6.2. NEUTRON NUCLEAR PHYSICS

CONTENTS

Measurement of P-odd Asymmetry in the $^{10}B(n,\alpha)^{7}Li$ reaction
V.A.Vesna, Yu.M.Gledenov, I.S.Okunev, S.S.Parzhitskii, Yu.P.Popov, E.V.Shulgina

Investigation of Charged Particles Emission Reaction Induced by Fast Neutrons
Yu.M.Gledenov, G.Khuukhenkhuu, Yu.P.Popov, Bao Shanglian, Tang Guoyou, Cao Wentian, Qu Decheng, Chen Zemin, Chen Yingtang, Qi Huiquan

Interaction of Polarized Neutrons with a Polarized Lanthanum Target and Structure of the Neutron Cross Section up to 20 eV
V.P.Alfimenkov, Yu.D.Mareev, V.V.Novitsky, L.B.Pikelner, V.R.Skoy

Study of the Depolarization of Resonance Neutrons in an Experiment to Search for the T-Noninvariance
V.P.Alfimenkov, Yu.D.Mareev, V.V.Novitsky, L.B.Pikelner, V.R.Skoy, C.R.Gould, D.G.Haase, N.R.Roberson

Multiplicity of Gamma-Rays in Neutron Resonances of ^{176}Hf and ^{179}Hf
G.P.Georgiev, Yu.V.Grigoryev, G.V.Muradyan, N.B.Yaneva

Situation in Study of Electric Polarizability and Mean Square Charge Radius of the Neutron
Yu.A.Alexandrov

On the Electric Polarizability of the Neutron
Yu.A.Alexandrov, L.Koester, L.V.Mitsyna, P.Prokofiev, G.S.Samosvat, J.Tambergs, W.Waschkowski

UCN High Density Pulse Source at the BIGR Reactor (Arzamas-16) and Neutron Lifetime Experiment
A.V.Strelkov, V.N.Shvetsov, A.D.Stoica

A Moving Converter as a Possible Tool for Producing Ultracold Neutron at Pulsed Neutron Sources
Yu.Pokotilovski

On Experiment Verification of the Skobeltsin-Baldin Hypothesis of Emission of a Nonstable Particle Following the Decay of ^{214}Bi
Yu.N.Pokotilovski, G.G.Takhtamyshev

Mossbauer Effect Based Experiments to Search for New Light Bosons
Yu.Pokotilovski

Some Aspects of Estimation of n,e-amplitude and Neutron Polarizability
V.G.Nikolenko, A.B.Popov

Properties of ρ - and ω -mesons in Dense and Hot Nuclear Matter Near the Critical Pion Mode Softening
G.G.Bunatian, B.Kampfer

Quasi-Particle Description of a Strongly Interacting Pion Gas
G.G.Bunatian, B.Kampfer

Quantum Phenomena at Fast Modulation of a Neutron Wave
D.V.Amandzolova, A.I.Frank, V.G.Nosov

Interaction of Waves and Particles with Layered Media (all media can be considered to be layered)
V.K.Ignatovich

Promising and Crucial Examples of Cluster Radioactivity Processes
S.G.Kadmensky, V.I.Furman, Yu.M.Tchuvil'sky

Possible equidistance of the excitation energies of the intermediate levels of intense γ-cascades

V.A.Khitrov, Yu.V.Kholnov, Yu.P.Popov, A.M.Sukhovoj, E.V.Vasilieva, A.V.Vojnov

Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research

The "regularity" exhibited by the intermediate levels excitation energies of the most intense two-step cascades has been shown to be most clearly manifested in the intensity distributions of the cascades [1] between the compound state of ^{174}Yb and its first excited level (Fig.1). In the correspondig spectrum there are no less than four groups of intense cascades. The distances between these groups are practically constant. A similar equidistance can be revealed in practically all the cascade intensity distributions hitherto obtained for nuclei distinguished by such parameters as the neutron number parity or by their deformation. It should be noted, that at a quite definite distance from the intermediate level of the observed intense cascade there may appear not only another level of a single intense cascade, but also groups (multiplet) of intermediate levels of intense cascades.

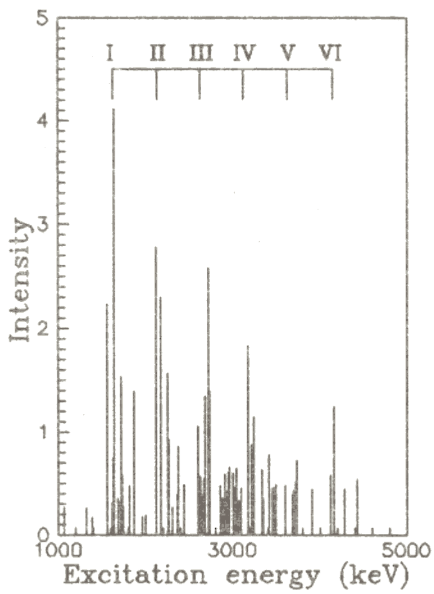


Fig.1. The dependence of the relative intensity of resolved intense two-step cascades to the first excited state of ^{174}Yb upon the excitation energy. The possible groups of equidistant states are marked by Roman numerals.

By now the cascades from two γ-transitions have been studied experimentally for more than 18 nuclei from the region $143 < A < 187$. These data allow us to perform an analysis in a broad range of nuclei.

It is now possible to single out one value for the equidistant interval T from our experimental data for many nuclei. In Fig. 2 the dependence is shown of the obtained equidistance period T as a function of the atomic weight of the nucleus under study.

It is seen from Fig. 2 that (in regard to errors of revealing the possible equidistant period) on the whole, regular dependence of equidistant period upon atomic weight is observed if one divides all studied nuclei into 4 groups differing by types of cascade transitions or by structure of decaying compound-state.

Obtained data allow one to suppose a presence of groups of vibration excitations with characteristic energy T≃500-800 keV.

Similar equidistant periods between intermediate levels of the most intense cascades were revealed also in nuclei ^{114}Cd and ^{124}Te.

For final proof of presence of pointed excitations it is necessary to search for two-step cascades in many neutron resonances.

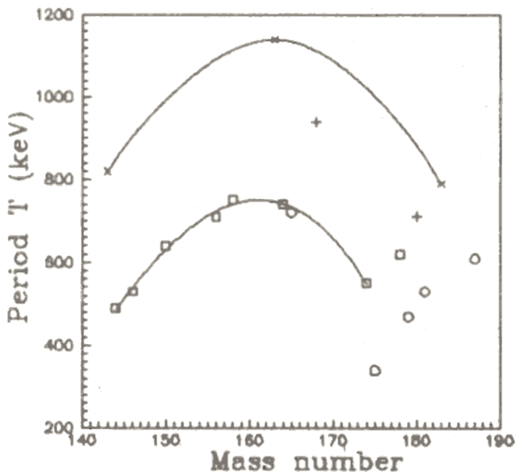


Fig.2. The dependence of the most probable equidistance period T on the mass number of the studied nuclei.
□ - even-even nuclei, cascades of E1+M1-transitions;
o - even-odd nuclei with $\Gamma_n^o / < \Gamma_n^o > > 1$;
×- even-odd nuclei with $\Gamma_n^o / < \Gamma_n^o > < 1$;
\+ - nuclei ^{168}Er and ^{180}Hf, cascades of E1+E1-transitions.
The maximum and minimum values are connected by lines separately.

Boneva S.T. et al. Izv. Akad. Nauk SSSR, Ser. Fiz. V53, 2092 (1989)

The peculiarity of the high-lying states excitation of the even-even nuclei from the region $150 \leq A \leq 164$

V.A.Khitrov, A.M.Sukhovoj, A.V.Voinov

Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research

Performed by now investigations of the peculiarities of the heavy deformed nuclei states excitation and decay at the excitation energy region below neutron binding energy show that usually accepted notions of their neutron resonances γ-decay mechanism does not take into account some important features.

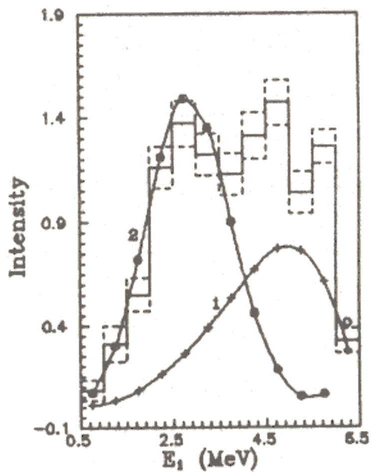
So, the single-particle transitions between the 4s and 3p neutron shells must influence essentially on the cascade γ-decay in the 4s-region of the neutron strength function. It is impossible to distinguish such transitions by traditional methods of nuclear spectroscopy due to the fragmentation process (well studied theoretically) of such states over many nuclear levels. At the same time, the method of the cascades γ-transitions analysis, summing by natural manner the strength of states over a given excitation interval, allows us to observe directly these single-particle transitions.

Their significant role in the neutron resonances γ-decay process was demonstrated by investigation of the even-odd nuclei [1]. Up to one half of the total intensity of all the primary transitions may be due to the neutron transitions between 4s and 3p shells.

Similar effects cannot be unobservable also in the even-even nuclei γ-decay. To reveal the role of similar transitions we studied [2] cascades of γ-transitions in the even-even compound-nuclei ^{150}Sm, $^{156,158}Gd$ and ^{164}Dy. According to theoretical calculations single-particle state [510]↑, concentrating the strength of the 3p shell in deformed nuclear potential, lies by 2.5-3 MeV below neutron binding energy in this atomic weight region. This state must be excited intensively by the primary transitions with correspondent energy. It is seen from the figures that in all these nuclei at indicated primary transition energy it is really observed an enhancement of the cascades intensities relatively both model calculation (curve in figure) and cascades with some higher primary transition energy. Moreover, in some cases the experimental intensities exceed the model calculation by order of magnitude.

Hence, it is impossible to describe the neutron radiative capture process in heavy deformed nuclei [3] (including transuranium isotopes) without taking into account the shell effects of the similar kind.

1. Boneva S.T. et al., Particles and Nuclei, 1991, V.22, p.1433
2. Boneva S.T. et al., Z. Phys. A - Hadrons and Nuclei, 1991, V.338,. p.319
3. Beitins M.R. et al., Z. Phyz. A - Hadrons and Nuclei, 1992, V.A341, p.155



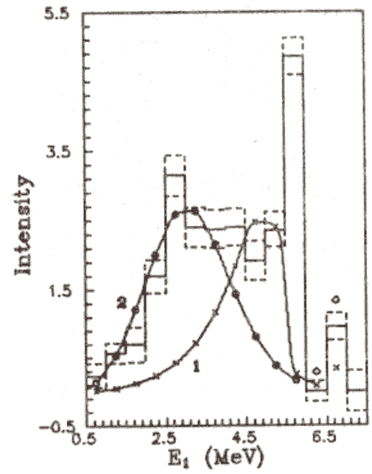
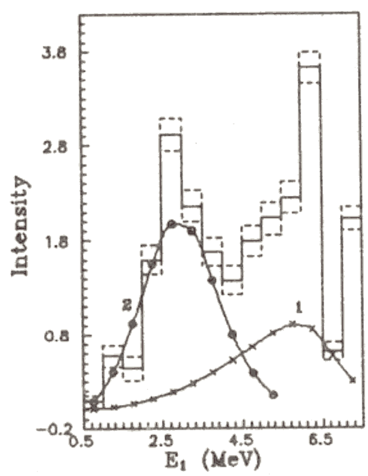


Fig.1. Sum intensity of cascades for the two low-lying levels in ^{150}Sm (% per decay) as a function of primary transition energy. Histograms represent the experimental data with ordinary statistical errors; curves 1 and 2 represent the BSFG and the Ignatyuk thermodynamical model predictions respectively.

Fig.2. The same as in Fig.1 for cascades to the three low-lying levels in ^{164}Dy.



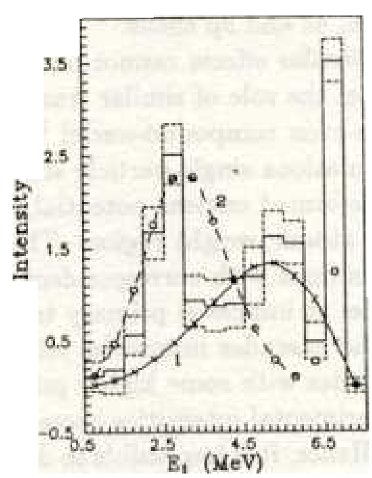


Fig.3. The same as in Fig.1 for cascades to the three low-lying levels in ^{156}Gd.

Fig.4. The same as in Fig.1 for cascades to the three low-lying levels in ^{158}Gd.

ON A NEW WAY OF COMPTON BACKGROUND SUBTRACTION IN INVESTIGATION OF γ γ-COINCIDENCES BY SUMMATION THE AMPLITUDES OF COINCIDING PULSES (SACP)

E.V.Vasilieva, A.V.Voinov, V.D.Kulik, Yu.P.Popov, A.M.Sukhovoi, V.A.Khitrov, Yu.V.Kholnov, V.N.Shilin

Frank Laboratory of Neutron Physics

The SACP method developed to study the γ-decay of compound states of nuclei [1] has been applied recently to investigate the decay of radioactive nuclei [2]. It is based on separation of two-quantum cascades with the same total energy, that is to say the cascades between two definite states of a nucleus. The work [3] (Fig.2) gives the SACP spectrum for the decay of $^{170}Lu \rightarrow^{170} Yb$. It contains 70 peaks against a continuous Compton background. Each peak is for the sum of two-quantum cascades with the same total energy. Some of these total energies are indicated in this picture. To obtain spectra of γ-quanta which form the cascades, one must subtract the Compton background. Fig.1 demonstrates the applied method of subtraction of the Compton background [4]. It schematically shows two SACP peaks: the peak "i" which is under investigation, and the peak "j" at a larger energy. Both are located on the continuous spectrum of sums. Two bands are shown on both sides of the peak with the sum of their widths being equal to the background width under the peak. The spectrum composition for the hatched sections and the background under the curve is practically the same. Therefore the subtraction of the hatched sections is equivalent to the subtraction of the background itself. Fig.2a presents the differential spectrum of the cascades with the total energy $E_s = 2498$ keV which has been obtained in this way. There are two cascades in the spectrum, i.e. two pairs of lines which are symmetrical with respect to the spectrum center. The x-axis corresponds to the objective zero and if the data are close to the x-axis it means that the Compton background has been subtracted completely.

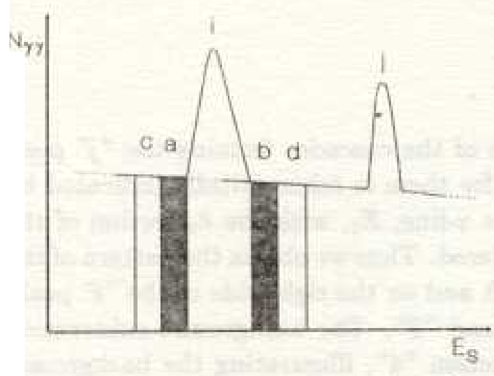


Fig.1. Schematic representation of a part of the SACP spectrum.

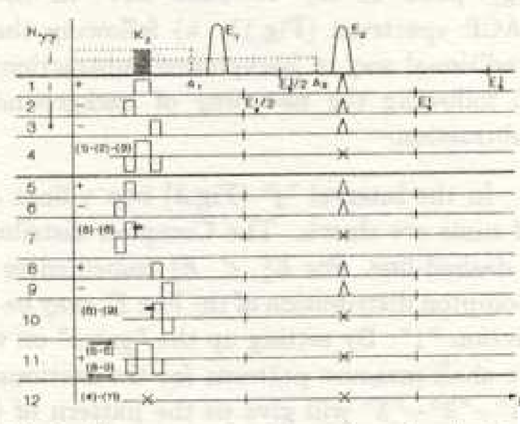


Fig.3. The way of subtracting the background in the SACP method.

However there is a background smooth component left in the form of structures of three peaks, one of them with a positive amplitude, two others with a negative one. These structures have no satellites in the other half of the spectrum. They appear following the background subtraction under the influence of the γ-lines forming the "j" peaks (Fig.1) of greater total energy. Fig.3 explains the nature of the false structures.

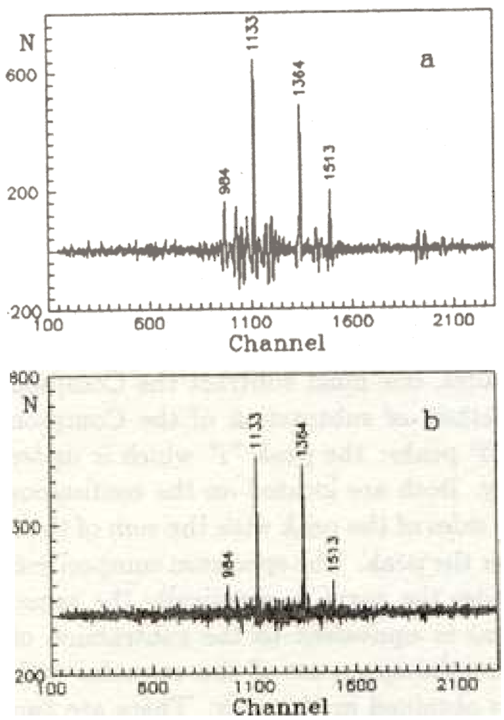


Fig.2. The γ-rays spectrum for the two-quantum cascades corresponding to the energy peak of $E_s = 2498\ keV$ in the SACP spectrum (Fig.1): a) following the traditional way of background subtraction; b) following the new way of background subtraction.

