1.2. NUCLEAR PHYSICS WITH NEUTRONS

1. Introduction

In the year 2001 the program for experimental research in neutron nuclear physics in the Frank Laboratory of Neutron physics included the following traditional research directions: experimental and theoretical investigations of the electromagnetic properties of the neutron and its beta-decay, studies of spatial parity violation and nuclear fission processes, research into high-excited states of nuclei in the reactions of thermal and resonance neutron capture, obtaining of the new data for the purposes of astrophysics, experiments with ultracold neutrons.

The investigations were mainly conducted on the beams of IBR-30 (the first half of the year), IBR-2 and EG-5. A number of experiments, however, were performed, in cooperation with other nuclear centers in Russia, Bulgaria, Poland, Czech Republic, Germany, Republic of Korea, France, USA and Japan.

1. Experimental investigations

1.1. Spatial and time parity violation at interaction of neutrons with nuclei

1.1.1 Parity violation in compound nuclei: TRIPLE's latest results

The activity in the frame of the Time Reversal Invariance and Parity at Low Energy (TRIPLE) collaboration consisted of analysis of the previously measured parity-violating asymmetries of cross sections in neutron p-wave resonances. Detailed parity violation data together with the final results for ^{117}Sn, ^{121}Sb, ^{123}Sb, and ^{127}I are published in Phys. Rev. C, v. 64 (2001). In addition, a comprehensive review of TRIPLE experiments and a compilation of all TRIPLE parity violation results are published in Physics Reports, v. 354, number 3 (2001). The use of statistical methods for the determination of the root mean square weak matrix element for 20 nuclei studied has lead to an experimental value of $1.8 \cdot 10^{-7}$ eV for the spreading width of the weak interaction in compound nuclei, which is in qualitative agreement with theoretical expectations.

1.1.2 Measurements of *P*- odd asymmetry of γ- quanta emission in the reaction ^{10}B(n,α)^{7}Li* → γ → ^{7}Li(g.s.)

The existence of weak currents in weak NN-processes has not been unambiguously confirmed experimentally yet. However, the possibility to determine directly the weak meson constants and consequently, the contribution of the neutron current from *P*- odd correlations evidences in favor of the cluster representation of reactions with slow polarized neutrons on light nuclei (A≤10). The correlation coefficients are then on the level 10^{-8} - 10^{-7}.

The experiment to measure *P*- odd asymmetry of the type $\alpha_{pn}(\vec{s}_n \vec{p}_\gamma)$ in the reaction ^{10}B(n,α)^{7}Li*→γ(0.478 MeV)→^{7}Li(g.s.) was carried out with cold ($\langle\lambda_n\rangle$ = 4.7 Å) polarized (94%) neutron beams from the reactor PF1B in ILL by a FLNP-PINP-ILL collaboration.

The testing of the system was done by measuring known values of the *P*- odd asymmetry in the (n,γ) reaction using Cl, Br and Cd samples. The main measurements were carried out with a ^{10}B sample for about 20 days and several "zero" experiments were made with an aluminum foil and lithium absorber. The obtained result is $\alpha^0_{pn} = (25.8 \pm 6.5) \cdot 10^{-8}$.

Since the possible contribution to the measured value from *P*-odd and *P*-even effects on impurity nuclei cannot be higher than 10^{-9} and the *P*-odd asymmetries in the investigated reaction are identically equal to zero, there exists a high probability that the discovered asymmetry is due to the given reaction.

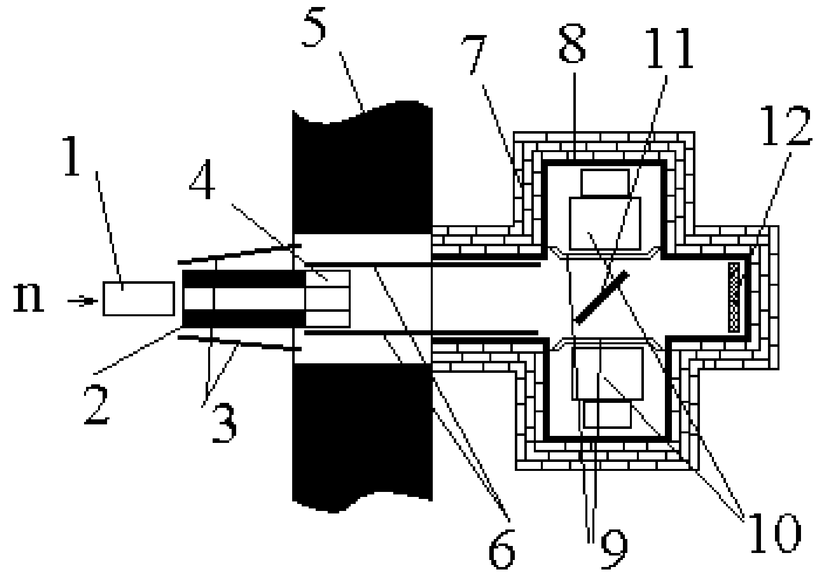

Fig. 1. *The schematic drawing of the experimental facility: 1 - polarizer; 2- adiabatic flipper with a boron collimator; 3- gradient magnetic field driver; 4- lead collimator; 5- concrete shield; 6- leading magnetic field driver; 7- lead shield; 8- boron rubber; 9 - Helmholtz coils; 10- detectors; 11-sample; 12- lithium absorber.*

To carry out further investigations, a multisectional ionization chamber with samples for the measurement of the *P*- odd correlation of the type $\alpha_{pn}(\vec{s}_n \vec{p}_t)$ in the reaction ^{6}Li(n,t)^{4}He is prepared. The experiment will be conducted in ILL in 2002.

1.1.3 Current status of the KaTRIn project

In the R&D stage of the KaTRIn experiment we tested the optical polarization of ^{3}He in an extremely low applied magnetic field. Permalloy magnetic shields were used to prevent fast relaxation of ^{3}He polarization owing to the inhomogeneity of the surrounding fields. The whole facility was installed on a neutron beam of the IBR–30 neutron facility and was used as a neutron spin filter. A prototype of the neutron polarizer of new design was thus introduced.

The polarizer comprises a 3 cm diameter spherical ^{3}He cell. The cell is inside an aluminum oven and is heated by air flow from a commercial "KRESS" fan. The oven also plays the role of protection from DC – fields. The axes of the neutron beam, laser light and magnetic shield coincide. The residual longitudinal field in the center of the shields where the oven is does not exceed 0.05 Gauss.

