n}}) = \sum_L A_L Y_{L0}(\theta_{\mathbf{n}_3,\mathbf{n}})$ does not depend on the polarization of compound nucleus and is defined by angle $\theta_{\mathbf{n}_3,\mathbf{n}}$ between flight directions of the third particle $\mathbf{n}_3$ and light fission fragment $\mathbf{n}$. Then the normalized AD of ternary fission products which takes into account P-odd and P-even correlations has the form:

$$P(\Omega_{\mathbf{n}},\Omega_{\mathbf{n}_3}) = \frac{1}{4\pi}P_3(\theta_{\mathbf{n}_3,\mathbf{n}})\{1 + a_o(\boldsymbol{\sigma},\mathbf{n}) + a_e(\mathbf{k},\mathbf{n}) + \bar{a}_e(\boldsymbol{\sigma},[\mathbf{k},\mathbf{n}])\}, \quad (1)$$

where $\boldsymbol{\sigma}$ and $\mathbf{k}$ are unit vectors of neutron polarization and ingoing neutron flight direction correspondingly and coefficients a_o, a_e and $\bar{a}_e$ coincide with P-odd and P-even correlation coefficients for binary fission. The integration of AD (1) over directions of light fragment $\mathbf{n}$ taking into account the experimental AD $P_3(\theta_{\mathbf{n}_3,\mathbf{n}})$ for α-particles gives AD of α-particle $P(\Omega_{\mathbf{n}_3})$ in ternary fission defined by formula (1) with replacement of $P_3(\theta_{\mathbf{n}_3,\mathbf{n}})$ by 1, the vector $\mathbf{n}$ in the braces by $\mathbf{n}_3$ and multiplication of coefficients a_o, a_e, $\bar{a}_e$ by a factor 0,12. If fission fragments detectors don't distinguish light and heavy fission fragments AD (1) in contrast to binary fission is not zero and gives the information about AD $P_3(\theta_{\mathbf{n}_3,\mathbf{n}})$ with odd values L. The use of light fission fragments detectors oriented parallel and antiparallel to vector $\boldsymbol{\sigma}$ allows to get the information about third particle AD $P_3(\theta_{\mathbf{n}_3,\mathbf{n}})$ for even and odd values of orbital moments L.

On the basis of formula (1) the possibilities of the P-odd and P-even correlations use for the observations of ternary fission with pre-scission neutrons and γ-quanta as third particles were analyzed. This work was supported by INTAS (grant № 03-51-6417) and by RFBR (grant № 06-02-16853).

[1] O.P. Sushkov and V.V. Flambaum, Uspekhi Fiz. Nauk 136, 3 (1982).
[2] S.G. Kadmensky, Phys. of At. Nucl. 66, 1739 (2003); 67, 258 (2004).

FISSILE NUCLEI ROTATION EFFECT IN $^{235}U(n,\gamma f)$ - PROCESS

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Abstract

Recently the small shifting of the angular distribution of light charged particles (LCP) relative to the fission axis in ternary fission of ^{235}U nuclei induced by cold polarized neutrons have been occasionally found at ILL HFR [1]. The authors explained this effect by the rotation of the fissile nuclei and called it the "ROT-effect". It's evident that the same effect can be also in the binary fission accompanied by some particle. From this reason we've performed at BENSC HMI BER-II reactor an experiment to search for the ROT-effect in $^{235}U(n,\gamma f)$ process. The small shifting of the pre-scission gamma-quanta angular distribution relative to the fission axis in ^{235}U fission induced by cold polarized neutrons has been observed [2]. The origin of the gamma-quantum which is the trigger of the ROT-effect is the task of our future investigations.

This work was supported by RFBR grant 04-02-16091, Russian Agency of Atomic Energy and Russian Federal Agency of Science and Innovations.

1. **A.Gagarski, I.Guseva, F.Gönnenwein, et al., XIV International Seminar on Interaction of Neutrons with Nuclei, Dubna (2006), Abstracts volume, p. 33.**

2. **G.V. Danilyan, P. Granz, V.A. Krakhotin, F. Mezei, V.V. Novitsky, V.S. Pavlov, M. Russina, P.B. Shatalov, T. Wilpert. Preprint 27-06 ITEP, 2006**

Heavy metals in mosses collected in the surroundings of oil plant SLOVNAFT

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The refinery and petrochemical company Slovnaft, one of the biggest in the Central Europe, allocates in the area of 5, 2 sq. km at the south-east border of a capital of the SR Bratislava. Yearly it processes approximately 5 millions tones of crude oil supplied mainly from the Russian Federation, which is transported to Bratislava by means of the pipeline system DRUŽBA. SLOVNAFT, a.s., delivers to the market the complete range of refinery, petrochemical products and plastics. The terrestrial moss *P. schreberi* and *H. splendens* were collected in the surroundings of the oil plant Slovnaft to monitor heavy metal atmospheric deposition. Epithermal neutron activation analysis (ENAA) and atomic absorption spectrometry (AAS) allowed the determination of vanadium, chromium, iron, cobalt, nickel, copper, zinc, arsenic, bromine, silver, cadmium and lead. The absolute, mean, median, maximum and minimum air pollution levels recorded at the affected areas are discussed. A high level of air pollution has been recorded near the zone of the oil-refining industrial complex. The concentrations of some elements (Al, V, Cr, Fe, Co, Ni, Sr, Mo, In and Sb) are up to ten times higher than at a distance of 40 km from the plant which is considered a relatively clean area. However, Al, V, Cr, Fe, Co, and Sr concentrations exceed those for the Slovakian median values.

DIFFERENTIAL AND ANGLE-INTEGRATED CROSS SECTION MEASUREMENT FOR THE $^{64}Zn(n,\alpha)^{61}Ni$ REACTION AT 2.5, 4.0 AND 5.5 MeV *

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Abstract

The activation method is not feasible for the $^{64}Zn(n,\alpha)^{61}Ni$ reaction cross section measurement because the ^{61}Ni isotope is stable. By using a twin-gridded ionization chamber, differential and angle-integrated cross section data of the $^{64}Zn(n,\alpha)^{61}Ni$ reaction were measured at neutron energies of 2.5, 4.0 and 5.5 MeV. The experiment was performed at the 4.5 MV Van de Graaff accelerator of the Institute of Heavy Ion Physics, Peking University, China. Quasi-monoenergetic neutrons of 2.54 MeV were produced through the $T(p,n)^3He$ reaction with a solid Ti-T target, and those of 4.0 and 5.5 MeV were produced through the $D(d,n)^3He$ reaction with a deuterium gas target. A BF_3 long counter was used as the neutron flux monitor and the absolute neutron flux was determined by the $^{238}U(n,f)$ reaction. Results of our work are compared with other measurements and evaluations.

* Project supported by National Key Project for Cooperation Researches on Key Issues Concerning Environment and Resources in China and Russia (Grant No. 2005CB724804), and by National Natural Science Foundation of China (Grant No.10575006).

The Investigation of the Energy Dependence of the Alpha Value and the Averaged Gamma-Rays Multiplicity Coincidence for ^{239}Pu in the Resolved Resonance Region

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Abstract. Measurements of time-of-flight spectra from 1st to 12th gamma-rays multiplicity coincidence were carried out on the 120 m and 500 m flight paths of the IBR-30 (W=10 kW, f=100 Hz, τ =4 mks) using the16-section liquid (n, γ)-detector [1] and the16-section scintillation (n, γ)-detector with NaI(Tl) crystals [2]. A thin metallic disc with 99.9% of ^{239}Pu (80 mm diameter, 0.3 mm thickness or 0.00114 at/b) were served as a radiator-samples.