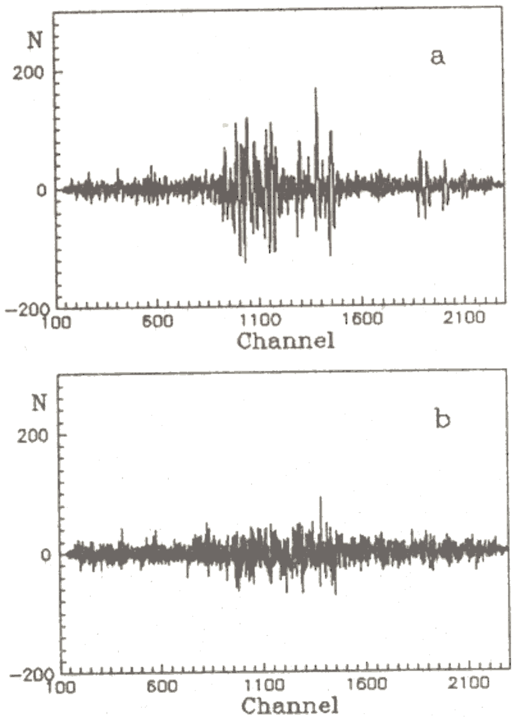


Fig.4. The same as in Fig.2 for the energy interval of the SACP spectrum of $2430 - 2443\ keV$.

In the interval "j" (Fig.3) two γ-lines of one of the cascades forming the "j" peak of sums are shown. The Compton distribution for them is schematically indicated by a dashed-line. For $E_s^i < E_s^j$ coincidences of the γ-line, E_2, with the k_2 section of the Compton distribution of the line E_1 may be registered. Thus we obtain the pattern of the section "1". By setting up the "gates" on the left and on the right side of the "i" peak, we shall measure patterns for the sections "2" and "3". The background subtraction "1"–"2"–"3" will give us the pattern of the section "4", illustrating the background structure in Fig.2a. The number of such structures increases rapidly with diminishing energy of the peak of sums under investigation, E_s^i. At $E_s < Q - 1\ MeV$ where Q is the energy of decay, measurements become practically impossible. A repeated background subtraction makes it possible to eliminate false structures.

Let us consider the "a" section (Fig.1) to be an effect and the "c" section — a background. The result of the above-mentioned operation will be the pattern of section 7 shifted to the left from the centre to a distance of "a" width. The same is true for the section 10 shifted to the right to a distance of "b" width.

If we shift both patterns as it was described above and add them together, as a result we shall have "11" identical to "4". The subtraction of "11" from "4" gives zero. The E_2 line turns out to be subtracted as well.

The shifts of "7" and "10" correspond to the move of the whole differential spectrum scale by a corresponding number of channels. Having performed the aforecited operations on the spectrum (Fig.2a) we obtained Fig.2b. All the background structures have disappeared completely.

The part of the spectrum of sums for the interval of $2430-2443\ keV$ is the best example in this respect. Fig.4a comprises more than 25 background structures. On applying this new method of background subtraction (Fig.4b) they are removed completely.

We have made use of this method to investigate the complicated scheme of the decay of $^{146}Eu \rightarrow ^{146}Sm$ [5]. The measurement has been taken for the whole energy interval. The method can be successfully applied to the study of the $(n, 2\gamma)$ reaction. It is dealt with in more detail in [6].

References

[1] Bogdzel A.A. et al., JINR, P15-82-706, Dubna, 1982

[2] Vasilieva E.V. et al., Izv. AS USSR, ser. phys. 1991, V.56, p.2, JINR, P6-91-568, Dubna, 1991

[3] Vasilieva E.V. et al., see the current report, p.

[4] Boneva S.T. et al., Izv. AS USSR, ser.phys., 1987, V.51, p.1882 JINR, P6-87-98 Dubna, 1987

[5] Vasilieva E.V. et al., The programme and abstracts of 43d International workshop on nuclear spectroscopy and the structure of a nucleus. Publishing house of PINP, St.-Petersburg, 1993

[6] Vasilieva E.V. et al., Izv. RAS, ser.phys., 1993, V.57, p.77; JINR,P6-92-148, Dubna, 1992

ON APPLICATION OF THE $\gamma\gamma$- COINCIDENCE METHOD INCLUDING SUMMATION OF THE AMPLITUDES OF COINCIDING PULSES (SACP) TO INVESTIGATION OF NUCLEAR RADIOACTIVE DECAY SCHEMES

E.V.Vasilieva, V.D.Kulik, E.V.Kulikov*, N.A.Lebedev* Le Hong Khjem, A.F.Novgorodov*, Yu.P.Popov, A.M.Sukhovoi, Fam Dinh Khang, V.A.Khitrov, Yu.V.Kholnov

Frank Laboratory of Neutron Physics
**-Laboratory of Nuclear Problems*

The decay of compound states of nuclei, produced by the capture of thermal neutrons, has been successfully investigated by the SACP method [1] for more than 10 years. The work [2] shows that the field of application of this method could be extended to investigation of complicated radioactive decay.

The gist of the method consists in successive measurement of the spectral composition of the two-quantum cascade groups with the same sum energy, E_s. After the decay of a compound state (Fig.1a), it will be groups of cascades between the compound state, (B_n), and different low levels of a nucleus, E_f; following the decay of a nucleus (Fig.1b) — between numerous levels populated by β-(α)- decay and low-lying levels.

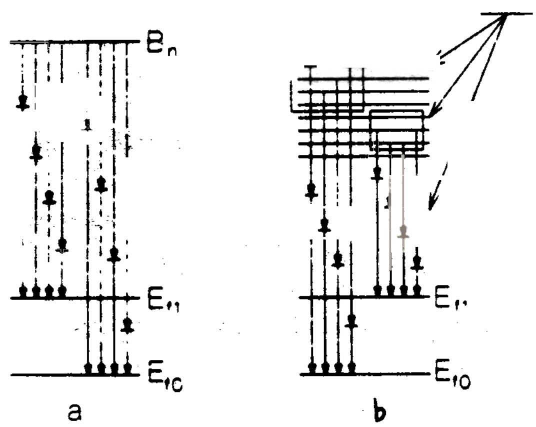


Fig.1 Two types of decay schemes for nuclei: compound states (a) and β- (α)- decay (b).

The energy of cascades (Fig.1a) is known beforehand. In the case of 1b it was not clear whether there would be some lines in the SACP spectrum.

The measured SACP spectrum for the $^{170}Lu \rightarrow ^{170}Yb$ ($Q = 3.5\ MeV$) decay is given in Fig.2. It contains 70 peaks (there are usually only a few of them for the reaction $(n, 2\gamma)$). They correspond to the cascades between pairs of levels (combinations of ≈ 80 levels). Thus, the whole γ-spectrum (≥ 600 transitions) falls into 70 spectra of two-quantum cascades. One of them with $E_s = 3081\ keV$ is shown in Fig.3. The pairs of lines, which are symmetric about the spectrum center, form cascades each of those determines the position of three levels of a nucleus. 497 cascades have been detected, and their characteristics are presented in the tables [2]. 413 γ-transitions are engaged in them. 129 new cascades, 133 new γ-transitions, and 17 new levels (3298, 3273, 3206, 3180, 3114, 3111, 3092, 3055, 3014, 3007, 2979, 2846, 2842, 2779, 2764, 2739 and 2657 keV) have been found.

It's surprising that such an abundance of new results have been obtained while investigating the scheme of the decay of ^{170}Lu, considered to be thoroughly explored at a high up-to-date level [3].

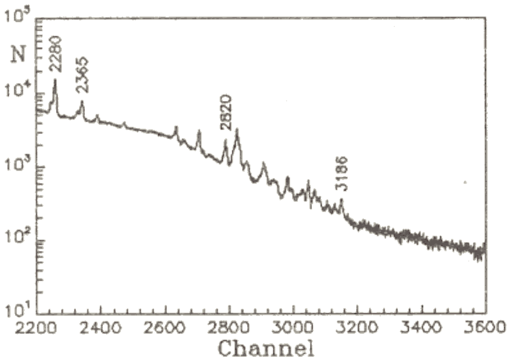


Fig.2 SACP spectrum for the decay of $^{170}Lu \rightarrow ^{170}Yb$.

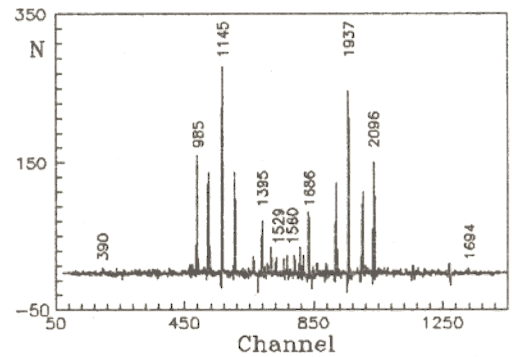


Fig.3 Distribution of intensities for the two-step cascades with the total energy $E_s = 3081\ keV$.

At the present time the construction of schemes of levels and transitions is based on the Ritz rule (the rule of sums and differences of transition energy values). In case of complicated decay schemes, when the total number of transitions $N > 100$, the number of accidental energy coincidences rises abruptly ($\approx N^2$), and application of these rules gives poor effect. For large N it is also difficult to interpret the results obtained with traditional method of coincidence with "gates".

To move further, it it necessary to increase considerably (by an order of magnitude) the measurement accuracy of transition energy or new methods should be found which either would not rely on the Ritz rules at all or would use them only to a certain extent. The present work has shown that the SACP method is one of such methods due to its following characteristics:

1. The possibility of dividing a complicated spectrum into a large number of sections, the rarefaction of spectra, and identification of weak components.
2. Weak degree of dependence on the Ritz rules.
3. The possibility of a complete subtraction of the Compton background.
4. The possibility of separating transition multiplets regardless of the component's energy value difference. It can be illustrated [2] by duplets 1514.26 - 1514.47 (2.6 - 61), 1674.11 - 1674.22 (15.6 - 2.73) and 1700.76 - 1700.80 (8.4 - 8.9) (in brackets the intensities are given per 10^{-4} decays)
5. The results can be easily interpreted.

References

[1] Boneva S.T. et al, Particles and Nuclei, 1991, V.22, p.479; V.22, p.1433

[2] Vasiljeva E.V. et al, Izv. RAS, V.57(9), p.77; JINR, P6-92-148, Dubna, 1992

[3] Dzhelepov B.S. et al, The properties of atomic nuclei. I.26 Schemes of a decay of radioactive nuclei. A = 169,170. 1988, L., Science, p.104-192

ON THE INDEPENDENT FRAGMENT YIELDS IN THE FISSION OF ^{239}Pu INDUCED BY RESONANCE NEUTRONS

N.A.Gundorin, A.B.Popov, Dao Ahn Minh, L.V.Michailov

Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research

The analises of gamma-spectrum from the resonance neutron induced fission of ^{239}Pu at 0.2 eV to 230 eV were developed [1].

The refined independent yields of some fragments as well as the time of life of some isomers were obtained /Table1 and Table2/.On the base of the comparison of our experimental results with those obtained for thermal neutron induced fission we may conclude that the variations in the mass distribution don't exceed 25 % for the fragments identified.

The relative yields of some fragments to the 11-th resonance with spin 1^+ were obtained for all identified fragments. The weighed mean values for 18 light and heavy fragments were calculated from these data as a function of E_n and $1/\Gamma_f$ /Fig.1 and Fig.2 /.

We have not seen the fluctuations from one resonance to other more than 5 % within the error of measurements.

The decrease of relative yields from the resonance with small Γ_f due to the competition between the (n,f) reaction and the (n,γ f) process is in qualitative agreement with the Cowan et al. data [2] on the P/V ratio /Fig.3/ as well as with the experimental [3] and calculated data [4] on the total energy of fission gamma-rays /Fig.4/. But no quantitative estimate in favour of this observation is possible to be made from these measurements due to considerable experimental errors.

So higher precision measurements of independent yields from the resonance neutron induced fission of ^{239}Pu are necessary.

References

1. N.A.Gundorin et al., Proceedings of the Second International Simposium on Nuclear Excited States, Lòdż, June 22-26, 1992.
2. G.A.Cowan et al., Phys.Rev., 144, no.3 (1966).
3. O.A.Scherbakov, Phys. Elem. Part and Atom. Nucl. 21, 419 (1990).
4. U.Gohs, Proceedings of International Conference on Nuclear Data for Science and Technology, Jülich, 1991.

Table 1.Independent yields of fission fragments from the resonanace neutron induced fission of ^{239}Pu in comparison with those from thermal neutron induced fission.

Z-Fr-A	Gamma energy E_γ keV	Preliminary results/9/ $Y_{res}\pm\Delta Y$ %	Refined results $Y_{res}\pm\Delta Y$ %	A.C.Wahl /8/ $Y_{th}\pm\Delta Y$ %	J.Kaufmann /10/ $Y_{th}\pm\Delta Y$ %
36-Kr-88	775	0.77±0.23		0.79±0.03	
90	707	1.58±0.27	1.00±0.20	1.18±0.05	1.25±0.03
38-Sr-92	814.7		0.60±0.24	1.00±0.06	
94	837.4	2.65±0.33	3.32±0.42[a]	3.14±0.16	3.30±0.05
96	815		1.40±0.56	1.90±0.10	1.75±0.04
40-Zr-98	1223	2.78±0.29	2.4±0.36	2.85±0.14	2.83±0.05
100	212.4	3.95±0.20	4.08±0.21	4.76±0.24	4.40±0.06
102	152	0.99±0.14		1.19±0.12	0.54±0.02
42-Mo-102	296		2.00±0.20	1.70±0.12	
104	192	4.02±0.20	5.07±0.21	4.12±0.21	5.19±0.06
106	171.7	1.48±0.21	2.20±0.24	2.06±0.10	2.05±0.04
52-Te-132	974	1.79±0.23	2.00±0.40	2.36±0.07	
134	1279.8	2.70±0.28[b]	4.50±0.81[c]	4.71±0.51	
54-Xe-136	1313	1.83±0.17[b]		3.02±0.36	
138	589	3.56±0.28	4.06±0.34	4.08±0.33	
140	376.8		1.30±0.27	1.50±0.09	
56-Ba-142	359.7	3.49±0.32	3.11±0.24	3.27±0.26	
144	199.4	2.51±0.15	2.32±0.19	2.05±0.23	
58-Ce-146	259	1.13±0.18		0.95±0.01	
148	159	1.70±0.16		1.09±0.12	

a-This value has been evaluated due to the large interference caused by the ^{72}Ge (n,n'γ) broad neutron inelastic scattering peak.

c(b)-This value has (not) been corrected for the cascade isomeric transition.

Table 2.Cascade delay γ-rays observed in the experiment.

Gamma energy keV	Z-Fr-A	Intensity $Y_\gamma\pm\Delta Y$ %	$T_{1/2}$ ns
115		1.60±0.16	162/5/[a]
297	52-Te-134	2.90±0.26	165±18
1280		3.20±0.32	154±15
161	40-Zr-97	0.80±0.16	104/11/[a]
1103		1.50±0.30	76±11
314		0.90±0.18	10.0±1.0
400	54-Xe-137	1.10±0.20	7.0±1.0
1221		0.80±0.16	9.0±1.4
204	38-Sr-95	2.40±0.15	22.0±1.5
352		2.40±0.12	18.0±1.1

a-This value was taken from /Ref./ and used as input.

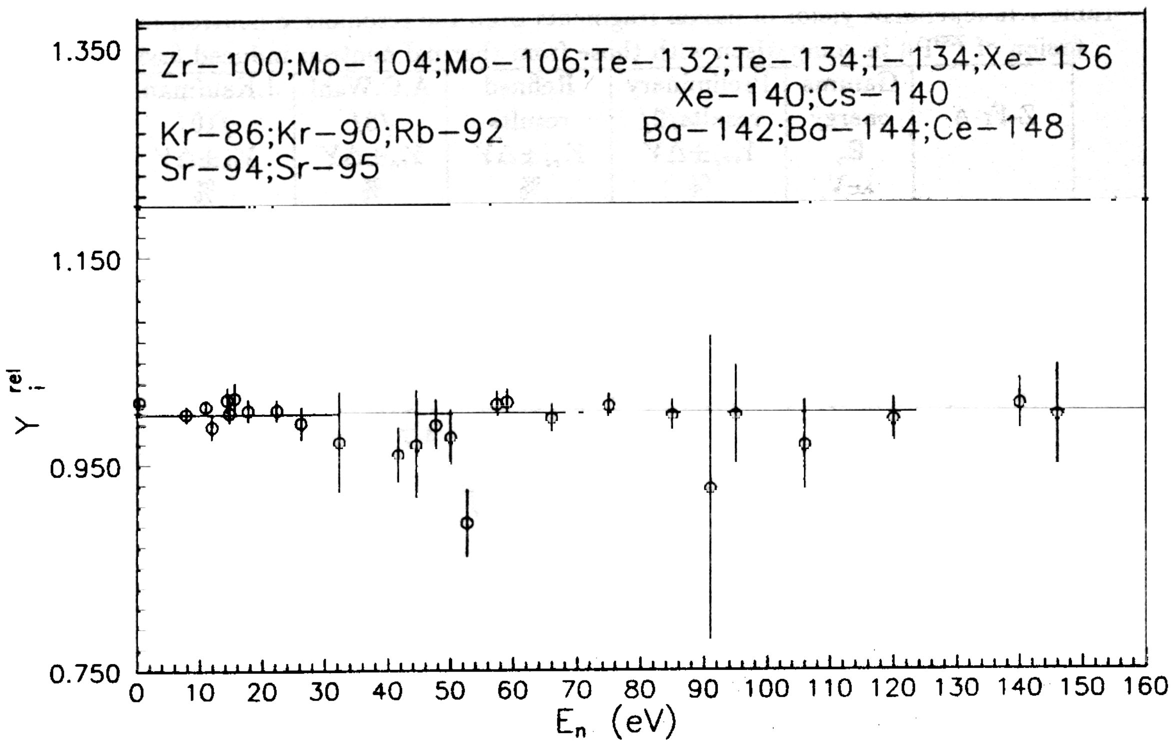


Fig.1 : The weiged mean value of relative yields for 18 fragments vrs neutron energy.