The neutron polarization was measured by the time-o-flight technique. If N_0 is the cell transmission for unpolarized and N for polarized ^{3}He, the neutron polarization is $p_n = \sqrt{1 - \left(\frac{N_0}{N}\right)^2}$.

The neutron polarization is measured 1.5 hours after the start of optical pumping when it approaches its equilibrium value. To perform measurements without a field, the ^{3}He polarization is completely destroyed with a magnet to restore initial conditions.

The energy dependence of the neutron polarization in both cases is shown in **Fig 2**. It is seen that in a "zero" field the rubidium and ^{3}He polarization is as efficient as in a nonzero guide field.

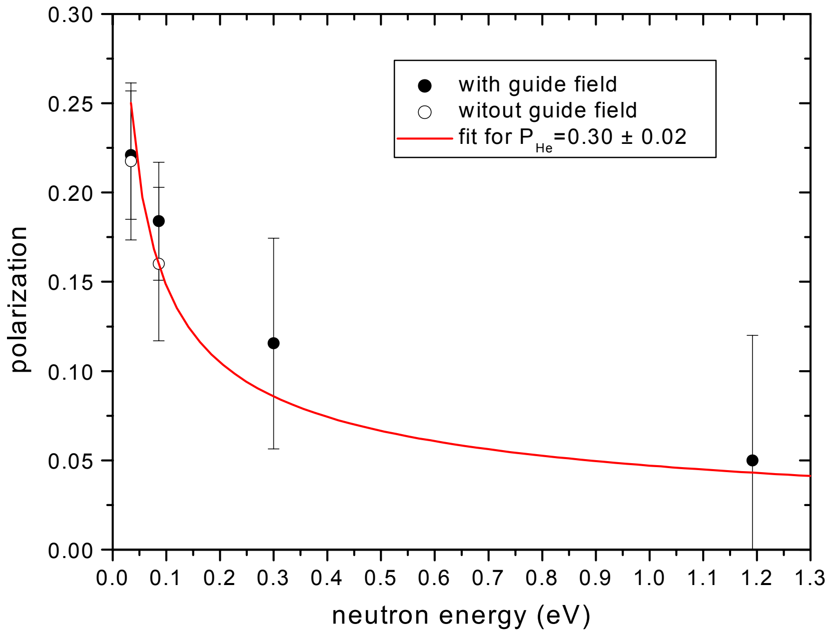

Fig. 2. *The energy dependence of the neutron polarization with and without a guide field.*

Thus, the possibility of ^{3}He and neutron polarization in an almost "zero" applied field has been confirmed. Besides, a prototype of the neutron polarizer of new design has been introduced. We intend to use this experience to design of a full-scale KaTRIn facility to test time reversal invariance in neutron-nuclear reactions.

1.1.4 Search and investigation of the structure of subbarrier neutron *p*-resonances in lead isotopes by the method of combined correlation gamma-spectroscopy

The theoretical works [1,2] confirmed experimentally [3] substantiate that in the region of weak neutron *p*- wave resonances the effect of spatial parity violation has a very large value exceeding the ratio of strong to weak interaction in nuclei by many orders of magnitude. The only unexplained result so far is the discovered and measured effect of weak spin rotation at transmission of polarized neutrons through a lead target [4]. In the recent experiments [5] it was shown that the effect is due to the nucleus ^{204}Pb. Basing on the concept of *s*- and *p*- resonances mixing it is possible to assess the expected effect of parity violation. However, for the even-even magic nucleus ^{204}Pb the level density is very small and a large distance between resonances suppresses the effect essentially. As a result, there arises a contradiction between the measured and expected value of the effect. The solution can be sought in two directions. One is indicated in the work by Zatretskii and Sirotkin [6] which, in addition to compound states mixing, assumes the participation of potential scattering in the realization of the violation effect. This approach,

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[1] Сушков О.П., Фламбаум В.В. УФН, 1982, т. 136, в. 1, стр. 3

[2] Бунаков В.Е., Гудков В.П. ЖЭТФ, письма, 1982, т. 36, в. 7, стр. 268

[3] Alfimenkov V.P., Borzakov S.B., Vo Van Thuan, Mareev Yu.D., Pikelner L.B., Khrykin A.S., Sharapov E.I. Nucl. Phys., 1983, v. A398, p. 93

[4] Heckel B., Ramsey N.F. et al. Phys. Lett., 1982, v. 119B, p. 298

[5] Ermakov O.N., Golub R., Karpikhin I.L., Krupchitsky P.A., Vasiliev V.V., ISSIN-9 Proceedings, Dubna, 2000, E3-2000-192, p. 377

[6] Зарецкий Д.Ф., Сироткин В.К. ЯФ, 1987, 45, в. 5, стр. 1302

however, is not favored by theoreticians and has not demonstrated itself in the experiment yet, which may be due to essentially larger density of states in other than lead nuclei. A different explanation may be possible if the nucleus ^{204}Pb has a *p*- resonance with suitable parameters in the energy region below the neutron binding energy, the so-called «negative resonance». In this case, the concept of compound states mixing would receive an appreciable confirmation as a counter to potential scattering. In this connection, it is quite important to discover, or vice a versa, disprove the existence of a close negative p-resonance.

As a method to discover the p-resonance it is proposed to investigate the dependence of the intensity of gamma-lines of the reaction ^{204}Pb(n,γ) on the neutron energy in the energy region from thermal to several tens eV. In the absence of resonances in the vicinity of the region the radiative neutron capture cross section is determined by distant s-resonances and obeys the «1/v law», where v is the neutron velocity. Another dependence, namely $\sigma \sim v$, holds for p- resonances. There thus exists a principal possibility to separate the contributions from s- and p-waves to neutron capture and its parameters and consequently, to estimate the possibility of the existence of the negative p-resonance as well as its parameters. The main experimental difficulty is that the cross section of p-wave capture is very small in the given neutron energy region, possibly less than 1% of the s-wave capture cross section. This imposes very strict requirements on statistical accuracy, requires careful analysis of the energy dependence of the cross section, etc., which in turn, imposes enhanced requirements on the experimental technique and measuring equipment. Nevertheless, to find a solution to the problem of two approaches to the explanation of spatial parity violation effects is intriguing and this stimulates the carrying out of the proposed experiment.