The spectra from 1st to 12th multiplicities coincidence of γ-rays and their averaged multiplicities $<K> = \Sigma P_k * K$ (K - multiplicity number, P_k - part of multiplicity) were determined in each time channel from measured time-of-flight spectra. A capture resonance at the energy of 52.52 eV with small fission width of Γ_f = 9 meV and a fissionable resonance at the energy of 47.56 eV with a big fission width of Γ_f =247 meV were used to divide the measured multiplicity spectra into two parts: from a radioactive capture and a fission processes. The detailed analysis of measured time-of-flight spectra was realized to obtain the averaged multiplicity coincidence values and the alpha values in each time channel, that is within the resolution function. The alpha value was defined in each time channel as a relation of areas under the gamma-rays multiplicity coincidence spectra

The Investigation of the Resonance Neutron Cross Sections Structure for Mn, Nb, Mo, In, Ho, Ta, W at 50 m flight path MMF

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Abstract On 50 m. flight path of a pulsed neutron source RADEKS of Moscow Meson Factory (MMF) INR RAN was created the setup REPS, which are consists the 8-sectional liquid and neutron (n, γ)-detector of volume 40 l (L=49.3 m) and the neutron detector of the battery of 4π-geometry with 10 ^{3}He counters of type CNM-18 (L=51.5 m). Time-of-flying spectra were measured for the thin metal disk samples-radiators Mn, Nb, Mo, In, Ho,Ta, W, with diameter of 80 mm by means of this setup REPS. The parameters of the pulsed neutron source of. MMF were the proton current of linear accelerater I_p = 0.5 mkA, the proton energy E_p.=209 MeV, the proton pulse repetition rate of f = 50 Hz, the proton pulse duration of τ = 1.5 mks. The setup REPS has the thick boron and lead shielding from the fone neutrons and γ-rays, which scattered in room of detectors. This shielding decreased the background in 4 times for the flying spectra of 50 m flight path by comparison with spectra of 50 m flight. The low background and the high energy resolution of spectrometer resolved to determinate the new resonances with energy 8 eV, 17 eV, 23 eV, 30 eV for W. Besides , the transmissions, the group total and capture cross-sections for Mn, Nb, Mo, In, Ho,Ta, W are obtained from the measured time-of-flying spectra in energy region 1 eV – 10 keV. The analogous values were obtained by GRUCON code on the basis of the estimated data libraries.

THE ESTIMATION OF SCISSION NEUTRON PARAMETERS FROM N-N ANGULAR CORRELATIONS

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It is well established that the major part of fission neutrons are emitted from the fully accelerated fragments. However, the investigation of neutron energy and angular distributions [1] as well as experimental data analysis of n-n angular correlations for emitted neutrons [2] have led to a conclusion that a fraction of total number of fission neutrons can be emitted isotropically in the laboratory system. It is assumed that these neutrons can appear just near to the rupture point (so-called scission neutrons).

The Monte-Carlo calculations simulating n-n coincidences in spontaneous fission of ^{252}Cf were performed to determine the part of this component and its energy spectrum. The first stage of this calculation simulated neutron emission from both fragments with the addition of the necessary fraction of scission neutrons. The averaged total multiplicity of emitted neutrons was taken as $\bar{\nu} = 3.76$. The actual number of neutrons evaporated by each fragment was chosen randomly by two-dimensional Gaussian distribution $(\bar{\nu}_L, \sigma^2_{\nu_L}, \bar{\nu}_H, \sigma^2_{\nu_H}, \mathrm{cov}(\nu_L, \nu_H))$ with experimentally defined covariation $\mathrm{cov}(\nu_L, \nu_H) = -0.21$ [3] and the ratio $\bar{\nu}_L / \bar{\nu}_H = 1.2$. The neutron spectrum of each fragment in its center-of-mass system was assumed to be Maxwellian form [4]:

$$N(E) = (\sqrt{E} / T^{3/2}) \cdot \exp(-E/T)$$

with fixed temperature for light ($T_L = 0.947\,MeV$) and for heavy ($T_H = 0.850\,MeV$) fragments. In process of calculation were used velocities of the most probable masses of fission fragments [5]. The Weisskopf distribution of scission neutron spectrum was used:

$$N(E) = (E/T^2) \cdot \exp(-E/T).$$

Thus we had two free parameters (the fraction and temperature of scission neutrons) to fit experimental data of angular distributions of n-n coincidence count rates measured with six different energy thresholds [6]. All these n-n angular correlations are well reproduced with the part of scission neutrons about 10% and their temperature near 0.8 *MeV*. The measurements of n-n angular distributions with different neutron energy threshold allow us to exclude the narrow energy distribution for scission neutrons.

This method was also applied for description of n-n angular correlations for the neutrons emitted in the reaction $^{235}U(n_{slow},f)$. The results of calculations for three different neutron energy thresholds were in a good agreement with experimental data [2] if we supposed that the temperature of scission neutrons is about 1 MeV and the part of these neutrons equals 15%. The last value corresponds to Skarsvag's result [1].

This work was supported by INTAS (grant № 03-51-6417).

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The new, high-intensity ultracold neutron source at Paul Scherrer Institut

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A new type of ultracold neutron (UCN) source based on the spallation process is currently under construction at PSI. It will make use of the full 590 MeV/ 2 mA proton beam at a 1% duty cycle. Spallation neutrons will be thermalized in D2O and further cooled in solid D2 where finally some of them will also be down-scattered into the UCN range. The macro-pulsing scheme (proton pulse on for about 4 to 8 s duration, pulse off for about 400 to 800 s) allows to keep the solid D2 moderator close to 6 K. In the intermediate storage volume of about 2 m^3 we expect a UCN density in excess of 1000 cm^{-3}; from this volume the UCN are distributed into 2 user beam lines. The construction is in an advanced state, first UCN are expected by the end of 2008. We will discuss the present status of the source construction and of the related R D program.

THE QUANTUM CHARACTERISTICS OF FISSION PROCESS

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On the basis of the fission quantum theory [1-2] the forming of binary primary fission fragments angular and spin distributions has been analyzed. These distributions are defined firstly by the penetrability factors in external region taking into account the fission channels coupling connected with the nonsphericity of fission fragments and secondly by the structure of fission shell model formfactors for the fission stage near scission point where the fissile nucleus has the axial symmetrical shape. This shape is characterized by neck with small number of nucleons between two heavy fission prefragments. The investigation of shell-model formfactors with taking into account the quantum-mechanical uncertainty principles [3,1] has led to the conclusion about the appearance in the fissile nucleus internal coordinate frame of the collective currents. These currents are born by 1) coherent superposition of prefragments orbital rotations relatively to fissile nucleus mass center and 2) coherentsuperpositions of rotations of the first and the second mentioned prefragments relatively to their own mass centers if these prefragments are deformed. These collective currents are not independent, the second rotations origin in the same directions which are opposite to the direction of the first rotations.

The collective currents are equivalent to zero-vibrations of fission prefragments own axes and of radius $\mathbf{R}$ connecting prefragments mass centers relatively to fissile nucleus symmetry axis and together correspondent to wriggling zero-vibrations [4].

The joint influence of penetrability factors and shell model formfactors lead to the pumping of big values of primary fission fragments orbital moments and spins. These effects have been analyzed for fission channels with two deformed, with the first deformed and the second spherical and with two spherical fission fragments.

It has been shown that the most probable primary fragments of actinide nuclei fission are deformed and have big values of their relative orbital moments L and spins (J_1 and J_2): $L \le L_m$, $J_1 \le J_{1m}$, $J_2 \le J_{2m}$, where $L_m \approx (J_{1m} + J_{2m}) \approx 30$. It has been demonstrated that big relative orbital moments and spins values of spherical primary fission fragments are exited by incoherent mechanism connected with nonadiabatic characteristic of fissile nucleus motion near scission point.

This work was supported by INTAS (grant № 03-51-6417) and by RFBR (grant № 06-02-16853).

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COMPARISON OF TWO EXPERIMENTS ON RADIATIVE NEUTRON DECAY

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Annotation

Over 10 years ago we proposed an experiment on measuring the characteristics of radiative neutron decay in papers [1, 2]. At the same time we had published the theoretical spectrum of radiative gamma quanta, calculated within the framework of the electroweak interactions, on the basis of which we proposed the methodology for the future experiment [3,4]. However, because we were denied beam time on the intensive cold neutron beam at ILL (Grenoble, France) for a number of years, we could only conduct the experiment in 2005 on the newly opened FRMII reactor of Technical University of Muenchen. The main result of this experiment was the discovery of radiative neutron decay and the measurement of its relative intensity B.R.= $3.2\pm1.6\cdot10^{-3}$ with C.L.=99.7% for radiative gamma quanta with energy over 35 kev [5,6]. Over a year after our first announcement about the results of the conducted experiment, "Nature" [7] published a letter asserting that its authors have also measured the relative intensity of radiative neutron decay B.R.=3.13±0.34 with C.L.=68% and gamma quanta energy from 15 to 340 kev. This article aims to compare these two experiments. It is shown that the use of strong magnetic fields in the NIST (Washington, USA) experiment methodology not only prevents any exact measurement of the relative intensity of radiative neutron decay, but also makes identification of radiative neutron decay events impossible.