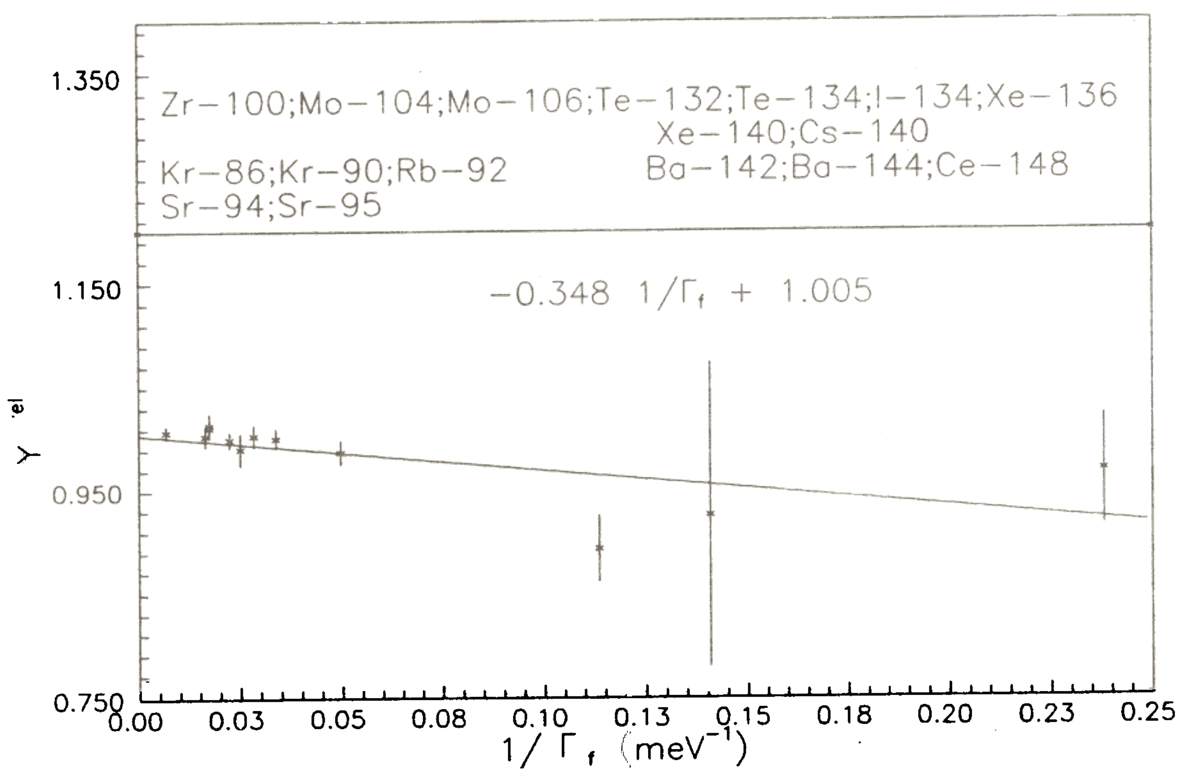


Fig.2 The weighed mean values of relative yields for 18 fragments vrs $1/\Gamma_f$ resonance.

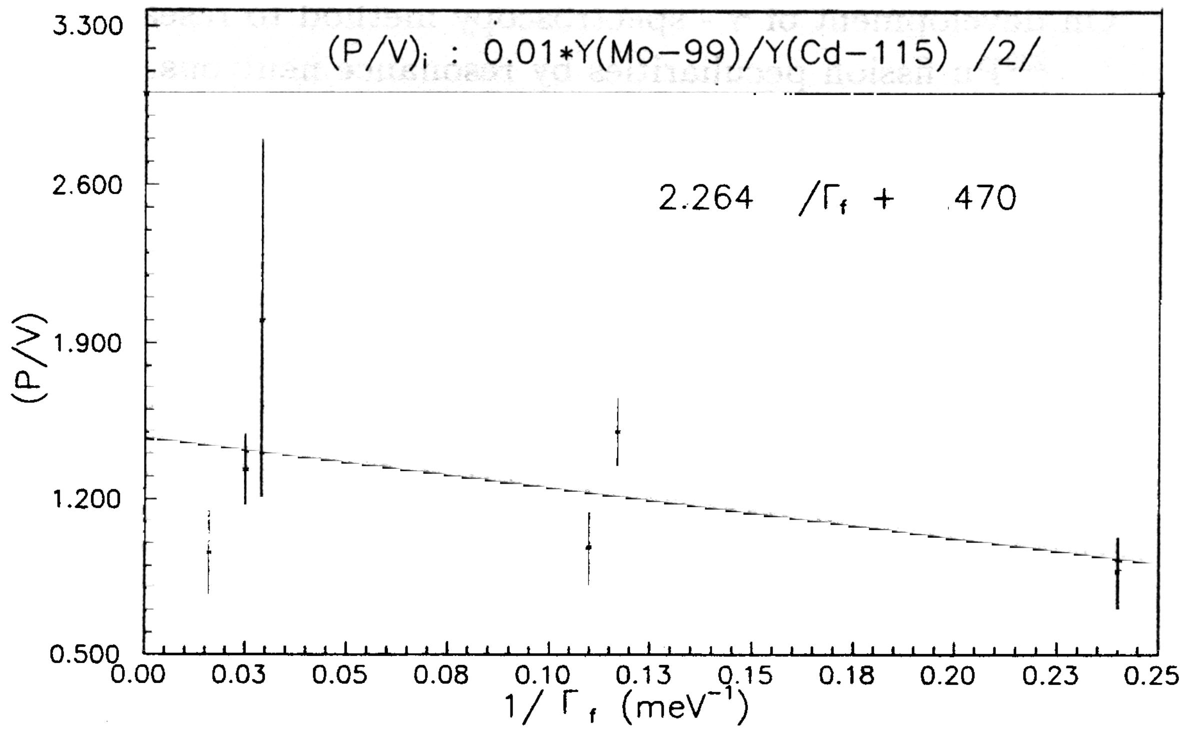


Fig.3 :The relative value P/V from the data of Cowan, et al. /2/ vrs $1/\Gamma_f$ resonance.

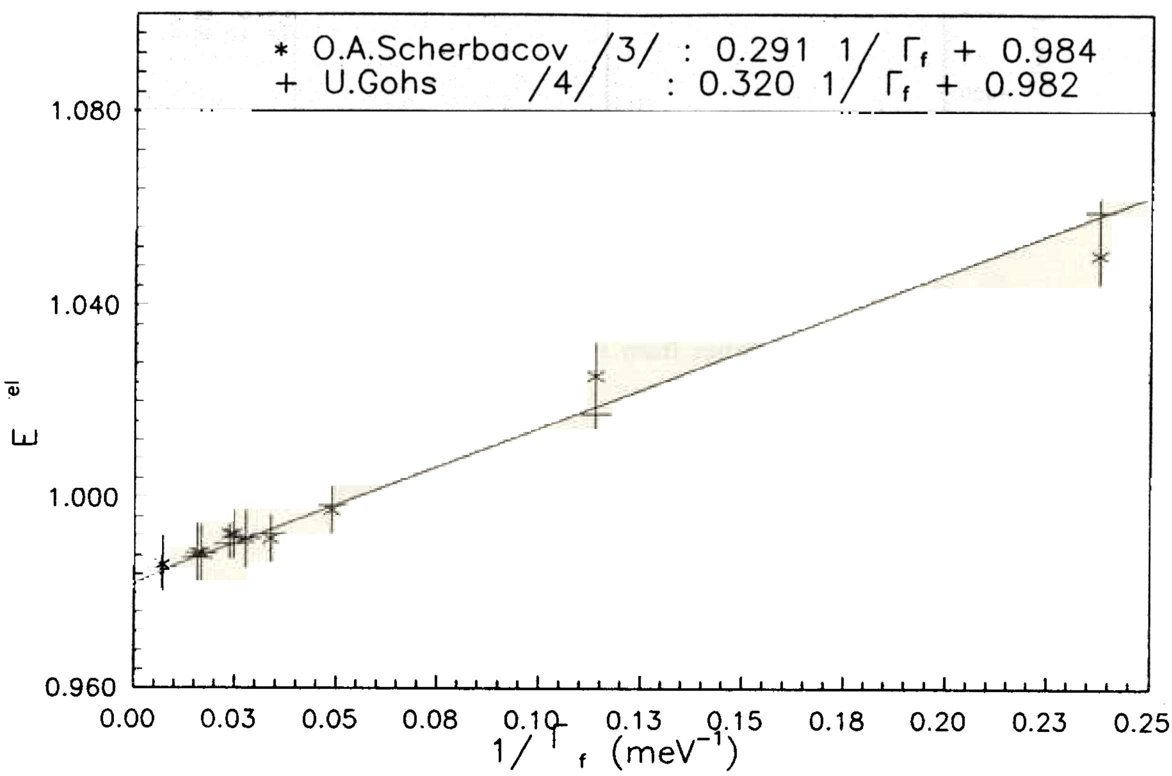


Fig.4 :The relative energy of gamma-rays from the (n,γf) process vrs $1/\Gamma_f$ resonance.

On development of γ - spectroscopy method to research ^{239}Pu fission peculiarities by resonance neutrons.

N.A.Gundorin
Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research,

The measurements of independent fission fragment yields by means of gamma - spectroscopic method was demonstrated during the investigation of spontaneous fission of ^{252}Cf [1],[2]. This method was used in the investigation of gamma - rays from fission fragments of ^{235}U induced by resonance neutrons [3]. Further developments of the gamma - spectroscopy method were in conjunction with the research of peculiarities in the fission of ^{239}Pu [4].

Neutron spectroscopy is carried out using the time - of - flight method with the IBR - 30 as a neutron source. The fission chamber is employed as the target and as the fast detector of fission events. The semiconducting Ge detector is used to measure the gamma - ray spectrum. The basic characteristics of the gamma - spectrometer are shown in Table 1. The time-of-flight spectrum from the fission chamber (fig.1) demonstrates insufficient energy resolution, especially for the range (40 - 230)eV.

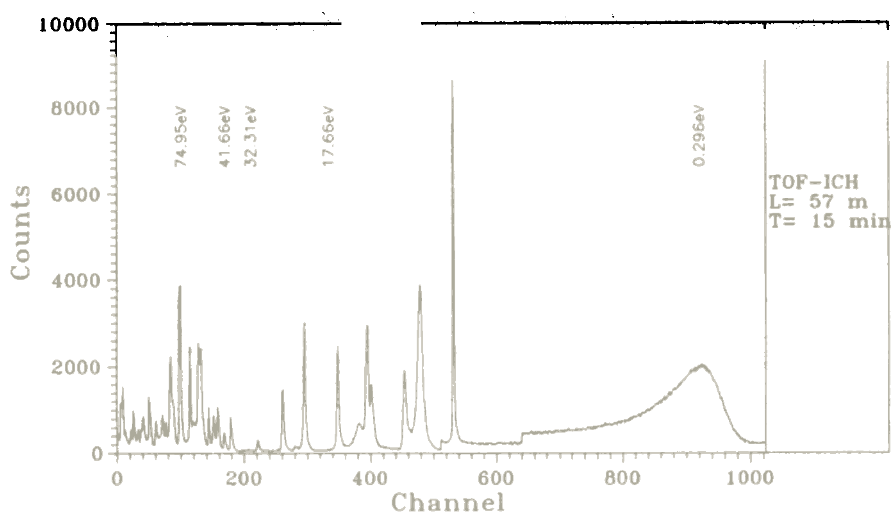


Figure 1: Time-of-flight spectrum from the fission chamber for energy region (0.2 230)eV.

For increased resolution it is necessary to use a source with shorter neutron pulse duration. It will be possible after reconstruction of the neutron source in Dubna according to the IREN project [5].

Table 1: Basic characteristics of fission gamma - spectrometer.

Parameters of Fission Gamma - Spectrometer		
Neutron spectrometer	IBR - 30 1992y.	IREN project
Distance of neutron flight (m)	57 - 60	57 - 60
Neutron flux (n/cm^2 s eV)	$2 \times 10^3 E^{-0.9}$	$3 \times 10^3 E^{-0.9}$
Energy resolution (eV)	$1.9 \times 10^{-3} E^{3/2}$	$1.9 \times 10^{-4} E^{3/2}$
Recycling energy (eV)	0.17	0.17
Fission chamber (IFC)	^{239}Pu	
Fission material (g)	1.6	
Number of targets	19	
Density (mg/cm^2)	1.0	
Target diameter (cm)	7.5	
Enriched (%)	99.9	
Efficiency (%)	60	
Time resolution (ns)	2.6	
Number of sections	19	
Ge - detector	DGDK-110	GR3019
Efficiency (%)	12	30
Energy resolution (keV)		
122 keV	1.4	0.9
1332 keV	2.3	1.9
Peak/Compton	24	48
Distance IFC - Ge (cm)	28 - 31	14
Raddition - resistance fluence (n/cm^2)	10^9	$\geq 10^{10}$
Price (in 1989y.)	30×10^3 rouble	48.5×10^3 \$ USA
Counting rate in spectroscopy channel (s^{-1})	$(3-4) \times 10^3$	6×10^4

The gamma - spectrum, measured by the spectrometer with Ge detector DGDK - 110 (fig.2), has a few "bumps" and a small ratio between gamma - lines and the underlayer due to insufficient quality of the Ge detector and the high neutron induced γ-background.

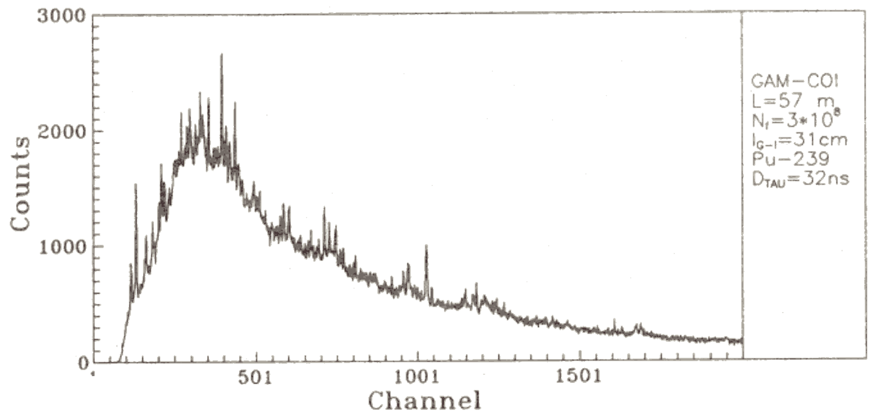


Figure 2: Coincidence gamma - spectrum for the energy region (100 - 1000)keV.

Efficiency of the gamma-spectroscopy method in investigating nuclear fission depends on the parameters of a spectrometer and the quality of a measured spectrum. Perfection of spectrum by reducing the Compton-underlay with the help of an "active" shielding of the Ge detector is doubtful due to unfavorable background conditions of the neutron beam. Nevertheless, that way of spectrum improvement was tested with a model spectrometer with incomplete "active" and complex "passive" shielding. An incomplete "active" shielding consisted of three plastic scintillators $20 \times 20 \times 40cm^3$ and one NaI(Tl) crystal - 15cm$\times$10cm (fig.3). A complex "passive" shielding - 5cm of ^{10}B - CH and 5cm of Pb - was used to decrease the gamma counts connected with a high neutron background.

The efficiency estimation of the Compton-underlayer reduction was defined to compare the ratio peak/underlayer for gamma - lines in the energy region (100 - 400)keV between two fragments gamma - ray spectrum: without (A) and with "active" shielding (B) (fig.4). The mean value of the reduced coefficient is $K_{red} = 2.6 \pm 0.2$. If the condition of incomplete shielding - nearly $(0.65 - 0.7) \times 4\pi$ - is taken into account, with the spectrometer's size and construction being optimized the reduction could be over 90%. As far as the main part of the experimental error is connected with the large spectrum's underlayer, after it is reduced 10 times, the precision of the data may be more than 3 times greater. The statistical error may be reduced more than 3 times using a quality n-HP Ge detector (GR3019), a fast electronic system and to reducing the distance between it and the IFC (Table 1).