1.2. Parity violation and interference effects in angular distributions of fission fragments

1.2.1 Interference effects in the resonance neutron induced fission of ^{239}Pu

Intense theoretical and experimental investigations of the fission process (spontaneous and induced) conducted over fifty years have not yet resulted in a sufficiently complete understanding of the dynamics and mechanism of fission and a strict unambiguous mathematical description of its individual stages. The reason for this is first, nuclear fission is one of the most complicated nuclear transformations of a multiparticle system associated with deep redistribution of the mass and charge of the primary nucleus, formation of heavily deformed fragments with high spins and excitation energies and second, in most of the experiments nuclear fission is studied in the conditions when it is impossible to obtain information about the basic amplitudes of the process characterized by the parity π, total spin of the fission system *J* and its projection to the fission axis *K*.

In the last time, in cooperation with FLNP physicists a new approach to the description of fission induced by low energy neutrons analogous to an ordinary theory of nuclear reactions is being developed [7]. In principle, this approximation consists of the description of interference effects in neutron fission with well-developed methods of the theory of nuclear reactions.

It appears to be of vital importance is to obtain direct information about the fission barrier parity dependence for the channels $J^{\pi}K$. To this end, unique possibilities are provided by studies of *P*- even nuclear correlations of fission fragments due to the interference of *s*- and *p*- resonance fission amplitudes. Such experiments of ^{235}U, ^{233}U [8,9] and ^{239}Pu were conducted by a Dubna-Gatchina collaboration at the booster IBR-30+LUE-40. The results were obtained from two types of experiments. In the first, "forward-backward", the energy dependence of fragments emission in and against the direction of the unpolarized neutron momentum was measured. In the second, "left-right", the asymmetry in fission fragments emission in the plane of the polarized neutron spin and momentum was investigated. A more detail description of the problems's state of the art is in the

[7] Barabanov A.L., Furman W.I., Z.Phys. **A357**, 411(1997)
[8] Alfimenkov V.P.} et al. JINR-E3-97-106, Dubna(1997); Alfimenkov V.P., Chernikov A.N., Lason L. et al., Nucl.Phys., **A645**, 31(1999)
[9] Gagarski A.M., Guseva I.S., Goloslavskaya S.P. et al., Preprint PNPI NP-32-1999, 2117, Gatchina(1999)

article «Analysis of *P*-even effects in the anisotropy of fission fragments from the resonance neutron induced fission of ^{235}U and ^{239}Pu» in the Section «Experimental reports» of the present report.

In 2001, measurements of interference effects in the polarized neutron-induced fission of ^{239}Pu at the IBR-30 booster completed. The emission asymmetry of light and heavy fragments in relation to the neutron momentum-neutron spin plane was measured. This, so-called left-right asymmetry, does not violate P-parity and is due to the interference between s- and p-resonances. The results together with those on the earlier measured forward-backward asymmetry make it possible to obtain yet unavailable information on p-wave resonances in heavy nuclei.

Another measured effect is the parity violating asymmetry of fragments emission in and against the direction of the captured neutron spin. It is the first time that such data are obtained for plutonium resonances **(Fig. 3).** At present, the processing of the experimental data on both effects is nearing completion and the preparation of publications is under way.

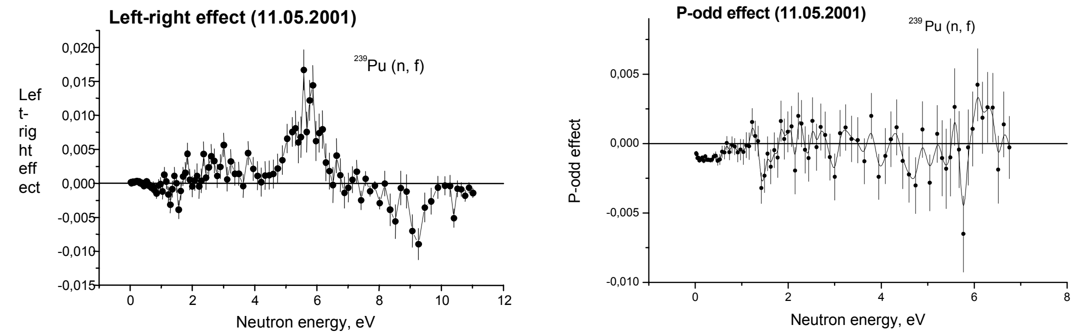

Fig. 3. *The effects of the left-right and parity violating asymmetry in the resonance neutron-induced fission of* ^{239}Pu.

1.3. High-excited states of nuclei

1.3.1 Investigation of two-step gamma cascades

In the 2001 study of the structure of high-excited nuclear states by registration of two-step cascades, the main effort concentrated on analysis and assessment of probable systematic error values using the method of model-free determination of the area of level densities and radiative strength functions of E1 and M1 transitions at neutron binding energies in nuclei with a maximally high level density proposed and developed in FLNP.

The possibilities of the method are illustrated in **Fig.4** showing two variants of the dependence of the intensity of cascades on the energy of their primary transition, the density of levels and the sum of their corresponding radiative strength functions. It also shows the estimated possible values of the sought parameters allowing exact reproduction of the intensity of the cascades (experimental and simulated). Though the intensity of the cascades can be reproduced with one and the same accuracy by an infinite number of parameters, the interval of their variations is rather small. The method has first made it possible to assess the level density in the given interval of spins (total for two parities and separately for each) without the aid of model representations of the emission probability of the nuclear reaction product (for example, neutron evaporation). The accuracy of the corresponding models in the excitation region above ~2 MeV and to the neutron binding energy is actually unknown. An analysis of the obtained results allows the statement that in spite of systematic errors our method provides a better description of the gamma-decay process of neutron resonances and improves essentially the calculation accuracy of, e.g., total gamma-radiation spectrum (especially for nuclei in the region N=82 and 126) in comparison with models of level density and partial radiative widths traditionally used for the purpose (see **Fig. 5**).