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STATISTICAL MODEL ANALYSIS FOR (n,α) REACTION CROSS SECTIONS

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Investigation of fast neutron induced (n,α) reaction is important to evaluate helium production, nuclear heating and displacement of atoms in the structural materials of fusion and fission reactors. On the other hand, the study of the fast neutron induced charged particle emission reactions is of interest for understanding of nuclear reaction mechanisms. Moreover, neutron-nuclear data evaluation analysis is an important one of the contemporary neutron physics problems. Specifically, it is often necessary in practice to evaluate the neutron cross sections of the nuclides for which no experimental data are available.

Because of this, in last years systematic analysis of the fast neutron induced (n,α) reaction cross sections in the wide energy interval of neutrons and for the broad mass range of target nuclei was carried out at the Nuclear Research Center, National University of Mongolia. As results of these studies we observed so-called isotopic effect in the energy range from 8 to 16 MeV [1]. However, consistent theoretical substantiation on existence of the systematical regularity for the (n,α) cross sections up to now no apparently is available. Several formulae have been suggested to describe the isotopic dependence of the (n,α) cross sections around the neutron energy 14-15 MeV, only. To explain the systematic regularity of known experimental (n,α) cross sections we deduced some formulae using the compound mechanism [2]. The evaporation model and the constant nuclear temperature approximation were used.

Using the formulae a systematical analysis of the (n,α) cross sections at the energy range from 8 to 16 MeV was performed.

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Measurement of excitation functions of proton induced reactions on ^{nat}W, ^{nat}Zn, and ^{nat}Mo up to 40 MeV

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Abstract

Excitation functions for the production of various radionuclides from proton bombardment on ^{nat}W, ^{nat}Zn, and ^{nat}Mo were measured using the stacked-foil activation technique for proton energies up to 40 MeV. A new data set has been given for the formation of the investigated radionuclides. The present results were compared with the earlier reported experimental data and theoretical data taken from the ALICE-IPPE code, and found good agreement with some well measured literature values in the overlapping energy region. The thick target integral yields were also deduced from the measured cross sections. The deduced yield values were compared with the directly measured thick target yield values, and found acceptable agreement. The measured cross sections of the investigated radioactive products have much importance in the field of nuclear medicine, thin layer activation analysis and trace element analysis.

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AIR POLLUTION STUDIES IN OPOLE REGION, POLAND, USING THE MOSS BIOMONITORING TECHNIQUE AND NEUTRON ACTIVATION ANALYSIS

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Biomonitoring multi-element atmospheric deposition with terrestrial moss is a well established technique in Europe. In October 2006 30 moss samples of *Hylocomium splendens* and *Pleurozium schreberi* have been collected over the territory around the city of Opole, capital of the agricultural Opole Region, situated between two industrial regions of Poland: Silesia-Kraków Industrial Region in the east and Legnica-Głogów Copper Basin in the west. A total of 34 elements including heavy metals and rare earths has been determined by instrumental neutron activation analysis using epithermal neutrons at the IBR-2 reactor of FLNP JINR. Mulivariate statistics (factor analysis) was applied to 20 elements (Na, Cl, Ca, Sc, V, Cr, Mn, Fe, Co, Ni, Zn, As, Se, Rb, Mo, Sb, Cs, W, Th, and U) to characterize different pollution sources. Three factors explaining 80% of the total variance have been identified. The interpretation of the obtained factors findings points to natural crustal and vegetation components, vehicle component and thermal power plant, as well as to long-range atmospheric transport of pollutants **(V, Cr, Co, Ni)** from the neighboring industrial regions. The role of rare-earth elements as traces of long-range atmospheric transport is discussed.

Investigation generations of neutrons and transmutation of I-129, Np-237, Pu-238, Pu-239 and Am-241 using the U/Pb-assembly "Energy plus Transmutation" setup on the JINR Synchrophasotron/ Nuclotron proton and deuteron beams from 0.7 to 2.5 GeV

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The series of experiments was conducted using Synchrophasotron / Nuclotron proton and deuteron beams with energies in the range from 0.7 to 2.5 GeV on the electronuclear setup "Energy plus Transmutation"[1], which was created in Laboratory of High Energies JINR (Dubna) during 1998-1999 years. The setup consists of a Pb-target (diameter 8.4 cm, length 45.6 cm), of a U-blanket (206.4 kg of natural uranium) and of transmutation samples. As a registration system the setup uses He-3 neutron detectors [2], nuclear emulsions [3],

thermometric techniques and a set of various activation threshold detectors which forms so called uranium fission calorimeter.

The hermetically sealed samples of I-129, Np-237, Pu-238, Pu-239 and Am-241 in notable amounts were irradiated in the field of neutrons produced in the Pb-target and propagated in the U-blanket. The estimation of nuclear transmutation cross sections were obtained through measurement of induced gamma activities of the samples.

Nuclei	Transmutation of nuclei (in %) with different proton energies (in GeV)			
	0.7	1.0	1.5	2.0
I-129	0.08	0.08	0.13	0.15
Np-237	1.64	3.53	3.46	3.18
Pu-238	-	0.34	-	0.34
Pu-239	0.91	0.79	0.90	1.17
Am-241	-	-	-	2.6

Transmutation is considered a possible method for the final removal of long-lived and highly radiotoxic isotopes and thus for the preservation of clean environment.

The information about generation of neutrons in the volume of the Pb - target and the U - blanket was obtained with help of activation threshold detectors (Al, V, Cu, Co, Y, In, I, Ta, Au, W, Bi and others), SSNT-detectors and nuclear emulsions. The comparison of the experimental data with the results of simulations with the MCNPX program was performed.

An extrapolation to high proton beam of 1 mA and 30 days of irradiation yields preliminary estimates of sample transmutation (incineration) for proton energies of 0.7 , 1.0 , 1.5 and 2.0 GeV [3,4] are given in the following table.

There were first time performed experiments [5] at deuteron beams with energies 1.60 and 2.52 GeV which permitted to estimate transmutations of mentioned above long lived radioactive waste of atomic energetic and of industries which use nuclear materials and nuclear technologies. With help of developed complex technique which includes gamma-spectroscopy and solid state nuclear track detectors the number of Pu-239 nuclei produced in the blanket of natural uranium during the irradiation of the U/Pb - assembly by deuteron beams was measured.

The series experiments which is a part of the scientific program „***Investigations of physical aspects of electronuclear method of energy production and transmutation for radioactive waste of atomic energy using relativistic beams from the JINR Synchrophasotron/Nuclotron***" - the project called „***Energy plus Transmutation***" [1] is discussed in this communication.

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Spin and parity assignments for ^{94,95}Mo neutron resonances measured by the multiplicity method with the DANCE array

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The gamma-rays following the $^{94,95}\mathrm{Mo}(n,\gamma)\mathrm{Mo}^{95,96}$ reaction have been studied by the time-of-flight method with the DANCE (Detector for Advanced Neutron Capture Experiments) array of 160 BF_2 scintillation detectors at LANSCE (Los Alamos Neutron Science Center). The targets were enriched samples. The gamma-ray multiplicities and energy spectra for different multiplicities were measured in *s*- and *p*-wave resonances up to the neutron energy of 10 keV for ^{94}Mo and up to the neutron energy of 2 keV for ^{95}Mo. Definite spins and parities were assigned for about one third of the observed resonances in ^{96}Mo, while tentative spins and parities were assigned for another one third of the resonances. In ^{95}Mo the parities are identified for the strong observed resonances, confiming the previously known assignments.

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NEW DEVELOPMENTS FOR THE NEUTRON ELECTRIC DIPOLE MOMENT EXPERIMENT

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A new measurement of the nEDM, using the Ramsey resonance method, is being planned for the spallation source of ultra-cold neutrons (UCN) at Paul Scherrer Institut (PSI) [1],[2]. While already the current limit for nEDM ($< 2.9 \times 10^{-26}$ e·cm, see [3]) constrains some extensions of the Standard Model, the new experiment aims at 2 orders of magnitude improved accuracy, to be achieved with better control of systematic effects and an increase of the number of UCNs, provided by the new PSI source. To gain statistics, new solutions are being tested. From Geant4-UCN simulations it is known that with an increase of the storage chamber Fermi potential from 90 neV (as for quartz, which was used in the previous experiment) to 170 neV, already a factor of 2 in the total UCN countrate could be gained. Additional requirements for the chamber include: very high electrical resistivity and dielectric strength, compatibility with the Hg co-magnetometer and non-magnetic character of the material.