As a result the summary experimental error could be improved by nearly one order of magnitude compared to the preceeding data [6]. Modification of the spectrometer by using a high quality n-HP Ge detector and a fast electronic system, will allow measurement of much more gamma-lines with the intensity precision of (1-3)%. Thus the efficiency of gamma-spectroscopy method will be increased essentially.

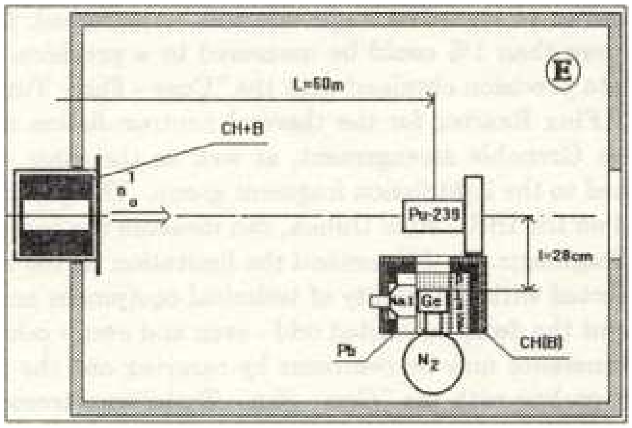


Figure 3: Scheme of gamma - spectrometer with incomplete "active" shielding on IBR - 30.

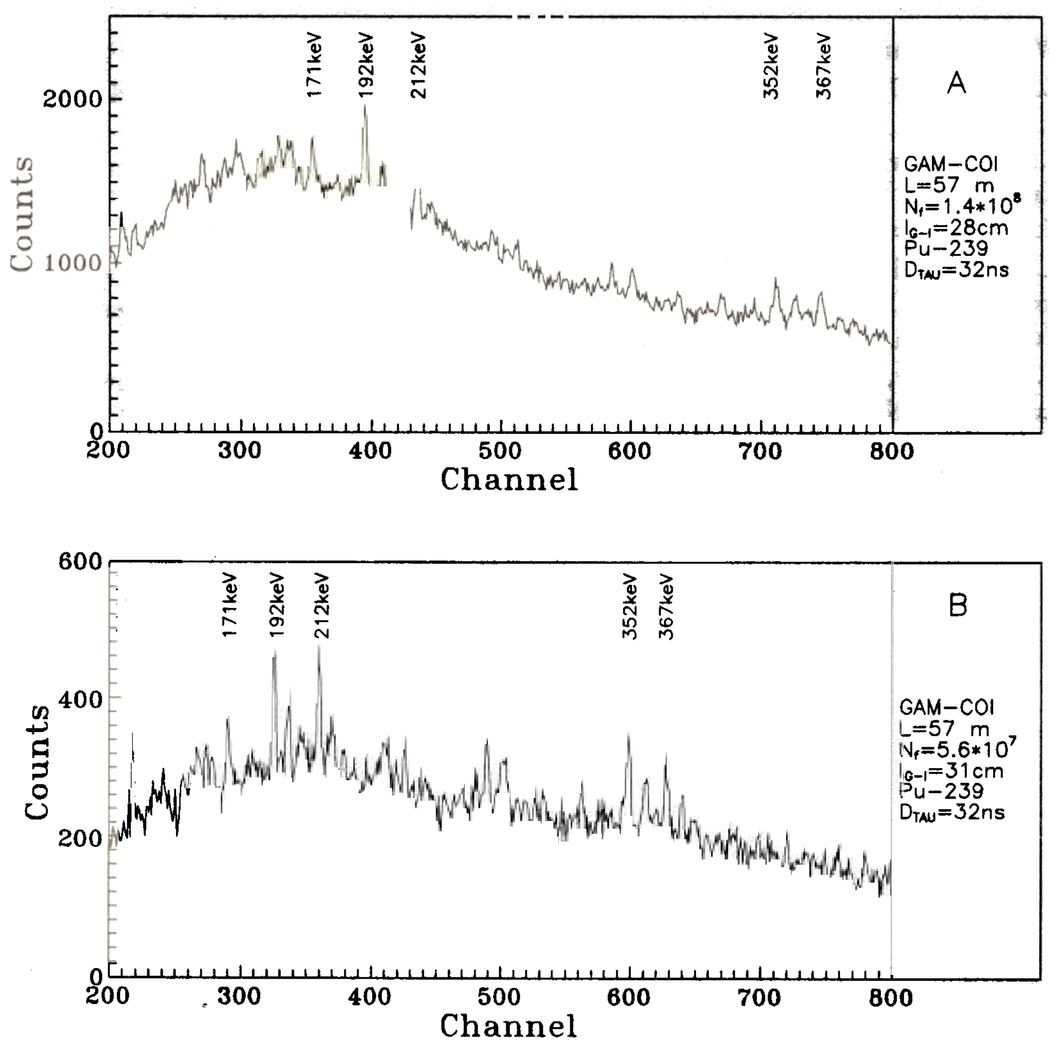


Figure 4: Coincidence gamma - ray spectrum without (A) and with "active" shielding (B) for the energy region (100 - 400)keV.

In this way the number of identified fragments will be increased; for those with independent yields of more than 1% could be measured to a precision of 1 - 3%. This value is close to the data precision obtained with the "Cosy - Fan - Tutte" spectrometer at the Grenoble High Flux Reactor for the thermal neutron fission of ^{239}Pu [7]. But the possibilities of this Grenoble arrangement, as well as the mass - separator "LOHENGRIN", are limited to the light fission fragment group. The gamma - spectroscopy method, which is used on the IBR - 30 in Dubna, can measure the independent yields of both light and heavy fragments. In this method the limitation on the number of identified fragments is connected with the quality of technical equipment and the incomplete spectroscopic data about the decay of excited odd - even and even - odd fission fragment states. This last circumstance may be overcome by carrying out the fission fragments gamma - spectroscopy on-line with the "Cosi - Fan - Tutte" spectrometer or any other similar arrangement at a high flux neutron source.

References

[1] W. John, Frank W. Guy and J.J. Wesolowski, Phys. Rev. C2, 1970, p. 1451.

[2] E. Cheifetz, J.B. Wilhelmy, R.C. Jard and S.G. Thompson., Phys. Rev. C4, 1971, p. 1913.

[3] S.A. Antonov, A.A. Bogdzel, N.A. Gundorin, À. Duka - Zòlyqmi, J. Kliman, D. Krjistec, A.I. Ostrovnoi, T.M. Ostrovnaia, A.B. Popov, B. Prespirin, V.G. Tishin, N.U. Shirikova, Communication of JINR 13-85-701, 1985, Dubna.

[4] A.A. Bogdzel, N.A. Gundorin, U. Gohs, À. Duka - Zolyòmi, J. Kliman, V. Polgorski, A.B. Popov, Dao Anh Minh, Proceedings of International Conference on Nuclear Data for Science and Technology, Jülich, 1991, pp. 150-152.

[5] V.L. Aksenov, N.A. Dikansky, V.L. Lomidze, A.V. Novokhatsky, Yu.P. Popov, V.T. Rudenko, A.N. Skrinsky, W.I. Furman, Communication of JINR E-3-92-110, 1992, Dubna.

[6] N.A. Gundorin, A.B. Popov, Dao Anh Minh, J. Kliman, V. Polgorski, À. Duka - Zolyòmi, U. Gohs, Proceedings of the Second International Symposium on Nuclear Excited States, Lòdż, 1992, p. 181.

[7] J. Kaufmann, Physikalisches Institut, Univ. Tübingen, private communication (1991).

THE FISSION CROSS SECTION AND RESONANCE PARAMETERS OF ^{237}Np IN THE SUB-BARRIER REGION ($E_n \leq 500eV$)

E.Dermendjiev, I.Ruskov, Yu.S.Zamyatnin

Frank Laboratory of Neutron Physics, JINR, 141980 Dubna, Moscow Reg. Russia

A.A.Goverdovsky

Institute of Physics and Power Engineering, 249020 Obninsk, Kaluga Reg., Russia

The reported work sought to achieve more precise values for the fission cross section, $\sigma_f(E_n)$, and the resonance parameters, $\sigma_o\Gamma_f$ and Γ_f for ^{237}Np in the sub-barrier range of neutron energies, where there is a considerable discrepancy (about three times) between σ_f values of American and Japan groups [1], [2] and the Saclay results.

It should be added that these neutron data on ^{237}Np are of important significance for simulating the processes going in high burnup reactors and for the transmutation of long-lived radioactive wastes.

The experiment was performed using the neutron time-of-flight method on beam 3 at the IBR-30 pulsed booster at JINR. The flight path of 58.5 m, the neutron pulse frequency of 100 Hz, and the pulse width of ≈ 4 μs were used.

A relative method of measurement was applied and the multilayer ionization fission chamber comprising 12 targets from ^{237}Np with the overall weight of 132 mg and one target from ^{235}U weighing 8.5 mg were used. The measuring time amounted to 1042 hours.

The cross section dependence $\sigma_f(\triangle E_n)$ was measured over the neutron energy interval from 3 to 500 eV.

The results, compared with other authors' data, are shown in Fig.1.

One can see that our data in resonance cluster range are in good agreement with both the American results obtained using neutrons from an underground nuclear explosion [1] and the Japan ones in a lead cube [2], but about three times larger than the Saclay data [3].

At the same time the inter-cluster cross section values are closer to those measured at Saclay [3] which can be attributed to the difference in resolution power of the measuring methods.

The resonance parameters, $\sigma_o\Gamma_f$ and Γ_f, obtained in Dubna recently and those that had been measured earlier [4] are given in Table 2. Also shown are the Saclay [3] and Geel [5] results. One can see that the Dubna data are systematically by several times higher than the data of the French group.

A conclusion is made that the new values of neutron constants for ^{237}Np measured in Dubna and Kyoto, and also at Los Alamos [6], although showing quite good agreement, still require correction and re-evaluation of the ENDF/B-VI and YENDL-3 values, relying on the measurements reported in the work [3].

References

[1] M.Hoffman et al., Bul.Amer.Phys.Soc. **21**, 655 (1976).

[2] I.Kimura et al., Report, Int.Sem. on Neutron Physics, Dubna, April 1992.

[3] S.Plattard et al., Nucl.Sci.Eng., **61**, 477 (1976).

[4] K.A.Gavrilov et al., Atom.Energy, **28**, 362 (1970).

[5] W.Kollar et al., Z.Physik, **248**, 355 (1971).

[6] A.D.Carlson et al., Report, *Measurements of the ^{237}Np cross section*, Reactor Dosimetry ASTM STP 1228, Amer.Soc. for Testing and Materials, Philadelphia, 1994.

[7] "Neutron Cross Sections", **1B**, Editor S.F.Mughabghab, BNL, Academic Press Inc., (1984), New York, USA.

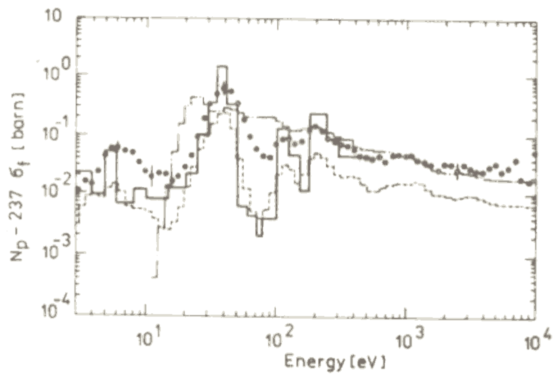


Fig.1 Comparison of σ_f values for ^{237}Np measured at Saclay [2], using neutrons from an underground nuclear explosion [3], in a lead cube of Kyoto University [5] and given in the present work.
– – – [2]; · - · - · [3]; · · · · · [5]; —— the present work.

Table 1. The cross section of ^{237}Np averaged by resonance neutrons in the energy interval from 3 eV to 500 eV.

Energy interval, (eV)	Averaged cross section $<\sigma_f>$ (barn)	Energy interval, (eV)	Averaged cross section $<\sigma_f>$ (barn)
3 – 4	0,022 ± 0,006	50 – 60	0,006 ± 0,002
4 – 5	0,009 ± 0,003	60 – 70	0,005 ± 0,002
5 – 6	0,055 ± 0,010	70 – 80	0,002 ± 0,001
6 – 8	0,006 ± 0,002	80 – 90	0,004 ± 0,002
8 – 10	0,012 ± 0,003	90 – 100	0,004 ± 0,002
10 – 15	0,008 ± 0,003	100 – 110	0,016 ± 0,004
15 – 20	0,014 ± 0,004	110 – 130	0,16 ± 0,03
20 – 25	0,023 ± 0,006	130 – 150	0,050 ± 0,009
25 – 30	0,11 ± 0,02	150 – 180	0,013 ± 0,003
30 – 35	0,35 ± 0,06	180 – 240	0,22 ± 0,04
35 – 40	1,64 ± 0,26	240 – 300	0,091 ± 0,017
40 – 50	0,34 ± 0,06	300 – 500	0,046 ± 0,012

Table 2. Resonance area ($\sigma_o \Gamma_f{}^I$) for ^{237}Np in the neutron energy interval from 0.5 eV to 50 eV

E, (eV)	Γ_f^I[ĈŶó]		
	Pikelner et al.[4] $\sigma_o \Gamma_f{}^I$, (barn.eV).10^{-3}	Plattard et al.[3] $\sigma_o \Gamma_f{}^I$, (barn.eV).10^{-3}	The present work $\sigma_o \Gamma_f{}^I$, (barn.eV).10^{-3}
0.489	2.9 ± 0.7		
1.321	3.8 ± 1.0		
1.479	3.5 ± 1.0		
1.969	1.9 ± 1.0		
3.865	16 ± 4	6 ± 0.9	12 ± 2
4.26		0.4 ± 0.3	1.3 ± 0.2
4.86		0.1 ± 0.1	1.0 ± 0.2
5.78	46 ± 9	1.6 ± 1.8	35 ± 6
7.42	12 ± 6	2.7 ± 0.6	6.6 ± 1.1
8.30		0.9 ± 0.5	3.5 ± 0.6
8.97		4.1 ± 0.5	12 ± 2
10.68		2.5 ± 0.4	10 ± 2
10.84		1.8 ± 0.6	3.0 ± 0.5
11.10		1.0 ± 0.3	2.6 ± 0.5
24.98		17.8 ± 1.8	43 ± 7
26.19		11 ± 4	44 ± 7
26.56		70.7 ± 5.5	170 ± 30
29.49		0.6 ± 0.2	23 ± 4
30.41		308 ± 12	850 ± 140
30.75		1.3 ± 0.6	5.2 ± 1
31.30		2.2 ± 0.7	1.5 ± 0.3
37.15		147.3 ± 12	440 ± 70
38.18		7.7 ± 2.2	82 ± 13
38.92		288 ± 24	890 ± 140
39.24		153.2 ± 12	530 ± 80
39.79		69.4 ± 22	190 ± 30
39.93		891.8 ± 44.5	2900 ± 470
41.35		389 ± 27	1230 ± 200
42.81		21.3 ± 7	95 ± 15
46.04		130.2 ± 7	400 ± 60
50.34		111.7 ± 13	370 ± 60

Table 3. Fission widths, Γ_f^I, of ^{237}Np resonances in the energy interval from 0.5 eV to 50 eV

E, (eV)	Γ_f^I[Ýó] Recommended values [7]	Pikelner et al. [4]	Plattard et al. [3]	The present work
	1.24 ± 0.26	1.3		
	8.7 ± 0.5	4.1		
	1.33 ± 0.14	1.1		
	4.2 ± 0.3	8.4		
	7.0 ± 0.7	7.8	3 ± 0.5	5.8 ± 1.0
	0.34 ± 0.20		0.2 ± 0.2	6.4 ± 1.2
	7.9 ± 0.2		0.07 ± 0.07	4.4 ± 0.9
	12.6 ± 0.5	13	5 ± 0.5	11 ± 2
	9.5 ± 0.9	19	4.2 ± 1.0	10 ± 2
	670 ± 2		2.1 ± 0.6	8.7 ± 1.6
	24.0 ± 1.2		8.8 ± 1.2	26 ± 5
	5.4 ± 0.4		1.5 ± 0.3	6.4 ± 1.1
	0.8 ± 0.3		0.8 ± 0.3	1.3 ± 0.2
	3.4 ± 0.3		0.4 ± 0.1	1.2 ± 0.2
		Kollar et al. [5]		
24.98	8.5 ± 0.6	40.8 ± 3.4	3.6 ± 0.5	8.2 ± 1.5
26.19	85 ± 5	71.6 ± 24	30.6 ± 8.5	160 ± 30
26.56	63 ± 2	64.2 ± 7.3	22.5 ± 3.2	57 ± 10
29.49	62 ± 46	–	9.9 ± 6.1	300 ± 50
30.41	270 ± 8	109 ± 13	79.8 ± 10.2	250 ± 40
30.75	6.6 ± 6.6	132 ± 40	5.1 ± 2.7	18 ± 3
31.30	17 ± 3	44.3 ± 23	6.9 ± 2.4	5 ± 1
37.15	340 ± 10	232 ± 46	142.3 ± 28.5	360 ± 60
38.18	20 ± 2	68.5 ± 21	8.6 ± 3.0	72 ± 13
38.92	1000 ± 200	710 ± 180	380.2 ± 84.0	970 ± 170
39.24	840 ± 12	533 ± 160	333.1 ± 105.8	1100 ± 190
39.79	21 ± 21	–	1686.9 ± 800.0	1500 ± 260
39.93	7720 ± 66	5500 ± 970	864.7 ± 122.7	6400 ± 1100
41.35	700 ± 20	275 ± 48	216.7 ± 32.5	720 ± 130
42.81	1000 ± 100	307 ± 88	236.8 ± 153.4	1100 ± 200
46.04	700 ± 40	550 ± 110	276.1 ± 139.8	820 ± 140
50.34	57 ± 70	57.2 ± 8.4	23.2 ± 5.9	310 ± 50

AN EXPERIMENT TO MEASURE DELAYED NEUTRON YIELD AND TO SEARCH FOR SHORT-LIVED GROUPS OF DELAYED NEUTRONS ($T < 0.5\ s$).