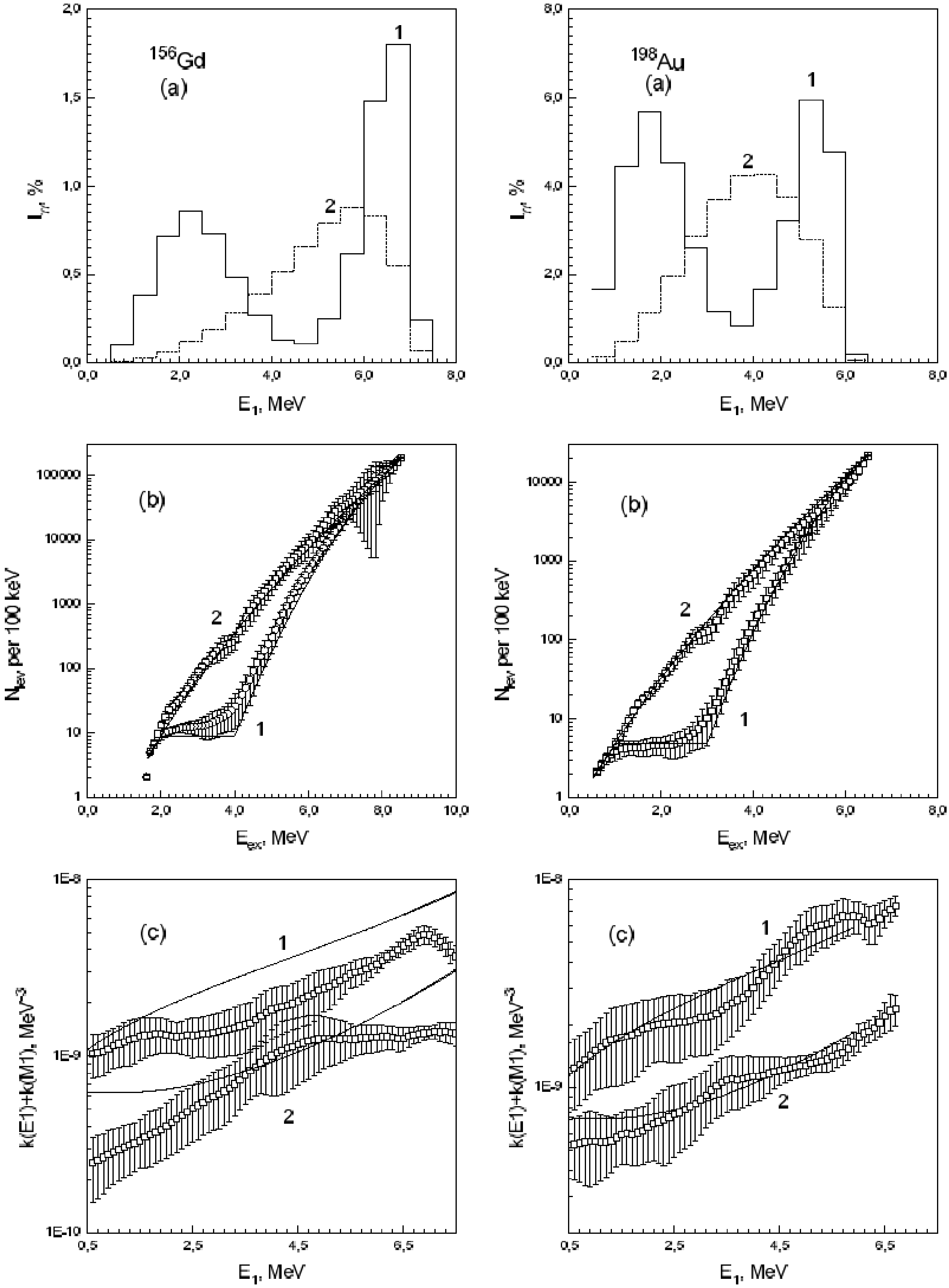

Fig. 4. *The intensity of two-step cascades (a) calculated making use of the level densities shown with solid lines in (b) and radiative strength functions (c). The points with errors represent an interval of an infinite number of level densities and strength functions enabling exact reproduction of the cascade intensities given in (a).*