Potentially suitable materials (CVD diamond, ceramics, polymers) are currently being investigated in terms of neutron storage properties and high-voltage performance.

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SIGN OF THE SINGLET LENGTH OF NEUTRON SCATTERING ON THE PROTON, NEUTRON RADIATIVE CAPTURE BY THE PROTON AND PROBLEM OF THE VIRTUAL LEVEL OF THE (np)-SYSTEM

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The low-energy neutron scattering on the proton is analyzed. As it follows from the experimental data on neutron scattering on the orthohydrogen and parahydrogen molecules, the length of singlet np-scattering is negative (at zero total spin of the neutron and proton and at zero energy the scattering amplitude is positive: $f_s(0) = -a_s > 0$). According to the optical theorem, the process of neutron radiative capture by the proton at zero energy leads to the fact that the singlet scattering length becomes a complex quantity and acquires a negative imaginary additional term: $\mathrm{Im}\, a_s = -\mathrm{Im}\, f_s(0) < 0$. It is shown, that, taking into account the signs of the real and imaginary parts of the length of singlet np-scattering, the singlet scattering amplitude has a pole on the second sheet of the Riemann surface at a complex energy E_s, the real part of which is negative and the imaginary part is positive. Since the imaginary part of the energy of a true quasistationary level should always be negative ($\mathrm{Im}\, E = -\Gamma/2$, where Γ is the level width), the inequalities $\mathrm{Re}\, E_s < 0$, $\mathrm{Im}\, E_s > 0$ mean that a singlet state of the (np)-system, which would decay into the deuteron in the ground state and the γ-quantum ("singlet deuteron") does not exist, and the pole E_s corresponds to the virtual but not true quasistationary level .

Calculation of Production Cosmogenic Nuclides in the Atmosphere

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Applications of cosmogenic nuclides as tracers in the environmental system require a good knowledge of the temporal and spatial variability of the source function. Since the pioneering work of Lal & Peters in the 60ies of the last century several different approaches to calculate the neutron and proton fluxes and atmospheric production rate of cosmogenic nuclides have been published. The most recent approach is based on Monte Carlo techniques to derive the proton and neutron fluxes as a function of altitude and latitude for different geomagnetic field intensities and levels of solar activity.

Some examples of the potential applications of these fluxes are demonstrated and compared to experimentally determined values.

p- AND n-INDUCED FISSION OF ^{232}Th and ^{238}U UP TO 200 MeV

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The excitation energy and nucleon composition dependence of the transition from asymmetric to symmetric scission of fissioning Th(Pa) and U(Np) nuclei is investigated for the ^{232}Th(n,F)(^{232}Th(p,F)) and ^{238}U(n,F)(^{238}U(p,F)) reactions.

The ^{232}Th(n,F) and ^{232}Th(p,F) data represent a mirror-like cases, i.e. for ^{232}Th(n,F) there are precise cross section data up to E_n=200 MeV, while the data on the ^{232}Th(p,F) observed fission cross section are scattering quite a lot. At the other hand, while there is virtually no data on the ratio of symmetric-to-asymmetric yields for ^{232}Th(n,F) reaction, there are scanty data on the relative yields of symmetric and asymmetric fission for ^{232}Th(p,F). The simultaneous analysis of the n+^{232}Th and p+^{232}Th data provides a further insight on the role of pre-fission neutron emission in forming the observed symmetric/asymmetric fission yields.

The influence of the interplay of fission barriers and entrance channel effects on the fission observables is shown to be different in case of n(p)+ ^{232}Th(^{238}U) interactions. In case of p+^{232}Th interaction the fissilities of Pa nuclei are responsible for the higher value of the σ(p, F) than σ(n, F} cross section at $18 \leq E_{n(p)} \leq 100$ MeV. In case of ^{238}U target σ(n, F)>σ(n, F) only at $E_{n(p)} \geq 50$ MeV due to the isovector terms in real volume $V_R{}^n$ and imaginary surface $W_D{}^n$ potential terms. In case of ^{232}Th target the entrance channel (nucleon absorption cross section) plays a decisive role at En(p) ≥100 MeV.

TEMPORAL VARIATIONS OF ELEMENTAL CONTENT IN ATMOSPHERIC AEROSOL IN BRATISLAVA, SLOVAKIA

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Abstract

In the frame of urban air pollution study the concentrations of some elements in atmospheric aerosol collected at urban site in Bratislava (Slovak Republic) are presented. Sixteen filter samples were exposed within the year 2004 in different year's season in order to show up the possible variations. As a result of two irradiations and four consecutive gamma-spectrometric measurements the concentrations of 30 chemical elements were determined using the instrumental neutron activation analysis. Additionally the concentrations of other 5 elements were set by the atomic absorption spectrometry. The main goal of this project is to better understand the processes taking place in the atmosphere and to study the temporal variations of elemental concentrations in the airborne particulate matter. For some elements elevated concentrations are observed for the summer season, the others have the concentrations on rather stable level over the year. The correlations between concentrations of elements and some meteorological characteristics are discussed in this paper.

Keywords: INAA; atmospheric aerosol; elemental composition; temporal variations

On Neutron Electromagnetic Constants Derived from Neutron Scattering by ^{208}Pb

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Abstract

The measurements in the final work cycle of the booster IBR-30 in 2001 were the concluding stage of the Dubna – Garching investigations with the enriched ^{208}Pb target. New values of the total cross sections σ_{tot} in the energy range from ~ 4 up to 43000 eV were obtained and processed together with σ_{tot} obtained in [1-3] at ~ (1–24000) eV. All these data are used for estimation of the neutron electromagnetic constants: neutron-electron scattering length b_{ne} and polarizability coefficient α_n.

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New neutron lifetime measurement by storing UCN with neutron loss monitoring

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New project to measure neutron lifetime has the aim to achieve precision better than one second. For this our experimental method will be improved to escape systematic errors linked with UCN looses during storage. Up-scattering of UCN at interaction with storage vessel wall providing the method to control concurrently these losses by counting the flux of up-scattered neutrons will be used in experiment. Moreover, the effect of weak heating of UCN will have proper account.

Multilevel Approach in the Evaluation of the Asymmetry Effects on (n,p) reaction for ^{35}Cl and ^{14}N nuclei

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In our previous work were evaluated the asymmetry effects in (n,p) reaction on ^{35}Cl and ^{14}N using 2 resonance for ^{35}Cl and 3 resonance for ^{14}N. In the both cases was used the formalism of the mixing states of the compound nucleus with opposites parities.

In the first case of ^{35}Cl were evaluated the asymmetry coefficients un the two-level approximation up to 1 keV. These levels are closed and the next resonance is far from these two so we have a quite good agreement between theoretical experimental data but will be of interest to obtain the behavior of asymmetry effects higher then 1 keV and with participation of more resonance.

In the second case of ^{14}N the resonance are far from which other and our evaluation was realized up to 1 MeV where are present more then 10 resonance. In our last evaluation we used only 3 resonance and the asymmetry effects are results of the interference of two positive resonance with more then 100 keV between them. All these indicate that it is necessary to have an evaluation of the asymmetry effects with participation of all resonance in the neutron energy interval.

New experimental method to determine the averaged squared radius of the nuclei in the process of the direct and isomer fission

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It is proposed a method for the measurement of the mean squared radius of the ^{236}U nucleus during the fission process from the first and second potential barriers. This approach consists on precision determination of the energetic isomer shift of the X-ray quanta of the ^{236}U nucleus or difference in the intensity of the K_{α} and K_{β} lines measured in coincidence with processes of isomer and (n,γf) fission.

Comments to the problem of experimental determination of the neutron-electron scattering length and its theoretical interpretation

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We discuss the existing experimental data on the n,e-scattering length and obtained from them values of mean square charge radius of the neutron, which are estimated last years as

$$< r_e^2 >_n = \frac{3\hbar^2}{M_n e^2} b_{ne}^{exp}$$

without taking into account the so called Foldy's length. It is shown that the accumulated during the last 50 years most significant experimental estimates of the b_{ne} in this approach are not contradictory and lead to the average value

$$< r_e^2 > = -0.1178 \pm 0.0037 \; fm^2 .$$

Assuming that all the authors have underestimated the errors on their measurements by a factor of 1.7, the combined fit of all available experimental data would lead to $\chi^2 \sim 1$ per point.