E.Dermendziev, Ju.S.Zamjatin, V.M.Nazarov, I.Ruskov

Frank Laboratory of Neutron Physics

1. A setup to investigate delayed neutron yields has been constructed and tested at the IBR-2 pulsed reactor. It includes a neutron chopper, a collimation system and a neutron detector. The setup is placed on beam 11 of the IBR-2 reactor.

The neutron chopper is synchronised with reactor pulses and has an adjustable phase shift and a variable rotation frequency. The measuring interval for delayed neutrons is $50 - 200\ \mu s$ at a neutron pulse frequency of $5\ Hz$, and up to $1\ s$, at a chopper frequency of $1\ Hz$.

Test measurements have been made to study the setup capabilities and characteristics in different modes of operation (at a chopper frequency of 5 and $2.5\ Hz$ and different phase shifts).

The results of the preliminary measurements with ^{235}U and Pb samples inside the detector have shown that for the measuring time of $400\ \mu s$ the number of delayed neutrons in the groups with the known periods falls by 15% (See Figure 1). The new groups with shorter periods over the background level have not been detected yet. The ways of reducing the background by means of neutron beam filtration and decreasing the number of fast neutrons have been outlined.

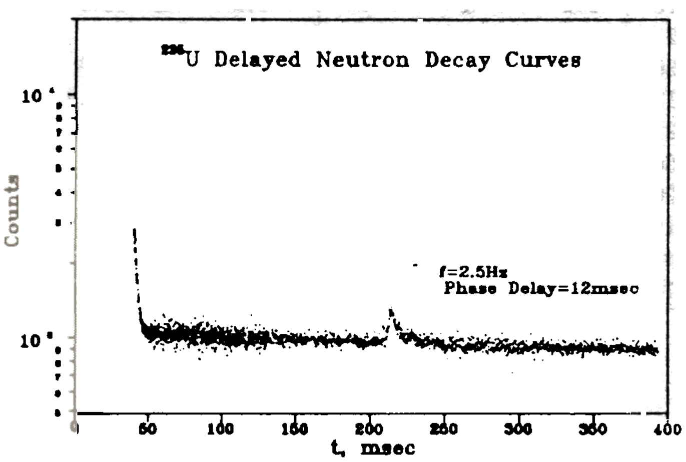


Fig.1.

INVESTIGATIONS OF THE ^{235}U NUCLEI FISSION INDUCED BY RESONANCE NEUTRONS

N.N. Gonin, L.K. Kozlovskiy, D.I. Tambovtsev
IPPE, Obninsk

A.A. Bogdzel, N.A. Gundorin, L.V. Mikhailov, A.B. Popov, W.I. Furman
Frank Laboratory of Neutron Physics
Joint Institute for Nuclear Research, Dubna, Russia

The measurements of the angular distribution of fragments from the resonance neutrons induced fission of aligned ^{235}U nuclei have been started at the 5th beam of the booster at the IBR-30 reactor on the 30 m flight path.

The purpose of these investigations is an independent evaluation of the $A_2(E_n)$ anisotropy factors for the resonance neutrons in the interval of 0.3 to 50 eV as well as the analysis of the angular-dependent part of the fission cross-section within the frames of the multilevel and multichannel model of fission.

The nuclei alignment is attained by cooling the rubidium uranyl nitrate (RUN) single crystals down to 0.15K in the $^3He -^4 He$ dilution refrigerator (Fig. 1). Two sets of the single crystal targets with the area of 20 and 24 cm^2 are attached back-to-back to the each side of the copper plate which is in thermal contact with the refrigerator dilution chamber. The fission fragments from each sample side are registered by the silicon detectors of 2 x 5 area at 0°, 45°, and 90° with reference to the c-axis of the single crystals (the c-axes of all the crystals are directed along the neutron beam).

By now, only the preliminary measurements have been carried out. Low content of the uranium nuclei in the samples ($\sim 10^{20} cm^{-2}$) leads to the necessity of the long-time measurements. Certain problems in using the surface-barrier superconductor detectors have arisen. At the helium temperatures, the contacts sometimes give trouble, the noise arises, and other instabilities take place.

Fig. 2 shows the example of the effect observed in the time-of-flight spectrum caused by alignment of ^{235}U nuclei. The spectrum has been registered by the detector positioned at θ=90°. One can see relative changes of the resonance areas when comparing the "warm" and the "cold" spectra

The first estimations show that the mean value of A_2 within the interval of 0.3 to 50 eV is colse to $< A_{2>}$ value obtained by Pattenden and Postma (1971) in the similar experiment which has been the only one up to now.

This experiment is the first and preparatory step towards the future experiments at the IREN installation which will have more perfect parameters.

The experiment is intended to be performed in cooperation with Delft and Darmstadt.

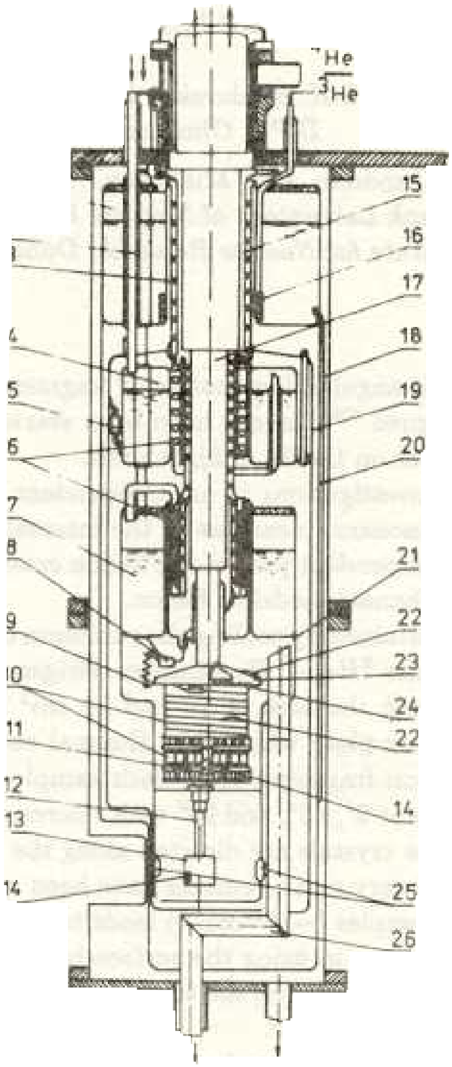
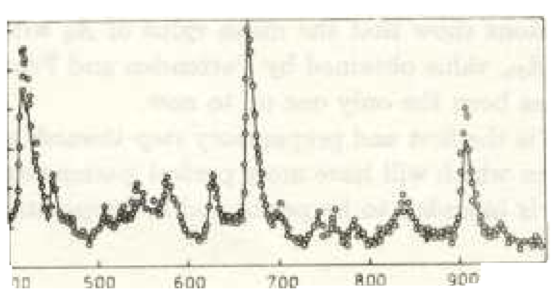

^4He
^3He
15
16
17
18
19
20
21
22
23
24
22
14
25
26
4
5
6
7
8
9
10
11
12
13
14

Fig.


500
600
700
800
900

ig.2.

$^{36}Cl(n,p)^{36}S$ cross section from 25 meV to 800 keV and the nucleosynthesis of rare isotope ^{36}S

P.E.Koehler, S.M.Graaf, H.A.O'Brien
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA
Yu.M.Gledenov, Yu.P.Popov
Frank Laboratory of Neutron Physics, JINR, Dubna

The $^{36}Cl(n,p)^{36}S$ reaction can play a critical role in the production of the rare isotope ^{36}S in explosive nucleosynthesis and s-process calculations. We have measured the $^{36}Cl(n,p)^{36}S$ cross section from thermal energy to approximately 800 keV. The main measuremens were performed at the moderated "white" neutron source of LANSCE (Los Alamos). Protons and α- particles from this reaction were detected with a silicon surface-barrier detector. Measurements were also made with a dual-gridded ion chamber. The result from the latter detector were limited to energies below a few keV, however it give us possibility to separate of the alpha-particles from the protons for the E_0=902.6 eV and 1297.3 eV resonances.

Our value for the thermal cross section 46.2$\pm$ 0.4 mb is in good agreement with value of 46$\pm$ 2 mb [1], but disagree with the value reported in [2]. Additional measurements of thermal cross section were performed by us at the WWR-M reactor in Gatchina.

In a multilevel analysis of our data we determinated parameters for eight resonances in the energy range from 900 eV to 70 keV instead three in [3]. The $^{36}Cl(n,p)^{36}S$ cross section for energies between 500 eV and 800 keV from our measurements is shown in Fig.1.

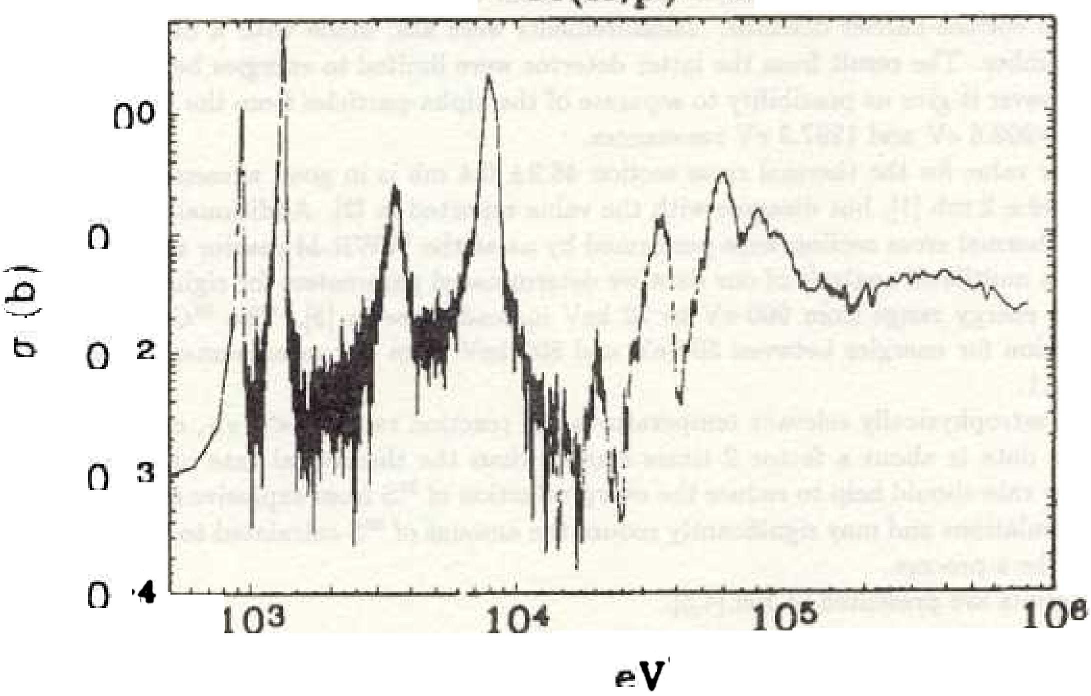
At astrophysically relevant temperatures the reaction rate, $N_A<\sigma\ v>$, calculated from our data is about a factor 2 times smaller than the theoretical rate used early. The new rate should help to reduce the overproduction of ^{36}S from explosive nucleosynthesis calculations and may significantly reduce the amount of ^{36}S calcalated to be synthesized in the s-process.

Results are presented in Ref.[4,5].

References

1. S.Druyts et al. Ann.Geophys.**9**(Suppl.), 336 (1991)
2. J.Andrzejewski et al. JINR Communication, P3-87-319, Dubna (1987)
3. Yu.M.Gledenov et al. Z.Phys.**A322**, 685 (1985)
4. P.E.Koehler et al. Phys.Rev.**C47**, 2107(1993)
5. P.E.Koehler et al.In: 8th Intern.Symp. on Capture Gamma-Ray Spectroscopy and Related Topics, p.65, Fribourg (1993)

$^{36}Cl(n,p)^{36}S$



'ig.

$^{14}N(n,p)^{14}C$ Reaction Cross Section at Thermal, 24.5 keV, 53.5 keV and 144 keV Neutron Energy

Yu.M.Gledenov, V.I.Salatski, P.V.Sedyshev, M.V.Sedysheva, Li Ho Bom
Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia
V.A.Pshenichnyj
Institute for Nuclear Research, Academy of Science of Ukraine, 25028 Kiev, Ukraine
J.Andrzejewski
Department of Nuclear Physics, University of Lodz, 90131 Lodz, Poland

Depending on the $^{14}N(n,p)^{14}C$ reaction cross section, ^{14}N isotope may exhibit essential influence on the neutron balance and the formation of certain elements at the stage of stellar nucleosynthesis. Our measurements were carried out on the IBR-30 pulsed booster of the Frank Laboratory of Neutron Physics in Dubna and on the beam of filtered neutrons from the VVR-M reactor of Institute for Nuclear Research in Kiev. The ionization chamber served as the detector of charged particles. Solid adenine targets were used. Fig.1 presents the experimental spectrum read out during the measurement in Kiev on the neutron filter for the 53.5 keV neutrons. The peak A is the protons from the $^{14}N(n,p)^{14}C$ reaction on the 53.5 keV neutrons. The proton peaks B and C from the same reaction appear due to 0.49 MeV and 0.65 MeV neutron resonances of the ^{14}N, because the filter transmits about 1% of the neutrons of such energies. The cross sections were found to be 1.83±0.07 b, 2.02±0.16 mb, 2.08±0.23 mb and 2.07±0.27 mb for thermal, 24.5 keV, 53.5 keV and 144 keV neutron energy, respectively.

Our results are in a good agreement with earlier estimations [1,2] and with experimental data which were obtained by Koehler et.al. in Los Alamos [3], but about a factor of 2 larger than the results [4] by Brehm et.al. According to the our data the ^{14}N isotope may act as a strong neutron "poison" in s-process during the operation of the chain of reaction involving the $^{13}C(a,n)^{16}O$ neutron source. Also, ^{14}N may play a crucial role in the nucleosynthesis of ^{19}F. Our results have been presented in [5,6,7].

1. N.A.Bahcall and W.A.Fowler. Astrophys.J. **157**, 659 (1969).
2. F.Ajzenberg-Selov. Nucl.Phys. **A449**, 1 (1986).
3. P.E.Koehler and H.A.O'Brien. Phys.Rev.C**39**, 1655 (1989).
4. K.Brehm et.al. Z.Phys. A **330**, 167 (1988).
5. J.Andrzejewski et.al. In "Nuclei in Cosmos". Int.Symp. on Nucl. Astrophys., Karlsruhe, Germany, 6-10 July 1992.
6. Yu.M.Gledenov et.al. Z.Phys. A **346**, 307 (1993).
7. Yu.M.Gledenov et.al. 8th Int.Symp. on Capt. Gamma-Ray Spect. 20-24 Sept. 1993.

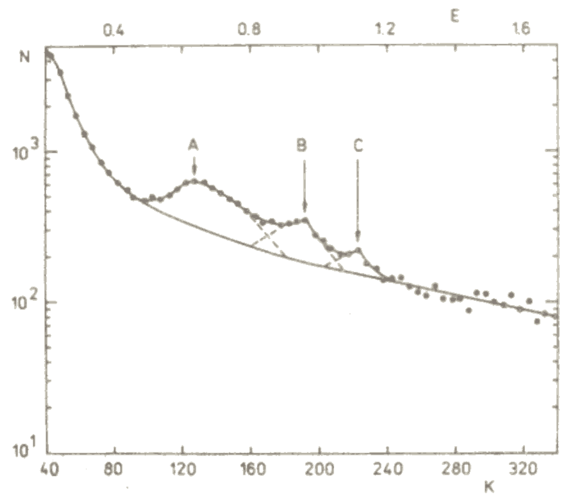


Fig.1. Spectrum of the protons from the $^{14}N(n.p)^{14}C$ reaction when the majority of neutrons have the energy 54 keV.