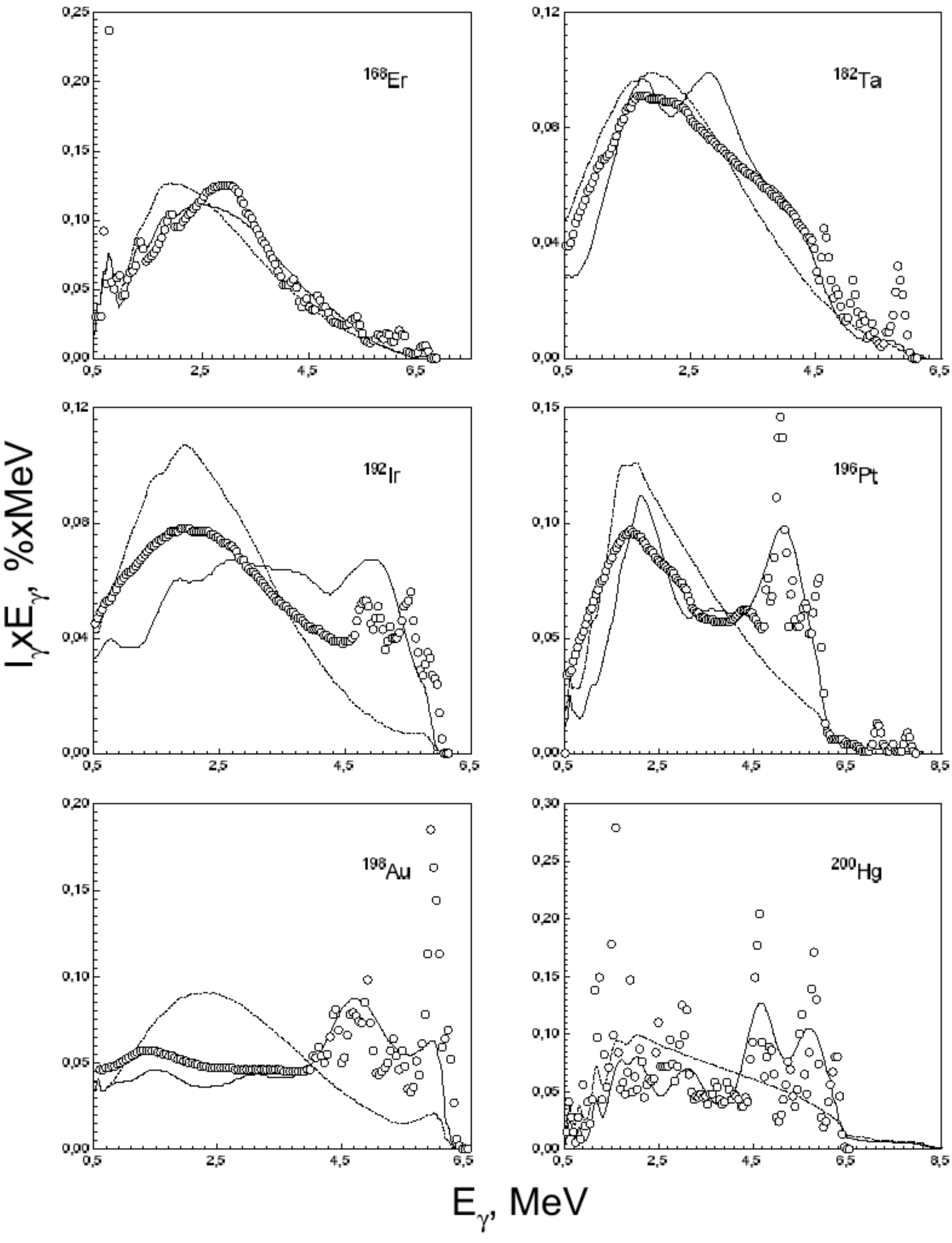

Fig. 5. *The experimental (points) total spectra of gamma-radiation after the capture of thermal or fast neutrons for the compound nuclei ^{168}Er, ^{182}Ta, ^{192}Ir, ^{196}Pt, ^{198}Au and ^{200}Hg. The solid and dot lines illustrate the results of the calculation by the method of the model-free determination of level densities and radiative strength functions and the predictions of models usually used for the purpose, respectively.*

In addition, it is established that the energy dependence of the radiative strength functions k(E1)+k(M1) of the primary and secondary transitions in the cascade differ. Also, it has been shown that this does not violate essentially the earlier conclusion about the existence in the formed nuclei at least of an excitation energy area of the width not less than 2 MeV with a practically constant or weakly changing density of levels. This is evidence of principal changes in the properties of deformed nuclei in the excitation energy region 3-4 MeV.

The last cycles of IBR-30 were used to investigate the background conditions of the registration of two-step cascades in the fissionable target nuclei U-235. It is established that prompt quanta do not interfere with the registration of two-step cascades to the final levels in U-236 with an energy up to 1÷1.5 MeV. This means that there is a possibility to obtain new precision experimental data on the fission and capture cross sections of actinides with the help of this technique.

Besides, it is possible to obtain detail information about the density of excited levels and radiative strength functions of dipole transitions at radiative neutron capture in even-odd fissionable target nuclei at least. Without this information it is impossible to improve the accuracy of the theoretical description of the interaction processes of neutrons with materials of importance in the reactor construction practice. As a result, the study of two-step cascades in fissionable nuclei through development of model representations may provide an increase in the accuracy of the interaction cross section estimates of neutrons with an energy from tens to hundreds keV.

1.3.2 Investigations of radiative neutron capture, the nuclear data program

In the first half of the reported year, on the 122-m flight path of IBR-30 there were measured the multiplicity spectra of gamma-quanta from the reactions (n,γ), (n,f) for the isotopes ^{238}U,^{235}U, ^{239}Pu and natural Pb with the help of a 16-section liquid detector of the spectrometer PARUS. For the isotope ^{235}U, similar measurements were performed with the spectrometer ROMASKHKA on the 500-m flight path. For ^{238}U,^{235}U, ^{239}Pu, the time-of-flight spectra of gamma-ray multiplicity were measured with and without sample filters from uranium or plutonium in the neutron beam at two temperatures, 77 K and 293 K. The measurements were conducted in good geometry with thin sample radiators (293 K) in gamma-detectors and with filters of equal thickness (0.5mm) in the neutron beam. These investigations will make it possible to determine the coefficients of resonance blocking and Doppler effects in the capture and fission cross sections, as well as in the value of $\alpha = {}^{\sigma_\gamma}\!/_{\sigma_f}$. In parallel, on the 124-, 504- and 1000-m flight paths there were conducted measurements of the time-of-flight spectra of natural lead and fissionable nuclei of uranium and plutonium using batteries of boron and helium counters to determine the transmission abilities and total cross sections of these materials in the energy range from 1 eV to 100 keV. The conducted measurements will make it possible to achieve a higher accuracy of determination of neutron constants (within (2÷7)% error).

1.3.3 Measurements of capture partial cross sections by the shift of the primary gamma-transition energy

In 2001, EG-5 experiments to measure the energy dependence of partial cross sections of the (n,γ) reaction continued. In the basis of the method lies the dependence of the primary gamma-transition populating one of the low-lying levels of the daughter nucleus on the incident neutron energy. At the same time, the intensity of the registered γ- transition is proportional to the (n,γ) reaction cross section. As a neutron source there was used the reaction ^{7}Li(p,n). The energy range of neutrons incident on the sample was 5÷100 keV. The γ- spectra were registered with a Ge(Li) detector. Also, gamma-spectra from the reaction $^{48}Ti(n,\gamma)^{49}Ti$ were measured. It is the first time that the energy dependence of the partial cross section is obtained for the γ- transition populating the first excited state (1382 keV, $J^{\pi} = 3/2^{-}$) of the daughter nucleus ^{49}Ti. The results of the experiments were reported to the international seminar ISINN-9 and published in the ISINN-9 proceedings.

1.4. Neutron reactions with emission of charged particles

1.4.1 Analysis of α-widths of neutron resonances in ^{147}Sm over energy interval from 3 eV to 700 keV

In 1999-2000 a FLNP JINR- Oakridge National Laboratory- Lodz University collaboration conducted an experiment to measure the cross section of the reaction $^{147}Sm(n,\alpha)^{144}Nd$ on resonance neutrons at the neutron source ORELA, Oakridge, USA. The data on total α-widths of 104 resolving resonances with $J^{\pi}=3^-$ and $J^{\pi}=4^-$ at energies from 3 eV to 700 keV were obtained (**Fig. 6**).

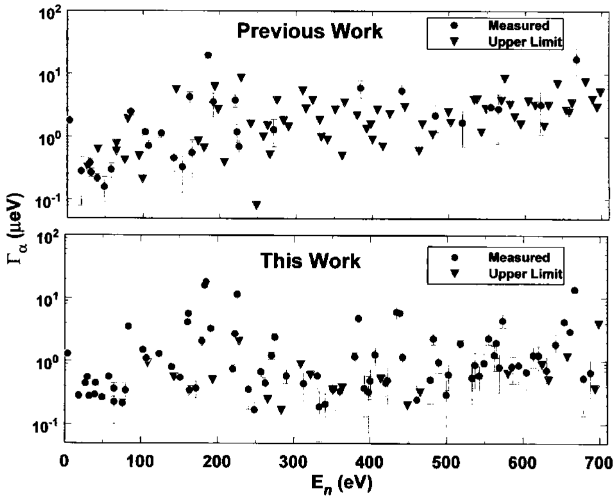

Fig. 6. The experimental obtained α-widths and the data from earlier works.