Different modern theoretical predictions of $< r_e^2 >_n$ are considered. They are found to be in good agreement with the obtained experimental value $< r_e^2 >_n$. However the existing theoretical description of the structure of nucleon can not provide a value of $< r_e^2 >_n$ with a sufficient accuracy.

Collinear multicluster decays of Pu* isotopes

Yu.V. Pyatkov for HENDES and FOBOS collaborations

In our previous reports [1-3] we have presented first results on searching for collinear tripartition of the excited Pu isotopes from the reaction ^{238}U + ^{4}He (40MeV). Additional arguments in favor of existence of such decay mode based mainly on the analysis of the events with multiplicity two will be presented. Possible mechanism of the phenomenon observed is discussed as well.

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TOWARDS A NEW MEASUREMENT OF THE NEUTRON EDM: THE nEDM PROJECT AT PSI

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Electric dipole moments (EDM) of particles are direct signatures for CP and T violation. Whereas the Standard Model predicts very small EDM values due to a unique CP violation phase, most of its extensions (e.g. SUSY) incorporate new mechanisms and tend to predict large EDMs, already severely constrained by experiments. Improving the accuracy over the present limit provides therefore a unique opportunity to observe new physics.

We propose here to perform a new high precision experiment of the neutron electric dipole moment (nEDM) with an accuracy of 5×10^{-28} e.cm or better, an improvement of nearly two orders of magnitude over the present best measurement ($d_n \leq 2.9 \times 10^{-26}$ e.cm), obtained by the RAL/Sussex collaboration at the Institute Laue Langevin in Grenoble.

Our experiment will use the new spallation UCN source under construction at the Paul Scherrer Institute, and will optimize the in vacuum Ramsey resonance technique, at room temperature. The basic features of our experiment will include (i) an increased sensitivity due to much larger UCN densities at the PSI source, larger storage volume, better polarization product and possibly larger electric field strength, (ii) a better control of systematics thanks to a double-chamber system, (iii) an improved monitoring and stabilization of the magnetic field with an array of laser pumped Cs magnetometers, (iv) an improved co-magnetometer system.

The final goal will be reached in three steps: (i) operating and improving the existing room temperature apparatus of the former RAL/Sussex/ILL collaboration until 2008 at ILL, while designing in parallel of a new spectrometer, (ii) gaining a factor 5 in sensitivity with this upgraded apparatus at PSI in 2009-2010, (iii) running with the new apparatus at PSI in 2011-2015 in order to reach an other order of magnitude improvement.

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SEARCH OF ^{12}Be CLUSTER STATES IN CHARGE EXCHANGE REACTION FOR CARBON

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117312 Moscow 60-th October Anniversary prospect 7a.

Clustering is a relatively widespread phenomenon [1]. The study of halo systems and clustering in light, neutron-rich nuclei are discussed here through illustrative examples taken from the ^{6}He, ^{12}C, ^{12}Be nuclei chain. Search ^{12}Be cluster states with T=2 at the excitation energy from above 10 MeV is proposed in $^{13}C(\boldsymbol{n}, 2\boldsymbol{p})^{12}Be^*$ reaction. Impulse neutron sources, based on the proton linac (energy above 200 MeV and current up to 0.1 mA) produce fast neutron fluxes of about 10^7 n·cm^{-2} s^{-1}. Protons register by thin plastic scintillators. Particles from ^{12}Be* decay have to register between impulses. Count rate is 1s^{-1} (the background is 10^{-3} s^{-1}). The production and detection of multineutron clusters in charge exchange reaction for carbon is presented [2].

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INVESTIGATIONS OF THE ANGULAR DEPENDENCES OF NEUTRON-NEUTRON COINCIDENCES FROM ^{235}U FISSION INDUCED BY THERMAL NEUTRONS AND SPONTANEOUS FISSION OF ^{252}Cf

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Abstract

With the aim of the neutron emission mechanism investigation the coincidences between the prompt neutrons from spontaneous fission of ^{252}Cf have been measured in PNPI (Gatchina, Russia). The same measurements in ^{235}U fission are performed at present. Thermal neutron beam from the neutron guide of WWR-M reactor is used to induce fission in uranium target enriched to 90% of ^{235}U.

Two plastic scintillation detectors measured the coincidence rate of pairs of fission neutrons emitted at relative angles ranging from 20° to 180° in (5-10)° intervals. The γ-ray events rejection was realized by neutron-gamma pulse shape discrimination and by subsequent mathematical analysis of obtained coincidences spectra. The Monte Carlo simulation based on a simple evaporation model with some admixture of the other possible mechanisms of neutron emission was used for theoretical description of the experimental data.

From the measurements at angles of 20° to 180° between the directions of the fission neutrons it was found that the number of coincidences has minimum near 90° and increases by about a factor 2 to 20° and 180°. In the ^{252}Cf theoretical analysis [1] with use of different thresholds for fission neutron energies the correlation could be adequately described by a simple evaporation model, assuming isotropic neutron emission from the fully accelerated fragments frames in their centre of mass together with about 10% isotropic scission component. The theoretical analysis for ^{235}U correlation is in progress.

This work was supported by INTAS Grant 03-51-6417.

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APPLICATION OF A LINAC OF THE IREN FACILITY FOR PHOTON MULTIELEMENTAL ACTIVATION ANALYSIS AND PRODUCTION OF SOME RADIONUCLIDES

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The possibility to develop multielemental activation analysis and production of some radionuclides widely used for the nuclear medicine, radiobiology and ecology monitoring at the linear electron accelerator (E_{e^-} =100 MeV) of the facility IREN (FLNP, JINR) are considered.

Based on the experimental data obtained at low energy (E_{e^-}<30 MэB) electron accelerators as well as the microtron MT-25 (FLNR, JINR) with the power 0.5 kW, are estimated photonuclear reaction yields for some radionuclides for the linear electron accelerator (E_{e^-} = 100 MeV). Technical parameter of the linac will be as follow as: the electron beam current 3 A in 100 microsecond impulse and frequency 50 Hz, that means the electron beam power -1.5 kW in the target. Expected photonuclear reaction yields for some radionuclides are calculated as well as: ^{99}*Mo*-80 kBq/microA h mg; ^{225}*Ac*-15 kBq/microA h mg and -30 kBq/microA h mg.

APPROXIMATION OF SUMS OF EXPERIMENTAL RADIATIVE STRENGTH FUNCTIONS OF DIPOLE GAMMA-TRANSITIONS IN THE REGION $E_\gamma \approx B_n$ FOR THE ATOMIC MASSES $40 \leq A \leq 200$

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The sums of radiative strength functions of dipole primary gamma transitions were approximated with high precision in the energy region of $0.5 < E_1 < B_n - 0.5$ MeV for nuclei: ^{40}K, ^{60}Co, ^{71,74}Ge, ^{80}Br, ^{114}Cd, ^{118}Sn, ^{124,125}Te, ^{128}I, ^{137,138,139}Ba, ^{140}La, ^{150}Sm, ^{156,158}Gd, ^{160}Tb, ^{163,164,165}Dy, ^{166}Ho, ^{168}Er, ^{170}Tm, ^{174}Yb, ^{176,177}Lu, ^{181}Hf, ^{182}Ta, ^{183,184,185,187}W, ^{188,190,191,193}Os, ^{192}Ir, ^{196}Pt, ^{198}Au, ^{200}Hg by sum of two different functions $k(E1, E_\gamma) + k(M1, E_\gamma) = F_f + F_b$:

$$F_f = w \frac{1}{3\pi^2\hbar^2c^2A^{2/3}} \frac{0.7\sigma_G\Gamma_G^2(E_\gamma^2 + \kappa 4\pi^2 T^2)}{E_G(E_\gamma^2 - E_G^2)^2} \tag{1}$$

$$F_b = P\exp(\alpha(E_\gamma - E_p)) + P\exp(\beta(E_p - E_\gamma)) \tag{2}$$

with 5 free parameters: κ, w, P, E_p, α (for $E_\gamma < E_p$) or β (for $E_p < E_\gamma$).

It has been shown that this parameter of gamma decay is the dynamic value in any nuclei and the values $k(E1) + k(M1)$ for specific nuclei are determined by the structure of the decaying and excited levels, at least, up to the neutron binding energy.