$^{26}Al(n,p)^{26}Mg$ and $^{26}Al(n,a)^{23}Na$ Cross Section from Thermal Energy to Approximately 50 keV

Yu.M.Gledenov, Yu.P.Popov
Frank Laboratory of Neutron Physics , Joint Institute for nuclear Research, Dubna, Russia
P.E.Koehler, H.A.O'Brien
Los Alamos National Laboratory, Los Alamos, NM, USA.
S.M.Graff
9413 Stitt Rd., Whitehouse, Ohio, USA
J.A.Harvey, N.V.Hill
Oak Ridge National Laboratory, Oak Ridge, TN, USA
R.W.Kavanagh
Caltech, Pasadena, CA, USA
R.B.Vogelaar
Princeton University, Princeton, NJ, USA
M.Wiescher
University of Notre Dame, Notre Dame, IN, USA
F.Kappeler, H.Schatz
Kernforschungszentrum Karlsruhe, Karlsruhe, Germany
H.-P.Trautvetter
Ruhr-Universitat Bochum, Germany

At our participation preliminary measurements on ^{26}Al isotope were carried out within neutron energy region from thermal up to 50 keV. Most of this energy range has not been explored by previous measurements. Understanding the origin of ^{26}Al is important because it is one of the few radioactive products of stellar nucleosynthesis to be observed directly by γ-ray telescopes or indirectly as a ^{26}Mg anomaly in some meteorites. The $^{26}Al(n,p)$ and $^{26}Al(n,\alpha)$ reaction are thought to be major means for the destruction of ^{26}Al in some astrophysical enviroments.

The measurements were made at the white neutron source of the Manuel Luian, Jr. Neutron Scattering Center (LANSCE) using a ΔE-E semiconductor detector telescope. Several resonances were observed. The preliminary results for the (n,α_0) channel are in a good agreement with data obtained from the investigation of reversal reaction [1] , but for the (n,p_1) channel they are about a factor of 2 larger than previous measurements [2]. Thus, our measurements indicate that the destruction of ^{26}Al in neutron enviroments is even greater than previously thought.

1.R.T.Skelton and R.W.Kavanagh, Phys.Rev. C **35**, 45 (1987).
2.H.-P.Trautvetter et.al. Z.Phys. A **523**, 1 (1986).
3.P.E.Koehler et.al. April Meeting of Am.Phys.Soc. 12-15 April, 1993.
4.P.E.Koehler et.al. 8th Int.Sym.Capture Gamma-Ray Spec. 20-24 Sept., 1993.

Measurement of P-odd asymmetry in the $^{10}B(n,\alpha)^{7}Li$ reaction

V.A.Vesna[1] Yu.M.Gledenov[1] I.S.Okunev[2] S.S.Parzhitskii,[1]
Yu.P.Popov[1] E.V.Shul'gina[2]

[1] Frank Laboratory of Neutron Physics, JINR, Dubna
[2] Petersburg Nuclear Physics Institute, Gatchina

On the high flux beam of the polarized cold neutrons of the WWR-M reactor at the PINP (Gatchina) in frame of collaboration was performed the measurements of asymmetry of the emission of α-particles in the $^{10}B(n,\alpha)^{7}Li$ reaction. Asymmetry of the type: $W \sim 1 + \alpha_{pN}(\vec{\sigma}_n \cdot \vec{k}_\alpha)$ was measured where $\vec{\sigma}_n$, $\vec{k}_\alpha$ are the neutron spin and the unit vector of α-particle emission direction, respectively .

The measuring conditions was following

neutron intensity	$N = 3 \cdot 10^{10}$ n/s
mean wavelength	$\lambda = 4.5$ A
polarization	$P = 80$ %

For the detection of the charged particles was used an assambly of twenty four identical double proportional chambers (layout of the experimental apparatus on the reactor lid presented in Fig 1) operating in ionization current mode /1/. The conditions of a detector work (geometry, the insensetive gas-filled gap, the gas pressure) was selected such to not detect the ions ^{7}Li in the reaction and mean cosine of the detected α-particles with respect to the target plane was equal ~0.8. With selection of gas work pressure mixture it was possible not to detect α_1-particles from a α-decay in the first excited state of the daughter nucleus ^{7}Li also.

As a target was used the layers of a amorphous ^{10}B of the 50-150 μg/cm^2 thickness with enrichment ~90% sprayed on an aluminium foil of the thickness d = 20 μm. Thanks to the experimental geometry chosen in which $\vec{\sigma}_n$, $\vec{k}_n$, $\vec{k}_\alpha$ vectors are collinear a suppression factor of the left-right hand asymmetry ($\vec{\sigma}\,[\vec{k}_n\,\vec{k}_\alpha]$) was achieved to be not worse than 10^{-4}, what allowed the exclusion of the possible contribution of this asymmetry into the effect to a level of $\sim 10^{-8}$.

The measurements performed gave the following values for the coefficients of P-odd asymmetry /2,3/

$$\alpha_{0pN} = (3.4 + 6.7)\ 10^{-7}$$
for α_0-line $E_{\alpha 0}$ = 1780 keV

$$\alpha_{1pN} = -(2.5 + 1.6)\ 10^{-7}$$
for α_1-line $E_{\alpha 1}$ = 1479 keV

The obtained values improve essential the values of the coefficients P-odd asymmetry measured in works /4,5/.

1. Vesna V.A. et al. Preprint PNPI N 1694 , S.-Petersburg, 1991.

2. Vesna V.A. et al. Annotations of the projects of experiments in field of the fundamental particles physics and nuclear science proposed in 1991-1995, S.-Petersburg, 1991, p.92.

3. Vesna V.A. et al. Proceedings of 111 International Symposium on Weak and Electromagnetic Interactions in Nuclei (WEIN'92).Ed.by T.D.Vylov, World Scientific, p.419.

4. Vesna V.A. et al. Pisma ZhETF, v.38, 1983, p.265.

5. Ermakov O.N. et al. in book: Neutron Physics Proceed.of the

6. Conference on Neutron Physics, Kiev, 1983, M.: CNII-atominform, 1984, v.3, p.403.

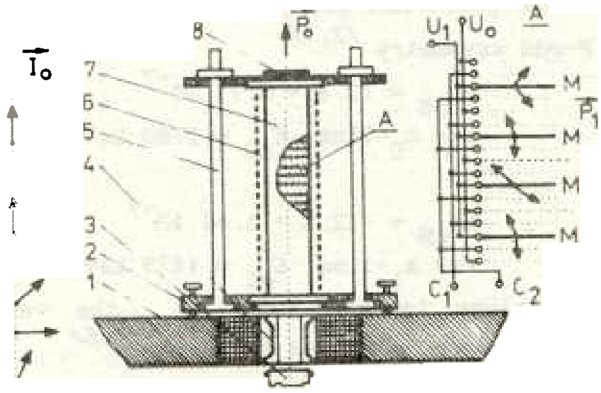


Fig. 1. Layout of experimental apparatus on the reactor lid. 1 - the lid of the reactor, 2 - table for proportional chamber , 3 - polarizing neutron guide, 4 - radio-frequency flipper, 6 - magnetic field guiding the neutron spin, 7 - proportional chamber, 8 - ^6LiF neutron absorber. The cross section "A" shows one chamber module. I_0 - is the neutron spin, P_0 - is the neutron momentum, P_1 - is the momentum of the detected alpha-particle. C_1, C_2 - are the outputs from signal grids of the "forward" signal (U_f) and the "backward" signal (U_1). $U_{o,1}$ - the potential supply the block grid and the target, respectively.

Investigation of Charged Particles Emission Reaction Induced by Fast Neutrons

Yu.M.Gledenov, G.Khuukhenkhuu, Yu.P.Popov
Frank Laboratory of Neutron Physics, JINR, Dubna

Bao Shanglian, Tang Guoyou, Cao Wentian, Qu Decheng
Peking University, Beijing, China

Chen Zemin, Chen Yingtang, Qi Huiquan
Tsinghua University, Beijing, China

Experiments carried out on the D+D neutrons using the Van de Graaff accelerator at the Institute of Heavy Ion Physics, Peking University, China. Charged particles emitted in the investigated reactions were detected with a double-grid, parallel-plate, twin ionization chamber with a common cathode, which was manufactured at the Frank Laboratory of Neutron Physics, JINR. Argon mixed with 5% carbon-dioxide was utilized to fill the chamber. The first section of the twin ionization chamber contained studied target. The second section was empty and was used for background measurements.

Two dimensional energy spectra of signals from the anode and cathode were obtained for emitted charged particles from neutron induced reactions with the help of a measuring system based on the IBM PC AT-386 computer. Measured angular distributions of α- particles emitted in the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction at E_n= 4 and 5MeV are nearly symmetrical with respect to $\vartheta=90^o$ (Figs.1 and 2). This fact shows that the compound nucleus mechanism predominates in the energy range E_n= 4-5 MeV for the double magic target nucleus ^{40}Ca. Cross section of the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction at a neutron energy of 5 MeV was found to be $\sigma(n,\alpha_0)=234\pm23$ mb. Measurements also carried out on natural zink and ^{64}Zn at E_n=2.7 and 5 MeV. Alpha-peaks from the $^{64}Zn(n,\alpha)^{61}Ni$ reaction were observed. Additionally to those of the investigated reactions there were observed alpha-peaks from $^{36}Ar(n,\alpha)$ ^{33}S as a background.

References

1. Tang Guoyou et al.Communication of nuclear data progress, No.8, p.7-15 (1992)

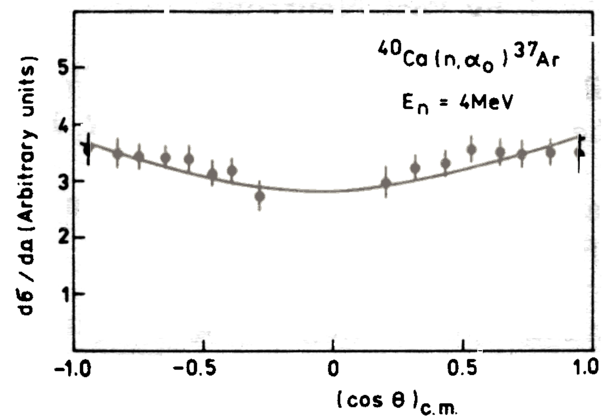


Fig.1. The angular distribution of α - particles from the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction at E_n=4 MeV. The solid curve is only an eye-guide.

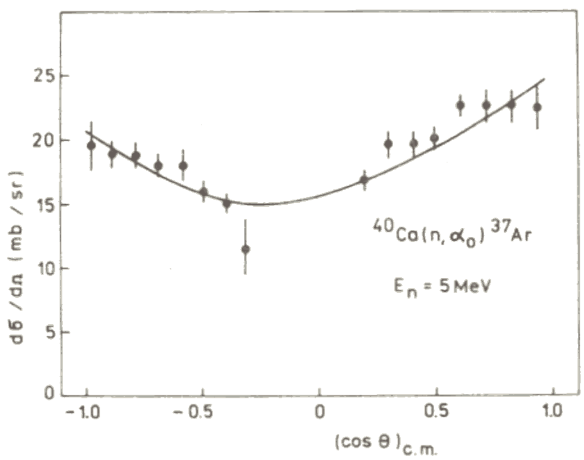


Fig.2. The same as in Fig.1 at E_n=5 MeV.

INTERACTION OF POLARIZED NEUTRONS WITH A POLARIZED LANTHANUM TARGET AND STRUCTURE OF THE NEUTRON CROSS SECTION UP TO 20 eV

V.P.Alfimenkov, Yu.D.Mareev, V.V.Novitsky, L.B.Pikelner, V.R.Skoy
Joint Institute for Nuclear Research, Dubna, Russia

Interest in the neutron cross section of lanthanum is connected with the discovery of a very strong parity nonconservation effect in the *p*-wave resonance of ^{139}La at 0.74 eV. This stimulated a theoretical search for the possibility of a T-noninvariance test in lanthanum. A principal part of the neutron cross section of La at low energy is connected with a negative resonance. It influences the parity violation in the *p*-wave resonance and must be studied in more detail.

All of these circumstances have stimulated our measurement of the total cross section in vicinity of the 0.74 eV resonance up to 20 eV, and our research of the polarization property of La in an experiment with polarized neutrons and a polarized La target.

The interaction of polarized neutrons with a polarized La target was measured on a neutron beam of the IBR-30 by use the POLYANA installation. Neutrons were polarized by transmission through a polarized proton target, and polarization of the metallic La sample was achieved by cooling it to about 0.1 K in a magnetic field of 1.5 T. The neutron time-of-flight spectra for two directions of neutron polarization were measured and the dependence of the transmission effect,

$$\varepsilon = \frac{N_+ - N_-}{N_+ + N_-} = f_n th(f_N n \sigma_{pol})$$

on neutron energy in the 0.5-20 eV interval was obtained. The value of the polarization cross section σ_{pol}, which was measured with polarized neutrons and nuclei was found to be in good agreement with the results of our total cross section measurement.

All data were described very well by the negative ^{139}La resonance with the parameters of $E_0 = -28\ eV,\ \Gamma_n^0 = 60\ meV, \Gamma_\gamma = 50\ meV, J = 4, \sigma_{pot} = 5b$. Spin of the 3.0 eV resonance of ^{138}La was identified as $I + 1/2 = 11/2$.

STUDY OF THE DEPOLARIZATION OF RESONANCE NEUTRONS IN AN EXPERIMENT TO SEARCH FOR THE T-NONINVARIANCE

V.P.Alfimenkov, Yu.D.Mareev, V.V.Novitsky, L.B.Pikelner, V.R.Skoy
Joint Institute for Nuclear Research, Dubna, Russia
C.R.Gould, D.G.Haase, N.R.Roberson
TUNL, North Carolina, USA

Experiments on the measurement of the five-fold correlation for time reversal test have been discussed in recent years. In these experiments the transmission of polarized resonance neutrons through aligned nuclear targets must be measured. The effect which is under investigation consists of a change in the total neutron cross section of the change of the sign of the $\vec{s}[\vec{I}\times\vec{k}](\vec{I}\cdot\vec{k})$ term. Here $\vec{s}$ and $\vec{I}$ are the spins of the neutron and nucleus, respectively, and $\vec{k}$ is the neutron momentum. The experiment is very complicated technically because the effect is very small and is easily masked by additional false effects. All of them must be investigated and taken into account.

One of these effects is the depolarization of polarized neutrons at their transmission through a monocrystal sample with aligned nuclei. The value of the depolarization strongly depend on the crystal orientation and neutron energy.

Now an experiment to investigate this depolarization is ready and preliminary results have been obtained. Measurement with a *Ho* monocrystal was carried out at the POLYANA installation on a neutron beam of the IBR-30 system. A strong angle dependence of the depolarization was observed. Measurements were made for angles between the *c*-axis and the direction of neutron polarization, from $-\pi/2$ to $+\pi/2$.

Sample temperatures were 4, 80 and 300 K. The values of the depolarization at helium temperature are very large and reach up factor 3-4. We intend to develop these investigations which are of additional interest in the study of the magnetic properties of matter.

MULTIPLICITY OF GAMMA-RAYS IN NEUTRON RESONANCES OF ^{176}Hf AND ^{179}Hf

G.P.Georgiev, Yu.V.Grigoryev, G.V.Muradyan, N.B.Yaneva

Neutron time-of-flight spectroscopy measurements were made on the samples of Hafnium isotopes at the pulsed neutron booster IBR-30 of the Joint Institute for Nuclear Research in Dubna. A preliminary results are presented of an investigation of the radiative capture of resonance neutrons by ^{176}Hf and ^{179}Hf isotopes in the region of resolved resonances making use of the method of multiplicity spectrometry. The choice of the indicated isotopes for studies was due to the data on their spins and radiation widths being incomplete [1]. The cross section of radiative capture by Hafnium isotopes in the region of resonance neutron energies is interesting from the points of view of understanding nucleosynthesis and of reactor construction.

A multisection 4π- "Daisy-type" scintillation detector (Fig.1) located at the 500-metre-long time-of-flight base of the IBR-30 pulsed neutron booster of the JINR FlNP was used for measurements [2] . The detector consisted of 16 independent NaJ(Tl) crystal sections with a total volume of 36 litres and geometric efficiency of 80% . A ^{176}Hf target 2.88 x 10^{-4} nuclei/barn thick and a ^{179}Hf target 2.14 x 10^{-4} nuclei/barn thick were used in the measurements. The neutron time -of- flight and the coincidence multiplicity of gamma-quanta were determined for each interaction event. In parallel with the gamma-quanta from radiative capture in the target, single 480 keV gamma-quanta produced in the ^{10}B(n, $\alpha\gamma$) reaction caused by neutrons scattered in the target and occurring in the thin Bohr converter surrounding it were detected. Thus, the same detector registered events of radiative capture and of neutron scattering in the target simultaneously and in identical conditions.