An analysis of the renewed data was conducted. An unusual resonance with an energy around 184 eV was discovered Satisfactory fitting to the experimental points under R-matrix analysis is only possible under assumption of the existence of a doublet of resonances with E_0=183.30 eV and E_0=184.92 eV though having anomalously large α-widths – 16 μkeV and 18.1 μkeV, respectively (for $<\Gamma_\alpha(3^-)>$=2.54 μkeV, $<\Gamma_\alpha(4^-)>$=0.63 μkeV).

Another interesting result comes from an analysis of mean α- widths. By the statistical theory of nuclear reactions the α- particle strength function $S_\alpha = <\gamma_\alpha^2>/D$ is a constant value and consequently, the mean α-width $<\Gamma_\alpha> = <\gamma_\alpha^2>P$ cannot depend on the energy interval because the kinetic energy of the neutron is small compared to the binding energy and does not affect the penetrability of the potential barrier. The results of the mean α- width calculation for different intervals are shown in **Fig. 7.**

It is seen that mean α- widths may grow with increasing neutron energy, which in turn points to the manifestation of some nonstatistical effects.

1.4.2 Reactions with fast neutrons

The cross sections and angular distributions of the $^{64}Zn(n,\alpha)$ reaction products for E_n= 5-7 MeV were obtained with the Van de Graaf accelerator in the Institute of Heavy Ion Physics of the Peking University (**Figs.8 and 9**).

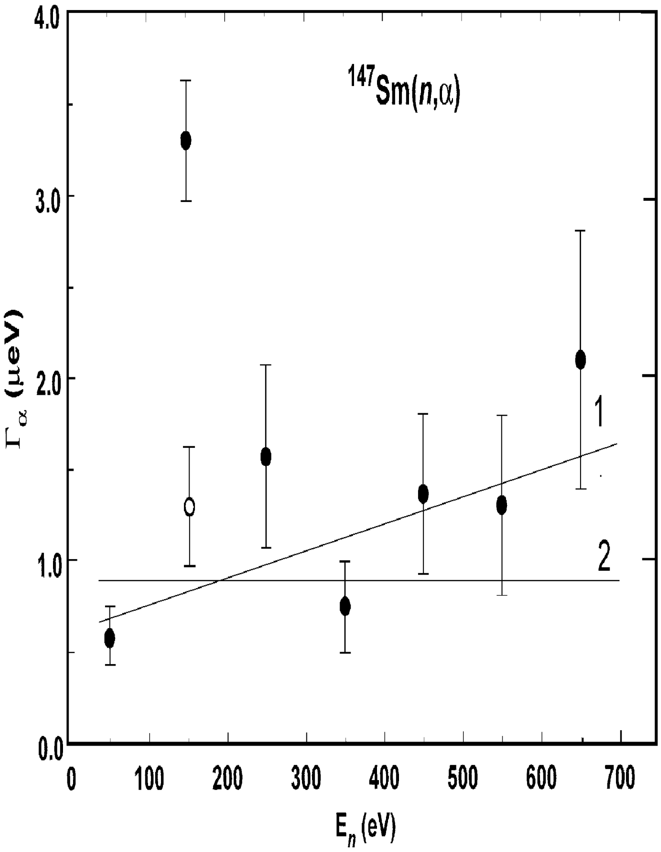

Fig. 7. Mean α-width values. The open circle – the doublet of resonances near 184 eV is excluded from analysis. 1-linear fit; 2- fitting under assumption that <Γ_α>=const.

A systematics of the cross sections of the (n,p) reactions on fast neutrons has been developed on the basis of the theses of the statistical theory of nuclear reactions.

A channel at the EG-5 accelerator of FLNP has been equipped to study the (n,p) and (n,α) reactions on neutrons from the D-D reaction at 3-6 MeV.

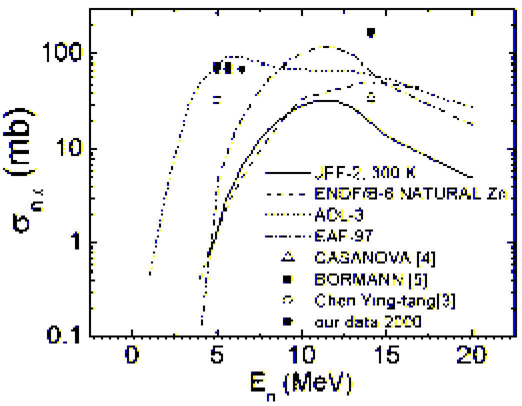

Fig.8. The experimental data and theoretical estimates of the $^{64}Zn(n,\alpha)^{61}Ni$ reaction cross section.

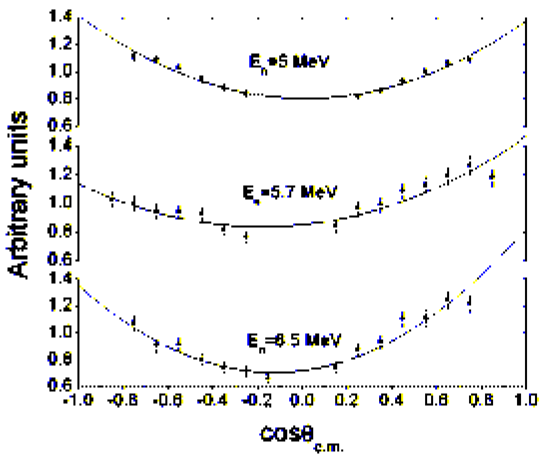

Fig.9. Angular distributions for the $^{64}Zn(n,\alpha)^{61}Ni$reaction.

1.5. Astrophysical aspects of neutron physics

1.5.1 Measurement of ^{147}Pm neutron capture cross section to determine neutron density in s-process

The data from a joint Dubna-Karlsruhe experiment to measure the neutron capture cross section on the radioactive isotope ^{147}Pm at the «standard» astrophysical temperature kT=25 keV have been processed. The isotope is one of the branching points on the way of the s-process in the region Nd-Sm and the cross section data are necessary for the determination of neutron density in the s-process of nucleosynthesis. The obtained cross section $<\sigma_{kT=25keV}>=685\pm69$ mb, which is almost two times smaller than the theoretical estimates.

1.5.2 Modeling of neutron nucleosynthesis in the region of sulphur and chlorine at helium burning in stars with the mass 25 M⊙

In cooperation with scientists from the Lodz University a program is elaborated to calculate neutron nucleosynthesis in a stationary phase of star evolution – practically constant temperature, electron density and matter density in the area of burning. The conditions are characteristic for hydrostatic burning of helium in massive stars which are considered to be the main suppliers of the nuclides of the weak component of the s-process. It is believed that it is in such stars the major part of neutron excess isotopes of light and average mass is formed. The program has been caried out under the computer program «Mathematics». Test calculations for the regions S-Cl-Ar (**Fig.10**) have demonstrated good agreement with the results of other authors.