New analysis of the two-step cascades following thermal neutron capture in ^{197}Au

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To further study the "pygmy" resonance phenomena in the photon strength function, we reanalyzed the two-step cascade data for the target nucleus ^{197}Al using the Dubna group approach [1] paper]. The range of obtained values allows for meaningful conclusions: the level density at low excitation energy shows a step-like behavior; the electric dipole photon strength function has a broad maximum around $E_\gamma = 5$ MeV and is not typical of a "pygmy" resonance; the level density below B_n also demonstrates step-like behavior.

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CALCULATION OF THE TOTAL GAMMA-SPECTRUM OF FAST NEUTRON CAPTURE IN ^{119}Sn FOR DIFFERENT PARAMETERS OF THE COMPOUND-STATE CASCADE GAMMA-DECAY

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The evaluation of the cross sections of interaction of fast neutrons with any nuclei requires reliable model presentations both on the level density of the studied nucleus and on the probabilities of processes occurring in this case. Reliable models can be developed only on the basis of reliable experimental data. Due to quite objective reasons the reliable data on the level density and radiation strength functions of the primary gamma-transitions of radiation neutron capture can be determined [1,2] only from the intensities of two-step cascades. In this case it is necessary and completely possible [2] to take into account a change in the cross section of the interaction of the excited nucleus with the gamma-quanta at the minimum) relative to the same cross sections for the nucleus in the ground state.

The degree of precision and reliability of the obtained values of the level density and radiation strength functions can be evaluated [3] by way of calculation of the total gamma-spectra of radiation neutron capture for different sets of the tested parameters. A good example of the possibilities appearing in this case is ^{120}Sn. Parameters of the process of the cascade gamma-decay of the ^{118}Sn nucleus are determined with the maximally possible accuracy in [2], and the total gamma-spectrum - in [4]. The forms of the expected values of the level density and radiation strength functions in ^{120}Sn can be easily extrapolated from the ^{118}Sn data taking into account only the density of low-lying levels and neutron resonances and binding energy differences. They are given in Fig. 1.

The calculated gamma-spectra for the set of models [5,6] (for k(M1)=const) and the data from [2] are presented in Fig. 2 to the left and to the right panels, respectively. As can be seen from these spectra, the sufficiently precise reproduction of the experiment is impossible without taking into account [7] the influence of the process of the break of the Cooper pairs of nucleons on the parameters of the process of the cascade gamma-decay of any nuclei.

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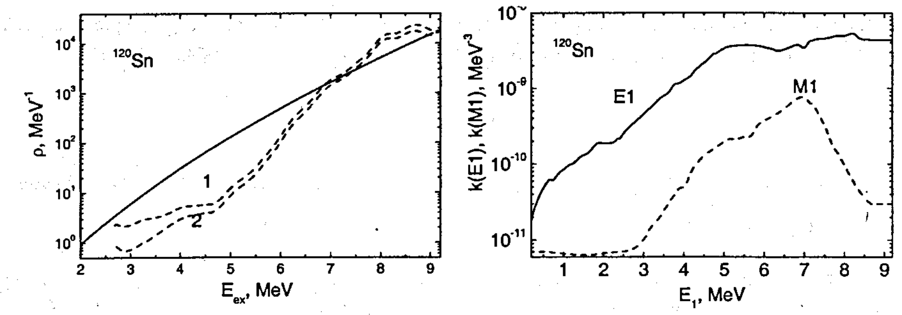

Fig. 1. The left panel presents line 1, i.e. the probable values of the level density with spins J=(0-2)$^{\pm}$, line 2 - the same for negative parity. Solid line - the same for [6]. The right panel presents the most probable strength functions k(E1) and k(M1).

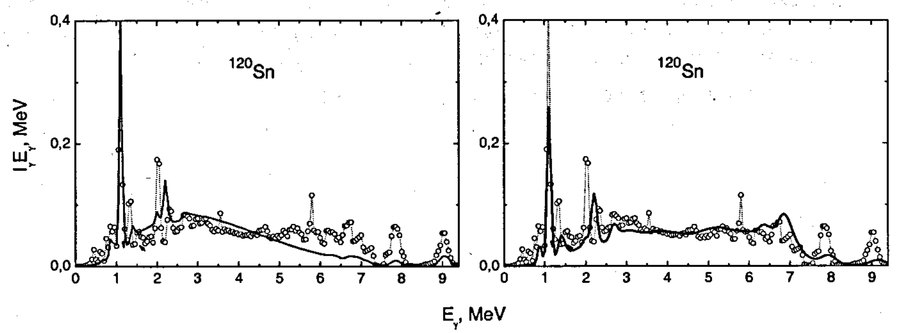

Fig. 2. The experimental ones (points+line) and the calculated (line) total spectra of γ-radiation following fast neutron capture for ^{119}Sn. The left panel illustrates calculations with models [5,6]. The right panel illustrates data from [2].

GAMMA DECAY OF THE COMPOUND STATE AND MAIN TREND OF THE ^{124}Te EXCITED LEVELS STRUCTURE CHANGING

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Independent analysis of a large amount of data on the spectrum of gamma-rays of the radiative capture of thermal neutrons in ^{123}Te ($\sum(i_\gamma E_\gamma)/B_n = 0.49$) measured in Řež [1] made it possible to obtain new and reliable information on the dependence of sums of radiative strength functions of dipole gamma-transitions on the energy of levels excited by them. These data, as does the level density in ^{124}Te, demonstrate a strong change of structure of the nucleus practically for the whole region of the levels excited by a captured neutron.

As in the earlier studied nuclei (using data on the intensities of two-step cascades), it is possible to reproduce the stated parameters of the gamma-decay process to the accuracy of experiment only by the models directly taking into account the coexistence and interaction of the usual and superfluid component of the nuclear matter.

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PROBLEMS OF THE EXPERIMENTAL DETERMINATION OF THE NUCLEUS PARAMETERS AND APPLICABILITY OF BOHR-MOTTELSON HYPOTHESIS

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Population of a number of excitation levels ^{51}V and ^{57}Fe is determined from data of ENDSF file up to the excitation energy of approximately 7 and 5.2 MeV correspondly. It cannot be reproduced in the region of their maximum energies within the framework of the assumption about the independence of partial radiation widths from the structure of the decayed and excited levels at least lower than $0.5B_n$.

Therefore the real degree of the reliability of the data about the level density and the radiation widths of cascade gamma-transitions in the light spherical nuclei cannot be estimated. It is connected to methods that not considering this circumstance of the analysis of the spectra of one step nuclear reactions.

ABOUT HISTORICAL POSSIBILITY OF INVESTIGATION OF FATIGUE DEGRADATION AND MARTENSITIC TRANSFORMATION OF AUSTENITIC STAINLESS STEEL IN COMPONENTS OF THE PRIMARY COOLING CIRCUITS OF THE IBR-2 AND BR-10 FAST NUCLEAR REACTORS BY NEUTRON-PHYSICAL METHODS

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A low-carbon titanium-stabilized chrome-nickel austenitic stainless steel of X18H9T type is widely used in highly technological and potentially dangerous industries because of the outstanding properties, in particular, high corrosion resistance, mechanical and welding characteristics. In the world, a few hundreds millions of tons of this steel are made. A main problem in application of this steel is its fatigue degradation in components of numerous industrial manufactures. During fatigue loading of material changes in the microstructure occur which affect both the mechanical and physical properties. The assessment of the actual fatigue damage and, thus, the remaining fatigue lifetime of material is a task of great practical relevance. This problem remains of current importance during many decades. The experimental modeling of these changes is made by cyclic mechanical loading, usually by uniaxial tension-compression cycling. Innumerable experimental and theoretical researches show that safe fatigue lifetime of a material is in an interval 50-100 years. If, for example, to double fatigue lifetime it will have huge world economic benefit, especially in nuclear power engineering.

However, at a modern level of an engineering science the improvement of fatigue properties of the steel demands significant intelligent and material inputs, frequently, with a small real output. The fact is that in engineering practice are used numerous conventional, though and good approved methods of researches, measurements and tests which give the macroscopic characterizations of materials. Break through a microscopic level is necessary. Such break can ensure neutron-physical methods of researches. Methods of neutron diffraction, small angle and inelastic neutron scattering and neutron tomography concern to them. The special place among them occupies the neutron diffraction method. A new direction of use of neutron diffraction advanced for the last 20 years, namely, the investigations of the internal mechanical stresses in materials and components, has enabled to combine research of macroscopic and microscopic properties of multiphase materials simultaneously on one object.