The experimental gamma - quantum multiplicity spectrum $P(k) = S_\gamma(k)/\sum S_\gamma(k)$ was obtained, and the mean gamma-quantum multplicity $\langle k\rangle = \sum kP(k)$ determined. It turned out to be that

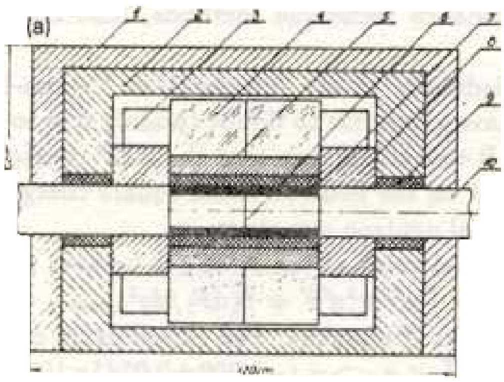
$\langle k \rangle=2.50$ for the even-even ^{176}Hf isotope, while in the case of the even-odd ^{179}Hf isotope the $\langle k \rangle$ values concentrated about two points: $\langle k \rangle=2.78$ and $\langle k \rangle=2.91$. Thus, in the range of energies up to 200 eV, 18 spin 4^+ resonances and 19 spin 5^+ resonances were successfully identified for ^{179}Hf. The multiplicity distribution $P(\nu)$ (Fig.2) for gamma quanta emitted by the nucleus was computed from the gamma-quantum multiplicity distribution $P(k)$ observed experimentally for ^{179}Hf. This was done making use of the gamma-cascade model, of the theoretical description of the strength function and of available data on the lower energy levels of the composite nucleus. Monte -Carlo simulation was performed of the propagation of gamma-quanta through the detector and the shielding. For determining the parameters of the resonances a program was written which made possible computation of the expected time-of-flight radiative capture and scattering spectra and fitting them to the respective measured spectra by varying the resonance parameters and fitting the parameters of the neutron spectrometer. The radiation width Γ_γ was fitted with the aid of the ratio of the partial areas A_γ and A_S under the respective resonance peaks in the radiative capture and scattering spectra, of the known neutron width Γ_n [1] and of the distribution function obtained. In the fit, that value of Γ_γ was determined for which the computed A_γ/A_S ratio was in agreement with its experimental value.

Besides the levels indicated in ref. [1], 17 new levels were observed for ^{176}Hf in the energy range up to 1500eV. The values of D_o = 37 +/- 7 eV and $\langle \Gamma_\gamma \rangle$ = 45 +/- 15 meV were obtained.

We obtained $\langle \Gamma_\gamma \rangle$ = 47+/-6 for ^{179}Hf. The strength function was calculated , with the aid of the spins determined , in the range up to 200 eV : $S_o = (1.8^{+1.0}_{-0.7}).10^{-4}$ and $S_o = (2.4^{+1.2}_{-0.8}).10^{-4}$ for the $J^\pi = 4^+$ and $J^\pi = 5^+$ set of resonances respectively , meaning that they are identical within the experimental errors .

References

1. S.F.Mughabghab, Neutron cross Section 1, Part B (Academik Press, New York, 1984) .
2. N.B.Yaneva, G.P.Georgiev et al., Nuclear Instruments and Methods in Physics Research A313 (1992), p.266 .



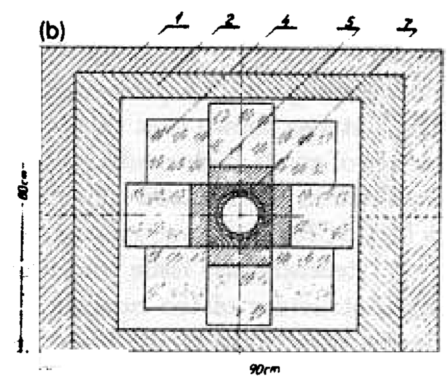
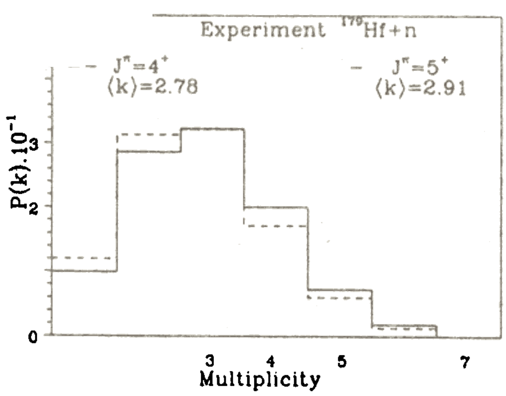


Fig. 1. Side - (a) and rear - (b) view of the detector . 1,5,8 - shield made of paraffin and boron carbide; 2 - lead shield; 3 - photomultiplier; 4 - NaI(Tl) crystal; 6 - sample; 7,9 - shield made of polyethylene and boron carbide; 10 - evacuated tube.



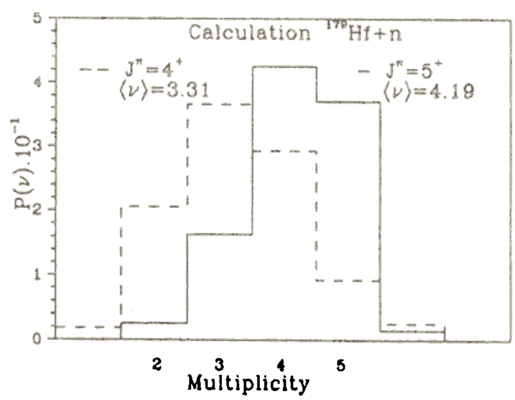


Fig. 2. Experimental P(k) and calculated P(ν) distributions of the gamma-quanta multiplicity of the ^{179}Hf (n,γ) reaction.

Situation in Study of Electric Polarizability and Mean Square Charge Radius of the Neutron

Yu.A.Alexandrov
Frank Laboratory of Neutron Physics, JINR, 141980 Dubna, Moscow Region, Russia

The concept of neutron electric polarizability (NEP) was introduced in 1955-56 in connection with studies of neutron scattering by the Coulomb fields of nuclei[1] . The best result for the NEP coefficient $< 0.7 \times 10^{-3} fm^3$ was obtained in Dubna-Garching cooperation (time-of-flight and neutron resonance technique methods, lead-208 and bismuth)[2-4] .

Concerning the job performed by Schmiedmayer et al. (cooperation Vienna-Oak Ridge)[5] it was shown that this job should have given rise to doubt (mainly due to the influence of small angle neutron scattering). It was also shown that the NEP coefficient determined in the neutron transmition depend on the neutron mean square charge radius (NMSCR) $< r_{in}^2 >_N$, related to the internal neutron structure.

Recently, the issue concerning the actual value of the NMSCR, related to the internal structure of the neutron, ($< r_{in}^2 >_N = \int \rho(\vec{r}) r^2 d^3\vec{r} = 6(dF_1/dq^2)_{q^2=0}$, where F_1 is the Dirac form factor) has been also under discussion. The experiments can be divided into two groups (see table): the results[6-7] $< a_{ne} > = (-1.309 \pm 0.024) \times 10^{-3} fm$, which lead to $< r_{in}^2 >_N > 0$ in contradiction with modern theory , and[2,8,9] $< a_{ne} > = (-1.577 \pm 0.034) \times 10^{-3} fm$ to lead to $< r_{in}^2 >_N < 0$ in confirmation of modern theory. It is shown that the most probable reason for the discrepancy between the results of the Garching and Dubna determination of the a_{ne} for bismuth is the difference in the method of accounting for the influence of negative energy resonances on the measurable a_{ne} . It is also shown that introduction into σ_{tot} of energy independent inter-resonance interference terms does not affect the result on a_{ne} obtained in Dubna.

1. Yu.A.Alexandrov and I.I.Bondarenko. *Zh.Eksp.Teor.Fiz.* **31**, 726 (1956).

2. Yu.A.Alexandrov et al. *Sov.J.Nucl.Phys.* **44**, 900 (1986).

3. Yu.A.Alexandrov et al. *JINR Rapid.Comm.* No.6[45]-90 (1990).

4. Yu.A.Alexandrov et al. *Intern.Semin. on Interaction of Neutr. with Nuclei*, E3-92-128, p.19, Dubna (1992).

5. J.Schmiedmayer et al. *Phys.Rev.Lett.* **66**, 1015 (1991).

6. V.Krohn and G.Ringo. *Phys.Rev.* **D8**, 1305 (1979).

7. L.Koester et al. *Z.Phys.* **A329**, 229 (1988).

8. E.Melkonian et al. *Phys.Rev.* **114**, 1571 (1959).

9. Yu.A.Alexandrov et al. *Yad.Fiz.* **20**, 1190 (1974); *Zh.Eksp.Teor.Fiz.* **89**, 34 (1985).

Table

Authors, year	Method	Magnitude of effect, ne/tot	$-a_{ne} \times (10^3) fm$	Ref.
P.Dee, 1932	Recoil electrons in cloud chamber		<1000	
E.Fermi, L.Marschall, 1947	Neutron scattering on noble gases	$\Delta\sigma/\sigma \cong 0.5\%$	100 ± 1800	
W.Havens, et al., 1947-51	Total neutron cross section on lead and bismuth	$\Delta\sigma/\sigma \cong 1.5\%$	1.91 ± 0.36	
D.Hughes et al., 1952-53	Neutron total reflection from $O_2 - Bi$ mirror	$\Delta\Theta/\Theta \cong 50\%$	1.39 ± 0.13	
M.Hamermesh et al., 1952	Neutron scattering on noble gases	$\Delta\sigma/\sigma \cong 0.5\%$	1.5 ± 0.4	
M.Crouch et al., 1956	Neutron scattering on noble gases	$\Delta\sigma/\sigma \cong 0.5\%$	1.43 ± 0.30	
E.Melkonian et al., 1959	Total neutron cross section on bismuth	$\Delta\sigma/\sigma \cong 1.5\%$	$1.56 \pm 0.05^*$	[8]
V.Krohn, G.Ringo, 1966-73	Neutron scattering on noble gases	$\Delta\sigma/\sigma \cong 0.5\%$	1.30 ± 0.03	[6]
L.Koester et al., 1970-88	Total neutron cross section and atomic scattering length on bismuth and lead	$\Delta\sigma/\sigma \cong 1.2\%$	1.32 ± 0.04	[7]
Yu.Alexandrov et al., 1974-85	Neutron diffraction on a tungsten-186 single crystal	$\Delta\sigma/\sigma \cong 20\%$	1.60 ± 0.05	[9]
Yu.Alexandrov et al., 1985	Total neutron cross section on bismuth	$\Delta\sigma/\sigma \cong 1.2\%$	1.55 ± 0.11	[2]

Without correction for Schwinger scattering and resonance scattering.

ON THE ELECTRIC POLARIZABILITY OF THE NEUTRON

Yu.A.Alexandrov*), L.Koester**), L.V.Mitsyna*), P.Prokofiev***), G.S.Samosvat*), J.Tambergs***), W.Waschkowski**)

*) Joint Institute for Nuclear Research, Dubna, Russia
**) Technical University Munich, Garching, Germany
***) Nuclear Research Centre, Salaspils, Latvia

Precise measurements of the total neutron cross sections were performed for samples of lead enriched up to 98, 83 92% by 208,207 and 206 isotopes accordingly. The quasi-monochromatic neutrons were used with energies 1.26, 5.19 and 1970 eV which were got on Munich Technical University FRM reactor by means of corresponding neutron resonances [1]. The obtained cross sections in barns are shown in the table.

Sample	1.26 eV	5.19 eV	1970 eV
208	11.4388(31)	11.4718(35)	11.4635(26)
207	11.1510(120)	11.1320(130)	11.0520(120)
206	10.7988(51)	10.8270(70)	10.8030(60)

Two different methods developed in Garching and Dubna were used to extract the neutron polarizability coefficient α_n; they both gave practically the same α_n values. The total results depends on accepted value of the $n-e$ scattering length b_{ne} and looks as

$$\alpha_n = \begin{cases} (-0.3 \pm 0.5) \cdot 10^{-3} fm^3, & if \quad b_{ne} = (-1.32 \pm 0.04) \cdot 10^{-3} fm, \\ -1.3 \pm 0.5) \cdot 10^{-3} fm^3, & if \quad b_{ne} = (-1.59 \pm 0.04) \cdot 10^{-3} fm. \end{cases}$$

So there is only one meaning result [2] $\alpha_n = (1.20 \pm 0.15 \pm 0.20) \cdot 10^{-3} fm^3$ by which teoretists are "satisfyed",it is possibly to confirm that present result intensifies the problem of reliable experimental value of not only α_n, but b_{ne} too.

References

1.Koester L.,Waschkowski W.,Meier J.Z.Phys.A,1988, v.329, p.229.
2.Schmiedmayer J.,Riehs P.,Harvey J.A.,Hill N.W. Phys. Rev. Lett., 1991, v.66, p.1015.

UCN High Density Pulse Source at the BIGR Reactor (Arzamas-16) and Neutron Lifetime Experiment.

A.V.Strelkov, V.N.Shvetsov
FLNP, JINR
A.D.Stoica
IFTM, P.O. Box MG52, Bucharest, Romania

Abstract. The method of dynamic ultracold neutrons (UCN) converter, using high flux pulse reactor BIGR (Arzamas-16) is proposed. Different types of converters have been compared and estimations of maximal UCN density were obtained ($n \approx 7 \times 10^5 n/cm^3$). The possible experiment on neutron lifetime (τ_β) determination is discussed (the accuracy 0.5% for τ_β per one reactor pulse can be achieved).

1. Introduction

Ultracold neutrons (UCN) - neutrons with extremely low energy $\propto 7 \times 10^{7}$ev (V $\propto$ 5 m/s)[1]. They have an unique property of total reflection from substance surface and so can be stored in evacuated material traps for a long time. UCN are very useful for experiments on studying of fundamental neutron properties:neutron lifetime, electric dipole moment an so on.

UCN can be produced from thermal neutrons for one impact. The probability of such process is very small($\propto 10^{-11}$) and flux density of UCN is:

$$F_{ucn} = \frac{1}{8} F_{th} \left[\frac{V_{lim}}{V_{th}} \right]^4 \frac{\sigma^{\ominus}_{ie}}{\sigma^{\oplus}_{ie} + \sigma_a} \quad (1), \qquad \frac{F_{ucn}}{F_{th}} \propto 10^{-12},$$

where F_{th} - flux density of thermal neutrons , V_{lim} - limiting velocity of the trap walls $\propto$(3-6)m/s, V_{th}= 2200 m/s - thermal neutron's velocity, $\sigma^{\ominus}_{ie}$ and $\sigma^{\oplus}_{ie}$ - inelastic cross-sections of cooling and heating, σ_a-capture cross-section .

The first experiments with UCN have been carried out with UCN density $\propto 5 \times 10^{-6}$ n/cm^3 [2,3]. In modern times the highest UCN density is $\propto 10^2$ n/cm^3 [4]. The possibilities of significance increasing F_{th} for stationary reactors are exhausted now, so further increasing of the UCN density may be done using pulse reactors only, where pulse flux densities are many times larger than at stationary ones.

2. Dynamical converter method

2.1 Constant density of the converter

UCN density inside the converter in nonstationary case described with differential equation:

$$\frac{dn(t)}{dt} = F_{th}(t)\bar{\Sigma}^{\theta}_{ls} - \frac{n(t)}{\tau(t)} \qquad (2), \quad \bar{\Sigma}^{\theta}_{ls} = N(t)\bar{\sigma}^{\theta}_{ls},$$

where n(t) - UCN density, N(t) - number of converter's molecules in cm^3, $\tau(t)$ - UCN lifetime in converter: $\tau(t)^{-1} = N(t)V(\sigma^{\theta}_{ls} + \sigma_a)$, V-UCN velocity.

For the Gaussian form of thermal neutrons flux and BIGR characteristics (fluence 10^{15} n/cm^3, s=1ms):

$$F_{th}(t) \propto \exp(-\frac{t^2}{2\sigma^2}) \qquad (3),$$

the equation (2) has been solved numerically. The values of n_{max} - maximal UCN density inside the converter - are: $1.8x10^5$ n/cm^3 for polyethylene converter, $2.5x10^5$ n/cm^3 for Be and $9x10^5$ n/cm^3 for parahydrogen ones. If N(t) value stays constant, the UCN density decreases for a short time due for a large value of losses cross-sections, and it becomes difficult to realize the isolation of UCN from converter. To provide the fast isolation of UCN cloud from converter without significant decreasing of it's density the method of dynamical converters is proposed.

2.2 Gaseous expanding converter

Sharp fall of pressure in gaseous converter in a time of reactor pulse, when thermal neutron flux reaches it's maximal value, leads to decreasing of UCN losses. The calculation of n(t) has been made using (2), and the time of the expansion beginning coincides with the time of maximal flux of thermal neutrons. Calculation shows that for real times of gas expansion one can store UCN cloud some times longer then without expansion.

UCN density $\approx 7x10^5$ n/cm^3 can be obtained with parahydrogen (30 atm.) converter.

2.3 Moving solid converter

The fast removing of the converter after reactor pulse can be realized also by mechanical movement of the converter. In this case the speed of UCN, unmovable in a lab frame, relatively converter will be V - the converter speed and the losses cross-section will be reduced by factor 1/V.

During the passing of converter in a field of the thermal neutrons, the veil of UCN is producing behind the converter. The UCN density subordinates for dependency similar that described with (2). Calculations for Be and polyethylene converters has been made to select the converter for preliminary experiment on method examination. It was found that it's possible to obtain UCN density up to 10^5 n/cm^3, using polyethylene converter about 10 mm thick with velocity ≈ 50 m/s. Be converter has to be about 100 mm thick at the same speed and the value of density will be $\approx 3x10^4$ n/cm^3.