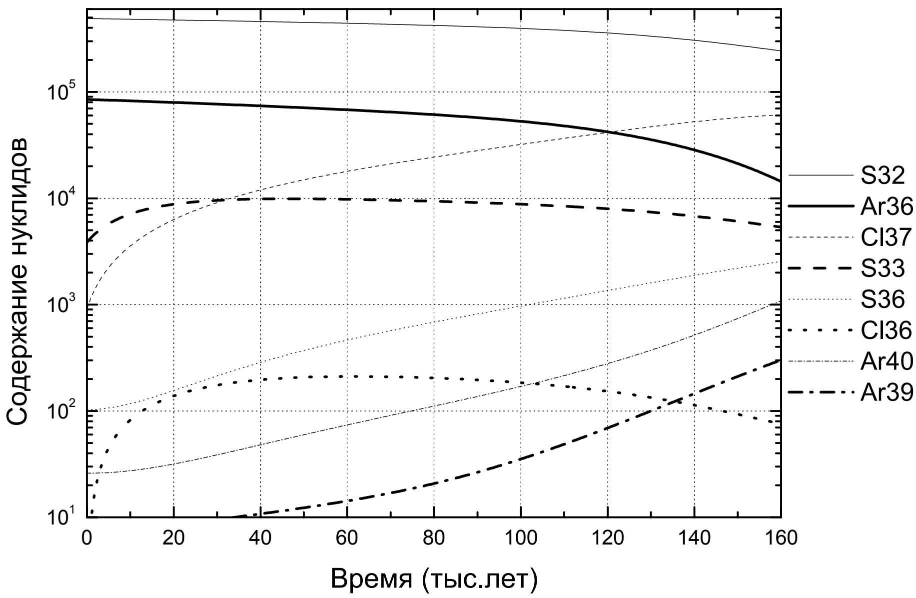

Fig. 10. *The calculated dependence of the abundance of a number of isotopes on the time at burning of He.*

1.6. Ultracold neutron physics, neutron optics

1.6.1 Investigation of super-small energy transfer processes at interaction of neutrons with surfaces of solid bodies

Under RFBR and INTAS projects comprehensive a experimental study of the new phenomenon, super-small UCN energy transfer at interaction with the surface of solid bodies, continued. Plans include the experimental determination of absolute values of the probability of super-small heating (in the energy interval up to 150 neV) and cooling of UCN at interaction with various substances, determination of the dependence of the discussed probability on the temperature over the interval 100 - 300 К, determination of the spectral characteristics of the processes, including the spectra of heated/cooled neutrons, the dependence of the energy transfer probability on the UCN spectrum. In 2001 the creation of the new gravitation spectrometer completed. The facility was moved to ILL (Grenoble, France) and assembled on the beam PF2 (**Fig 11**).

Test measurements were conducted with the new facility confirming its ability to operate as a spectrometer of ultracold neutrons with a higher (up to 8 times) sensitivity to small energy transfers than its predecessor. Of no less importance is good conformity between the probability of UCN "small heating" for copper and stainless steal surfaces obtained in the tests and the expected values determined from the previous experiments.

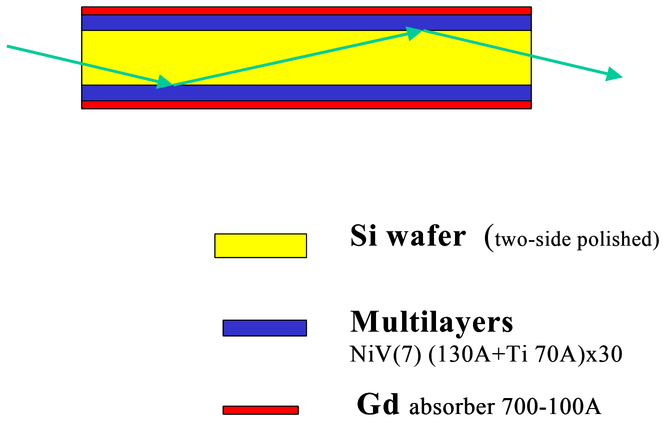

Fig. 11. *Assembling of the gravitational spectrometer on the channel PF2 .*

Of certain interest are the results of test measurements with sapphire. Total UCN losses on a sapphire monocrystal appear to be essentially higher than theoretical, which is possible to explain by surface impurities as the sample was not subjected to preliminary degassing and "small heating" on the sample in the energy range 50-150 neV does not give any noteable contribution against the background of heating on the spectrometer walls.

The created gravitational spectrometer is the most advanced instrument today for the study of "small transfers" of energy at interaction of UCN with the surface of solid bodies.

1.6.2 UCN Optics

Work to study the optics of strongly absorbing media with the help of an UCN spectrometer with interference filters started. The samples are natural gadolinium with an UCN absorption cross section of the order of 10Mb deposited on silicon substrates. A unique situation is created due to the fact that in this case, the UCN absorption wavelength in matter $(\rho\sigma)^{-1}$ is of the order of the neutron wavelength.

Initially, the purpose of the experiment was to show that the transmission ability of thin Gd samples does not depend on the velocity component parallel to the substance interface. It is the result that is predicted by the model of complex optical potential. However, a considerable deviation from the prediction was observed. The obtained result has not found its explanation yet.

In the second stage, systematic measurements of the dependence of the transmission ability of the samples on the ("normal") neutron velocity were conducted. In this case, the obtained results are also in contradiction with theoretical predictions. The explanation of the result as being due to methodological reasons fails, though it cannot be completely neglected because of extreme difficulties of staging such an experiment.

1.6.3 Measurement of interaction time of neutrons with quantum objects by the method of Larmor clock

Work to measure the interaction time of neutrons with quantum objects by the method of Larmor clock was carried out on the spin-echo spectrometer IN15 in ILL. In the basis of the method lies the fact that the neutron precessing in the magnetic field interacts with the sample. A finite time of interaction results in the appearance of an additional spin precession angle. The experiment to measure the tunneling time of neutrons to a quasibound state yielded the first result reported at an international conference.

An apparent delay due to the resonance character of the tunneling was registered. In the experiment to measure the neutron diffraction time, the time of neutron transmission through the sample was measured in the direct geometry of transmission and the double diffraction reflection geometry. The result is shown in **Fig 12**.