With a withdrawal of the Russian IBR-2 (Dubna) and BR-10 (Obninsk) fast nuclear reactors, there is the historical opportunity to investigate elements of the primary cooling circuits of these reactors made from X18H9T steel by conventional and, in the main, neutron-physical methods. Such researches of "historical" steel can give the completely new information about fatigue properties of steel, long time having been in intensive operation in conditions connected with periodic and aperiodic mechanical loads of complex multiaxial configuration, the experimental modeling of which represents a difficult engineering problem, as well as an assessment of the remaining fatigue lifetime of material. This information can have paramount meaning for the engineering science focused on development and creation of fast breeder nuclear reactors on liquid-metal coolants.

SEARCH FOR PT-NONINVARIANT EFFECTS IN NEUTRON INDUCED GAMMA TRANSITIONS

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Long way of well know lanthanum experiment (which was considered as optimal tool of search for PT-noninvariance in nuclear processes) from the idea to a real measurement make it reasonable to analyze other possibilities provided by neutron induced nuclear processes. Two schemes which look promising are proposed.

The first one is based on a three-vector correlation $(\vec{\sigma}_n[\vec{k}_{\gamma_1}\vec{s}_{\gamma_2}])$ where $\vec{\sigma}_n$ is the spin of neutron, $\vec{k}_{\gamma_1}$ - the linear momentum of the γ-quantum of the transition in which the discussed effect is searched for, $\vec{s}_{\gamma_2}$ - the circular polarization of the second transition which serves as an analyzer. The parallels between this scheme and the one in which $(\vec{\sigma}_n[\vec{k}_\alpha\vec{s}_\gamma])$ correlation is used [1] are obvious. Powerful source of polarized thermal or cold neutrons is required for the measurements.

The second scheme is a modified for neutron experiment version of the approach proposed for search for PT-noninvariance in γ-transitions produced by radioactive sources in [2] and originally realized in [3]. A five-vector correlation $(\vec{k}_\gamma[\vec{k}_n\vec{\varepsilon}])(\vec{k}_n\vec{\varepsilon})$ where $\vec{\varepsilon}$ is the linear polarization of γ-quantum is used in the scheme. Naturally *p*-resonance or fast unpolarized neutrons are required for the discussed purpose. Nevertheless linear polarimetry is much more convenient than circular one and a measurement of coincidences is not required here, so the efficiency of this method is compatible to the first one.

A choice of the target isotope and the γ-transition in both cases is determined first of all by the value of P-violation effect (measured or expected) in the transition.

High-energy γ-quanta induced by neutron capture make the problem of simulating of the effect by final state interaction of photons with atomic electrons inessential.

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$^3He/^4He$ Dilution Cryostat for Investigation of Interactions of Neutrons with Polarized Nucleus

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The purpose of the cryostat is to polarize nucleus in the wide range of mass numbers using the 'brutal force' method. The setup also includes a possibility of dynamic polarization of nucleus. The classical method of $^3He/^4He$ dilution is used for obtaining low temperatures. The setup consists of the following components:

- ^4He cryostat
- $^3He/^4He$ dilution route
- Superconducting solenoid
- Temperature control system
- Charge and management system for the superconducting solenoid

The following parameters have been obtained for the setup:

- Minimal temperature T=23mk with circulation speed of 1mmole/sec
- Maximal magnetic field in the solenoid center of 6T
- The solenoid current is set with a precision of 1mA in the current range of 0-110 A

The nuclear target specimens are cooled down in the $^3He/^4He$ dilution bath.

BIOMONITORING OF TRACE ELEMENT ATMOSPHERIC DEPOSITION IN TVER REGION: DATA OF BOTH MOSS-SURVEYS 2000 AND 2005

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Results of the trace element atmospheric deposition study in Central Russia based on moss analysis are presented. Epithermal neutron activation has enabled determination of up to 40 elements including heavy metals, rare earth elements, Th and U in 100 moss samples collected in 2000 and 2005. As bioaccumulators two common mosses have been used: *Pleurozium schereberi* (~70%), *Hylocomium splendens* (~30%).

The purpose of this study has been to apportion deposition patterns of such potent sources of air pollution as the largest metallurgical complex in Europe in the town of Cherepovets on the north-east shore of the Rybinsk Reservoir, as the oil refinery complex SLAVNEFT in Yaroslavl, the largest Russian thermal power plant in the town of Konakovo and to reveal previously unknown pollution sources located in towns and settlements within the sampled territory.

Multivariate statistical analysis has been applied to the obtained datasets. Comparison of the results obtained with those from other surveys in Russia and Europe shows that Tver region could be considered as a baseline territory for the Russian Federation. Examples of GIS-maps of the elemental distribution over the sampled area are given.

NUCLEAR LEVEL DENSITIES OF Ni ISOTOPES

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New sets of the nuclear level density parameters for Ni isotopes in the mass range $56 \leq A \leq 65$ have been obtained in the framework of generalized superfluid model, back-shifted Fermi-gas model and composite formula of Gilbert-Cameron. The nuclear level density parameters are determined by fitting new experimental data on the low-lying levels, the average spacings between neutron resonances, the evaporation spectra and the excitation functions of different reactions. In the model analysis the shell effects and collective enhancement due to vibrational states of nucleus have taken into consideration. The energy, spin and isotopic dependences of nuclear level density are discussed.

This work has been supported in part by the Russian Foundation for Basic Research and by the Government of Kaluga Region (grant 07-02-96400).

LEAVES OF *TAMARINDUS INDICA* USED TO MONITOR METAL CONTAMINATION IN HOCHIMINH CITY, VIETNAM

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Higher plants are used as monitors in the heavy metal pollution monitoring in the areas where lichens and mosses are absent. The *tamarindus indica* is one of the most widespread fruit trees, which culturally or wildly grows in tropical and near tropical areas. Thirty-nine samples of the *tamarindus indica* leaves collected over 12 districts of the Hochiminh City have been used in heavy metal pollution monitoring of the city. Seven samples of the *tamarindus indica* leaves collected in Cangio, the pristine region situated 60 km south-east of the Hochiminh City, at the seaside of the Pacific Ocean have been used to assess the basic level of pollution. A total of 33 elements has been determined by the epithermal neutron activation analysis. The median concentration differences of samples collected in the contaminated area and of those collected in the pristine region have been observed for most of the elements. The obtained results have been compared with the literary data on the similar trees. These studies have shown that the leaves of *tamarindus indica* could be used as a potential biomonitor in heavy metal contamination surveys in tropical and near tropical regions.

Factor analysis of neutron data

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The interpretation of neutron spectra patterns is subjective and difficult by instrumental means and sometimes the analytical methods have proved unsatisfactory to reduce uncertainty in nuclear data. In the present report, we investigated how to detect underlying nuclear characteristics of different neutron spectra by means of common statistical methods and factor analysis. We applied uni and bivariate statistical analysis methods with the use of co-occurrence and run-length matrices to analyze the spectra patterns. Factor analysis was used to determine whether a large number of independent variables actually measured one or more underlying common variables.

Development of a PIXE program for the EG-5 experimental installation

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The experimental arrangement for PIXE measurement at Electrostatic Generator EG5 employs a Si(Li) detector for recording the spectrum induced by 2 MeV protons. Elements of low and medium Z contribute with about six K X-ray lines and elements with high Z contribute with about twenty lines. The experimental PIXE spectra were fitted by a software program and the peak areas, element concentrations and corresponding analytical detection limits from the sample matrix were evaluated.

Calculation of the double differential neutron production cross-section in reactions induced by high-energy ions

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In this work the double differential cross-section of the reaction induced by proton and carbon ions of energies above hundred MeV/nucleon on carbon target will be evaluated. At this high incident energy a lot of channels will be open and a model of direct interaction with coupled channels will be used. The number of neutrons produced in the case of incident protons per particle is a not higher then 2 and about 8 - 10 neutrons per particle for incident carbon ions. For enough high intensity of incident ions millions of neutrons with energy distribution from thermal to MeV will be obtained.

The results of this study are intended to facilitate the research in cancer radiotherapy.

Experiment for the measurement of the neutron-electron scattering length in liquid Pb at the TS-3000K thermostat from IBR-2 reactor

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At the DIN-2PI channel from the IBR-2 reactor an experiment for the measurement of the neutron-electron scattering length on molten Pb using the thermostat TS-3000 K was realized. The experimental results were compared with previous theoretical calculations [1].