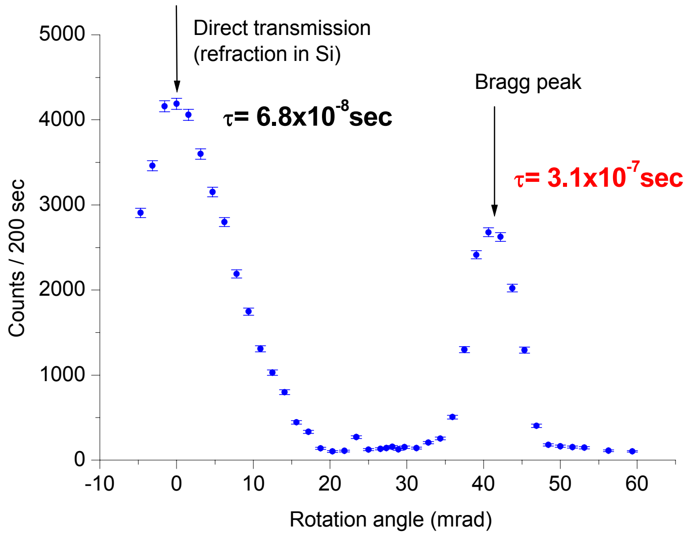

Fig. 12. *The transmission curve as a function of the neutron incidence angle.*

1.7. Proposal for direct measurement of neutron-neutron scattering at the reactor YAGUAR

The recent results of fundamental nuclear physics experiments indicate that the neutron-neutron interaction is stronger than the nuclear part of the proton-proton interaction implying breaking of the charge symmetry of strong nuclear force. The best way to verify this and to stimulate further development of the isotopic-spin invariance concept is to perform a direct measurement of neutron-neutron scattering by colliding free neutrons. The proposal for such an experiment - the ISTC Project 2286, which is a joint project of JINR (Dubna), VNITF (Snezhinsk) and TUNL (Durham, NC, USA) has been prepared and submitted to the International Science Technology Center.

The experimental study of thermal neutron fields formed by polyethylene converters inside the central channel of the aperiodic pulsed reactor YAGUAR demonstrates that the reactor provides a required instantaneous value of about 10^{18} n/cm^2·s for the thermal neutron flux density during the neutron burst of 700 μs. These results were presented at the Dubna ISINN-9 International Seminar.

2. Theoretical investigations

1.8. Weak parity-violating NN-potential

On the basis of the characteristic weak parity-violating *NN*-potential the weak parity-nonconserving single-nucleon Hartree-Fock potential V_W^{HF} has been constructed following a general theoretical scheme applied earlier to the case of standard strong *NN*-interaction. The general formulae for all the components of the weak single-nucleon HF-potential V_W^{HF} accounting for the isotopic dependence (τ_{1z} -terms) and explicit contributions of π- , ρ- and ω-meson exchanges have been derived. It is ascertained that the potential V_W^{HF} has a considerably more complicated structure than phenomenological weak nucleon-nucleus potentials but, nevertheless, incorporates some features which have direct phenomenological analogues. The calculation of the coefficients at ($\boldsymbol{\sigma}_1 \hat{\mathbf{k}}_1$) in the main *P*-odd term of the potential V_W^{HF} ($\hat{\mathbf{k}}_1$ is the nucleon wave vector operator) for the centres of the doubly-magic spherical nuclei ^{208}Pb and ^{40}Ca have demonstrated (for the nucleon energy range E = (0 ÷100) MeV) sufficiently good agreement with the phenomenological data. The relations between the magnitudes of various contributions to V_W^{HF} (Hartree and Fock parts, isoscalar and isovector components, π-, ρ- and ω-meson parts) are studied.

The investigation of the other terms in the potential V_W^{HF} and the study of radial distributions of different components in V_W^{HF} will continue.

1.9. Free neutron β- decay

This year, investigating the neutron β- decay was continued. Whereas the previous calculations were entirely based on the effective Lagrangian describing weak interactions on a pure hadronic level, the present-day inquiry is carried out upright within the electroweak standard theory (the Weinberg-Salam theory) treating interactions of leptons (e, ν,…), quarks (u, d, …), gauge bosons ($\gamma, W^{\pm}$, Z) and Higgs particles which all cause eventually the β- decay of neutrons. In describing the radiative corrections to the neutron β- decay, a renormalization scheme for the electroweak standard model is utilized in which the electric charge and the masses of the gauge bosons, Higgs particle and fermions (leptons and quarks) are used as physical input parameters. The effective quantities, formfactors, come naturally into consideration in order to allow for strong interactions. Detailed calculations of the one-loop electroweak radiative corrections to the neutron lifetime and electron angular distribution are for now under way and will come to fruition before long.

3. Methodology

3.1. Calibration of fast neutron detectors HEND

In 2001, in cooperation with DRRI specialists the program for the calibration of the fast neutron detector HEND (High Energy Neutron Detector) to operate on board the American research apparatus Mars Odyssey 2001 as an element of the gamma-spectrometer complex completed. The work was carried out under a long-term agreement with the Institute for Space Research of the Russian Academy of Sciences in accordance with which JINR was to develop the physical concept of the apparatus, accomplish physical and mathematical modeling of its characteristics and calibrate the apparatus efficiency. The calibration was done using one of the three instruments made in IKI RAS. One was installed on board the space apparatus and is presently operating successfully on the Mars orbit registering the neutron radiation of the planet.

3.2. Development and construction of new neutron scintillation detectors

Cooperation with RCL LNP in the creation of new detectors for neutron and neutrino investigations continued. The RCL synthesized organic scintillators with boron and gadolinium were tested on neutron beams in the Scientific Research Department of Physics of SRDPN to investigate the efficiency of their application.

4. Analytical investigations at IBR-2: neutron activation analysis and radiation research

A successful application of the nuclear analytical technique for biotechnological and biochemical development, namely, of **Selenium- and Chromium-containing pharmaceuticals** based on the blue-green algae *Spirulina platensis*) has brought two patents in co-authorship with scientists from the Tbilisi Institute of Physics named after Andronikashvili and a number of internationally recognized papers.

A combination of these vitally important elements with protein-containing algae, called the "food of the future", allows to produce pharmaceuticals of great potential for the treatment of a wide spectrum of diseases: from ishaemic heart disease - to enhancement of the immune system to fight AIDS. Investigations to develop a technique for the determination of the element content in *Spirulina platensis* are carried out by the group of Neutron Activation Analysis.