[1]. A.I. Oprea, C. Oprea, G.S. Samosvat, V.G. Nikolenko, Zh.A. Kozlov, 2007. *Proposal for the investigation of the neutron-electron scattering length in liquid Pb by the TS-3000K thermostat at IBR-2 reactor.* Proceedings of ISINN-14, May 24-27, 2006, Dubna

"ZERO" EXPERIMENT AND FINAL RESULT OF THE MEASUREMENTS OF THE P-ODD ASYMMETRY IN THE ^{6}LI(n,α)^{3}H REACTION

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The P-odd asymmetry coefficient in the reaction ^{6}Li(n,α)^{3}H has been measured to be equal to $\alpha_t = -(8.6 \pm 2.0)\cdot 10^{-8}$. This measurement has been carried out at the vertical channel of the WWR reactor of the PNPI RAS (Gatchina) and at the PF1B instrument of the ILL reactor (Grenoble). This result allows one to estimate the weak π-meson coupling constant dominated by neutral currents in the nucleon-nucleon electro-weak interaction.

In experiments, a multi-section ionization chamber was used as a charged particle detector. The ^{6}LiF targets utilized practically whole neutron beam ($\sim 3\text{-}5\cdot 10^{10}$ s^{-1}). The current method of event detection was applied. A combination of the procedure for the compensation of the reactor power fluctuations, a periodic change of the guiding field direction and certain sequence of data acquisition and treatment allowed one to compensate all possible false apparatus effects. A possible contribution of the P-even left-right asymmetry of reaction products ($\alpha_{LR} = 10^{-4}$) in to the value of measured P-odd asymmetry was suppressed below 10^{-8} by the choice of experimental geometry, where neutron spin, neutron momentum and triton momentum (a normal to the target plate) were parallel.

In order to prove reliability of the obtained result, one has to consider a possible admixture of the P-odd effects in various accompanying reactions of neutrons with the elements of the ionization chamber, with emitting of charged particles and γ-quanta following decays of radioactive nucleus. Because of uncertainties in the reliable estimation of the mentioned effects, one has to carry out experimental check of any possible contributions of some false asymmetry to the measured effect. The "zero" experiment for the P-odd asymmetry (measured in the chamber, in which the targets were closed by foils absorbing the products of the reaction ^{6}Li(n,α)^{3}H has been carried out at the PF1B instrument at the ILL; the following result was obtained: $\alpha_0 = -(0.0 \pm 0.5)\ 10^{-8}$. This value was normalized to the constant component of the signal in the main experiment and corrected to the neutron polarization and the average cosine of the tritons emission from the target (taking into account a difference in the amplification factors of the "zero" experiment and the main one). The result of the main experiment at the ILL: $\alpha_t = -(9.0 \pm 2.1)\cdot 10^{-8}$.

Comparison of these two results shows that the effect of the P-odd asymmetry in the main experiment is really due to the studied reaction.

CURRENT STATUS AND FUTURE NEEDS OF NUCLEAR ANALYTICAL TECHNIQUES AND THEIR APPLICATIONS: REVIEW OF IAEA CONSULTANTS' MEETING-2007

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For the purpose of this review we define nuclear analytical techniques (NATs) as those that use nuclear reactions, radioactive decay, or nuclear instrumentation to investigate properties of matter. This definition extends from the well-established radiochemistry, neutron activation analysis (NAA), and prompt-gamma activation analysis (PGAA) to advanced methods at the limits of science and technology, and includes the applications of these techniques to the determination of composition and structure of matter for science and technology.

The broad range of nuclear analytical techniques share a set of advantages over competing methods: (i) highly penetrating probe and response radiation; (ii) independence of chemical state and of analytical blank; (iii) nondestructive character, and (iv) sensitivity. NAA in particular is in regular use worldwide to perform elemental analysis of as many as forty elements in a variety of materials important to industrial process development and control, human health, environmental protection, and cultural heritage. NAA is especially valuable in the case of large samples, complex matrices, solid materials that are difficult to dissolve, and QA/QC. Although NAA is mature, several developing extensions to the method promise greater applicability to the analysis of large ultrapure solids and extremely heterogeneous samples. There is an urgent demand for the determination of ultra-fine particles in environmental studies and an understanding of their health impact. NAT's are and will continue to be applied in studies of atmospheric particulates and the developing field of engineered nanoparticles. The broad elemental coverage and high throughput of NAA have made the technique a dominant one in archaeometry.

Several obstacles stand in the way of further use of NATs. Foremost among them are the decline in the number of research reactors in the developed world. This problem may be partly offset by a number of new research reactors in the developing world but also by new developments in DD and DT neutron generator technology. Higher fluence rates, longer life time and reduced size of the tubes make them attractive as a source of neutrons for analytical purposes when combined with appropriate moderator/shielding and counting equipment.

New developments in analytical techniques and applications:

Over 200 small and medium charged-particle accelerators are in use in many countries for PIXE and other ion beam analysis techniques. Their applications in materials and life sciences are expanding, especially with microbeam facilities which allow imaging in two or three dimensions (more than 40 operational μ-beam facilities available at this moment). Charged-particle activation analysis (with or without radiochemistry) can be a complementary technique to NAA for the determination of particular elements in different matrices (biological, environmental, and certain technologically advanced materials). In the version of TLA (thin layer activation) this technique is effective for wear and corrosion studies on moving mechanical equipments for industrial applications and the assessment of the performances with time of human prostheses as well.There is a remarkable growth in the number and availability of particle accelerators related to the rapid expansion of diagnostic and therapeutic nuclear medicine procedures, notably positron emission tomography (PET), single-photon emission tomography (SPET), (including hybrid systems with CT or MRI), functional diagnosis, molecular imaging, and metabolic radionuclide therapy. For example, more than ten million tests are made with ^{99m}Tc annually in North America alone. The number of qualified and experienced professional nuclear scientists and engineers, in particular radiochemists and radiopharmacists, has not kept pace with this increase, leading to greater risks in these procedures. Analytical techniques based on synchrotron radiation are emerging which can provide qualitative and quantitative information on *in-vivo* elemental composition, structure, and molecular imaging. As many as ten of the new large facilities are dedicated to the biomedical sciences.

The role of trace elements in health and environmental studies:

NATs are playing a significant role in the three "new epidemics" (WHO 2000) of cancer, cardiovascular disease, and diabetes. NATs have a unique role to aid in understanding the mechanism of brain-gut interactions related to satiety and obesity, which appear to be related to the new epidemics, and are in other ways an important health issue in rapidly developing countries. It is noted that a few investigations have commenced involving NATs in the determination of the composition of biological tissues in connection with HIV incidence in sub-Saharan Africa. According with the recommendations of the international and European pharmacopoeia, the quality assurance/control (QA/QC) of labelled compounds and radiopharmaceuticals for human and animal investigations is required making use of sophisticated and sometimes unusual radiochemical and radioanalytical methods of analysis and NATs,. The development of rapid methods of analysis and visualization of radioactive specimens would give a substantial improvement to these technologies. The stability with time of the labelled species and the evaluation of the expiration time is of paramount relevance for the performances of labelled species. Artificially produced radioactive tracers, characterized by short half-life and high specific activity, are finding several applications in the life sciences, in particular in occupational and environmental toxicology, in metallobiochemistry and nanotoxicology as well as in living organisms (cell cultures, plants, animals, and fishes).

Recommendations of the IAEA international experts in the field of NATs to the IAEA policy programme are summarized.

Научное издание

NEUTRON SPECTROSCOPY, NUCLEAR STRUCTURE, RELATED TOPICS
XV International Seminar on Interaction of Neutrons with Nuclei
Abstracts of the Seminar

НЕЙТРОННАЯ СПЕКТРОСКОПИЯ, СТРУКТУРА ЯДРА И СВЯЗАННЫЕ ВОПРОСЫ
XV Международный семинар по взаимодействию нейтронов с ядрами
Тезисы докладов семинара

Ответственный за подготовку сборника к печати *А. М. Суховой.*

Сборник отпечатан методом прямого репродуцирования с оригиналов, предоставленных оргкомитетом.

Е3-2007-49

Подписано в печать 10.04.2007.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 4,0. Уч.-изд. л. 6,5. Тираж 170 экз. Заказ № 55732.

Издательский отдел Объединенного института ядерных исследований
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