3. Possible experiment on neutron lifetime determination

The cloud of UCN, produced with expanding gaseous or moving converter can be enclosed in a trap,transported out of reactor hall and placed into detector system, including thermal neutron counter and electron counter. The UCN density in a trap will be:

$$n(t) = n_0 \exp\left(-\frac{t}{\tau_\beta} - (\eta_{ie} + \eta_a)\int_0^t \gamma(t')dt'\right) \qquad (4),$$

where η_{ie}, η_a, $\gamma(t)$ - certain parameters, depending from neutron spectra and trap properties. Then, count rates for neutron and electrondetectors will be consequently: $J_{ie} = \varepsilon_{ie}\eta_{ie}\gamma(t)n(t)$ and $J_\beta = \varepsilon_\beta\eta_{ie}\frac{1}{\tau_\beta}n(t)$, where ε_{ie} and ε_β- detector's efficiencies. Therefore,

one can obtain: $$-\frac{d}{dt}\left[\ln(J_\beta)\right] = \frac{1}{\tau_\beta}\left[1 + \frac{\eta_{ie} + \eta_a}{\eta_{ie}}\frac{\varepsilon_\beta}{\varepsilon_{ie}}\frac{J_{ie}}{J_\beta}\right] \qquad (5)$$

Equation (5) shows, that neutron lifetime can be extracted with linear extrapolation of experimental data down to zero value of $\frac{J_{ie}}{J_\beta}$. The mathematical simulation of the UCN behavior in a trap has been carried out to obtain the evaluation of the neutron lifetime determination accuracy. It was found, that accuracy =0.5% can be achieved per one pulse of the reactor.

4. Conclusion

It's necessary to emphasize that dynamical converter method does not increase the initial UCN density in converter. Initial density determines only by the thermal neutron flux value and converter's properties. This method let us to extract UCN from significantly large area of the converter than for stationary converter.

To understand the advantages of the new UCN source one can turn to existing UCN sources and experiments. In experiment on neutron lifetime measurements [5] (that has been made at the best after Grenoble UCN source) the accuracy 0.3% has been achieved. The number of neutrons "used" in experiment at 2.5 months of the "reactor" time were $\approx 10^8$,that is the same order of magnitude as in proposing experiment for one pulse of BIGR reactor.

References

[1] Golub R. and Pendlebury J. M. 1979 Rep.Prog.Phys. 42 439-501
[2] Shapiro F. e.a. 1969 JETP Letters 9 40
[3] Steyerl A. 1969 Phys.Lett. 1969 29 33
[4] Steyerl A. e.a. 1986 Phys.Lett. A116 347
[5] Alfimenkov V P e.a. 1990 JETP Letters 52 984-989

A MOVING CONVERTER AS A POSSIBLE TOOL FOR PRODUCING ULTRACOLD NEUTRONS AT PULSED NEUTRON SOURCES

Yu.N.Pokotilovski
Frank Laboratory of Neutron Physics,
Joint Institute for Nuclear Research, Dubna, Russia

A method for producing ultracold neutrons (UCN) at aperiodic pulsed neutron sources is proposed. The method exploits an UCN converter that moves fast near a pulsed neutron source. The motion of the converter is synchronized with the pulse of the neutron source for the converter to cross the region of maximum neutron flux exactly at the moment of the pulse. The UCN born in the converter during the neutron pulse form a cloud in the region which the converter has occupied during the time of the pulse. Immediately after the pulse the UCN cloud is caught in a trap instantaneously (within a few miliseconds) moved into the region now occupied by UCN. Then the trap is slowly moved off to a region at some distance from the reactor for carrying out experiments with trapped UCN.

Estimates show that this method, if used with powerful aperiodic pulsed reactors of the TRIGA or BIGR type at a pulse fluence of 10^{15} n/cm^2, would allow having an UCN density of 10^5 UCN/cm^3 in a volume of $1-2$ *liters*. At present FLNP and the Institute for Applied Physics do preparatory work for realization of this method at the BIGR reactor (Arzamas-16).

1.Yu.N.Pokotilovski, Nucl.Instr.Meth., 1992, A334, 561.
2. Yu.N.Pokotilovski, Pis'ma ZhTF, 1980, 6, 1300 (in Russian).

ON EXPERIMENTAL VERIFICATION OF THE SKOBELTSYN-BALDIN HYPOTHESIS OF EMISSION OF A NONSTABLE PARTICLE FOLLOWING THE DECAY OF ^{214}Bi

Yu.N.Pokotilovski, G.G.Takhtamyshev
Joint Institute for Nuclear Research, Dubna, Russia

Interpretation of Darmstadt effect consisting in observation of narrow positron-electron pairs following collision of very heavy ions with the energy near the Coulomb barrier has been a serious problem for about ten recent years [1].

None of a few dozen hypotheses that have been advanced explains the observed phenomena. A.M.Baldin [2] assumed some relation of this effect with the experimental results of Skobeltsyn [3] who, investigating the scattering of β−rays with a Wilson chamber placed in a magnetic field, had observed anomalously large β−ray scattering by ^{214}Bi at large angles which exceeded that calculated after the Mott formula by a factor of a few tens. In these experiments he also observed numerous events of inelastic β−scattering with a considerable (by several times) loss of energy. Later Skobeltsyn [4] interpreted his observations as a birth with a probability of $7 - 12$ % following β-decay and a decay while flying of a particle with a mass ofabout 3 m_e and the lifetime of $(2 - 5) \times 10^{-10}$ *sec*. Independent calculations [5] in the frame of a quasipotential approach performed for a system of two fermions had yielded a conclusion about existence of a rich spectrum of relativistic Coulomb levels. These levels merged in continuum must exist in e^+e^-, (pp), and (e^-e^-) systems, and probably in a number of other systems which also include composed neutral particles. The calculations of [5] found confirmation in [6] where the $J = 0$, $L = 1$, $S = 1$ resonances in the (ee) system were obtained by solving under different approximations three different relativistic equations following from quantum electrodynamics. The hypothesis of [2] consists in actualization of Skobeltsyn's assumption [4] that the unstable particle observed in experiments [3] is a quasicoupled complex, $(e^+e^-e^-)$, which decays into an electron and a γ-quantum.

Under conditions close to those of Skobeltsyn's experiment we tested the possibility for a $(e^+e^-e^-)$ complex, decaying into an electron and γ-quantum, to be formed following the decay of ^{214}Bi. A ^{226}Ra source was positioned in a vacuum chamber. Decay events of $(e^+e^-e^-)$ hypothetical particles were sought for along a decay base by measuring electron spectra in coincidence from an electron and a γ-detector. To compare experimental data with the tested hypothesis we simulated numerically the events of emission from the source and decay of a hypothetical particle into an electron and a γ-quantum over the mass and the lifetime range of the $(e^+e^-e^-)$ complex from 1.5 to 2.0 MeV/c^2, and from 5×10^{-11} to 10^{-9} s, respectively. The limit for the probablity of $e^+e^-e^-$ complex emission is 10^{-3} in accordance with the hypothesis in [1,3] 10^{-3}.

Reports on the work have been published in JINR Rapid Communications No. 2(53)-92, p.29, and in Yad.Fiz. 1992, 55, 2017 in Russian.

1. H.Bokemeyer, W.Koenig. Preprint GSI-91-45 (1991).
2. A.M.Baldin. JINR Rapid Comm., N3(42)-90, Dubna, 1990, p.4 (in Russian); Lebedev Phys.Inst. Rapid Communications on Physics, 190, N6, 42 (in Russian).
3. D.V.Skobeltsyn. Izv. AN SSR, ser.fiz., 1938, N1-2, p.75 (in Russian); Doklady AN SSSR, 1938, 21, 435 (in Russian).
4. D.V.Skobeltsyn. In: "To the Memory of S.I.Vavilov", M., 1952, p.292 (in Russian).
5. B.A.Arbuzov et al. Pis'ma Zh.Exp.Teor.Fiz., 1952, **50** 236 (in Russian); Mod.Phys.Lett. 1990, **A5**, 1441; Phys.Lett., 19990 **240B**, 477.
6. J.R.Spence, I.V.Vary. Phys.Lett., 1991, **254B**, 1; **271B**, 1

MÖSSBAUER EFFECT BASED EXPERIMENTS TO SEARCH FOR NEW LIGHT BOSONS

Yu.N.Pokotilovski
Joint Institute for Nuclear Research, Dubna, Russia

Feasibility of an experiment on the basis of Mössbauer effect to search for new light bosons with the mass less than a few tens keV is discussed. The idea consists in using a pulsed neutron source for obtaining a large number of excited isomeric states after the capture of neutrons by nuclei:

$$n + (Z, N) \rightarrow (Z, N+1)^{**} \rightarrow (Z, N+1)^{*}, \qquad (\textit{the isomeric state}),$$

and a resonance detector containing the (Z,N+1) nuclei.

In such experiment a new light boson instead a γ-quantum could be emitted with a low probability during an isomeric transition, and then absorbed in the detector exciting the initial isomeric state. Estimates show that with a TRIGA type reactor and a detector with the volume of tungsten-scintillator of 10 l the sensitivity to boson emission of $\sim 10^{-10}$ would be achieved. For a pseudoscalar particle that value corresponds to the level of several hundred TeV in the scale of violation of Peccei-Quinn symmetry and is over two orders of magnitude higher than the level achieved in the most high sensitivity accelerator-based experiments.

1. Yu.N.Pokotilovski. Proc. of III Int. Symp. on Weak and Electromagn. Int. in Nuclei, Dubna, June, 1992, p.878; Ts. Vylov (Ed.), World Scientific, Singapore, 1993.
2. Yu.N.Pokotilovski. Pis'ma Zh.Exp.Teor.Fiz., 1983, **37**, 51 (In Russian); JETP Lett, 1983, **37**, 60.

Some aspects of estimation of n,e-amplitude and neutron polarizability

V.G.Nikolenko, A.B.Popov
Frank Laboratory of Neutron Physics, JINR, Dubna

1. The physical importance of the n,e-amplitude b_{ne} consists in the fact that it allows determination of the neutron mean square charge radius that is proportional to $(b_{ne} - a_F)$, where the Foldy term $a_F = -1.468$ mfm.

It is importent to note that, in spite of the many year investigation, the problem of b_{ne} estimation has not been solved. All known precise results fall into two groups: one near $-1.55(5)$ mfm [1-3] and the other near $-1.32(4)$ mfm in the range critical for sign assignment to the neutron mean square charge radius .

So, the obtained in [2] value of b_{ne} differs from the estimates of refs [4,5] by nearly 10 errors and, as we have shown [6], this is connected with different mathematical descriptions of the measured effects. But the difference between the values $-1.49(5)$ [1], $-1.55(2)$ [3] and $-1.31(4)$ [4,5] has not found any explanation up to now. And so, estimates of b_{ne} from [5] depend on the reliability and precision of the rich set of coherent amplitude b_{coh} values (for Bi) obtained in different years on the gravitational spectrometer and (in the last time) on the interferometer and lie essentially beyond error limits. These b_{coh} lead to the values of b_{ne} from -1.32(3) to -1.43(3).

Such uncertainty evokes the necessity of analysis of the measurement and data processing methods. Here one more approach to n,e-amplitude estimation is proposed. The nuclear scattering cross section $\sigma_s(0) = 4\pi R'^2(0)$ is calculated by extrapolation of known scattering cross sections from the energy region of tens or hundreds eV to $E \Rightarrow 0$. The values of b_{ne} are obtained from a comparison of $\sigma_s(0)$ and $4\pi b_{coh}$ with $b_{coh} = R'(0) + b_{ne}Z$. The authors discuss also the discrepancy between the existing b_{ne} estimates and conclude that it is yet impossible to reliably determine the neutron mean square charge radius. The obtained "nonmodel" estimates of b_{ne} agree nicely with the results [5].

Method	Bi	Pb
$R'_0 = const$ [5]	-1.30 ± 0.06	-1.32 ± 0.04
$R'_0 = const$ [6]	-1.30 ± 0.04	-1.32 ± 0.03
Extrapolation $\sigma_s \Rightarrow 0$	-1.33 ± 0.03	-1.32 ± 0.03

2. A reliable estimate of the neutron polarizability (α_n) depends on the accuracy of theoretical description of the neutron- nucleus interaction and the choice of corrections to be made in data processing. The experimental data relative precision must be of about 10^{-4} and higher.

In refs.[7,8] the α_n value was estimated with the statistical error $\Delta\alpha_n$ of about 3 and 5 for Bi and Pb, respectively. Schmiedmayer and colleagues [10] reported on the new value for $\alpha_n = 1.20 \pm 0.15 \pm 0.20$ that was obtained just by formal extraction of a proportional to k term (responsible for polarizability scattering contribution) from the energy dependence of σ_s expansion into a power series of the wave number k.

To pursue the aim of the reliable estimation of α_n one has to critically examine the analysis method and the different factors that affect the accuracy of calculated α_n values. The difficalty of the neutron polarizability coeffitient determination is connected with the smallness of its contribution into σ_s. So for $\alpha_n = 1$ (in 10^{-3} fm^3 , by analogy with measured proton polarizability) this contribution makes from 10^{-3} to 10^{-2} .

Our analysis of the two methods of α_n estimation and the description we made of σ_s by using the nuclear physical parameters have shown that the exactness of α_n estimate depends on variations of the resonance corrections which are of about the same order of $10^{-3} - 10^{-2}$. By using the neutron scattering cross section data for Bi, Pb and ^{208}Pb from refs [7,10] we investigated stability of the neutron polarizability α_n estimate to different corrections and data processing methods .

The α_n reestimated values [9,6] from data for Bi, Pb [7,8] and ^{208}Pb [10] turn out to be sensitive to account of resonance contribution uncertaincy and to accepted values of nuclear s- and p- scattering radii. That is why we conclude that to the existing α_n estimates (from Bi and Pb cross sections) not the statistical errors must be attributed, but some 5-10 times higher uncertainties. It is shown that the result [10] should be interpreted as $\alpha_n \leq 2$.

References

1.Melkonian, E., et.al.: Phys. Rev. 1959,**114**,p.1471.
2.Alexandrov, Y., et.al.: Sov. J. Nucl. Phys., 1986,**44**,p.900.
3.Alexandrov, Yu., et.al.: Yadernaya Fisika, 1974,**20**, p.1190.
4.Krohn, V., Ringo, G.:Phys.Rev., 1973,**D8**, p.1305.
5.Koester, L., et.al.: Z. Phys. A , 1988,**329**, p.229
6.Nikolenko, V., Popov, A.: Z. Phys. A - Hadrons and Nuclei,1992,**341**,p.365
7.Koester L. et.al.: Physica, **329**,229(1988)
8.Alexandrov Yu. et. al.: Sov.J.Nucl.Phys., **44**,900(1986)
9.Nikolenko V.,Popov A.:JINR, R3-90-568, Dubna, (1990)
10.Schmiedmayer J. et. al.: Phys.Rev.Lett.,**66**,1015(1991)

Properties of ρ- and ω-mesons in dense and hot nuclear matter near the critical pion mode softening

G.G. Bunatian[1], B. Kämpfer[2]

Forschungszentrum Rossendorf e.V., Inst. für Kern- und Hadronenphysik
O-8051 Dresden, PF 19, Germany

Abtract:

The propagators of ρ- and ω-mesons in nuclear matter are analyzed. Due to the strong coupling to pions in $\rho\pi\pi$, $\omega\pi\pi\pi$, $\rho\rho\pi\pi$ etc. vertices, the ρ,ω-meson properties depend sensitively on the behaviour of the pionic mode. Relying on previous investigations of the pion propagator in nuclear matter, we elucidate the main features of the ρ- and ω-meson behaviour in dense and hot nuclear matter in the asymptotic case near the critical pion mode softening. We find that under such conditions the ρ-meson mode becomes stiffer, while the ω-meson mode softens. The widths of both the ρ,ω-mesons increase significantly and become essentially greater than the ones of free mesons.

[1]permanent address: JINR Dubna, Lab. Neutron Physics, Head Post Office, P.O.B. 79, 101000 Moscow, Russia

[2]also: Inst. Theor. Phys. (KAI e.V.), Tech. Univ. Dresden, Mommsenstr. 13, O-8027 Dresden, Germany

Quasi-particle description of a strongly interacting pion gas

G.G. Bunatian[1], B. Kämpfer[2]

Forschungszentrum Rossendorf e.V., Inst. für Kern- und Hadronenphysik
O-8051 Dresden, PF 19, Germany

Abtract:

The pions system at nonzero temperature T, $m_\pi \sim T \ll m_{\rho,\sigma}, M_N$, is studied, the pion-pion interaction being described by underlying Weinberg Lagrangian. In the framework of Hartree approximation, the pion self-energy part and propagator are obtained. The modification of the pion spectrum proves consisting in the replacement of the free pion mass m_π by the effective one $\tilde{m}_\pi(T)$, depending on temperature and increasing with the temperature growth. The calculated thermodynamical quantities (the density of pion excitations, energy, entropy and pressure) of considering system come out to be smaller than ones of the free pions system.

[1]permanent address: JINR Dubna, Lab. Neutron Physics, Head Post Office, P.O.B. 79, 101000 Moscow, Russia

[2]also: Inst. Theor. Phys. (KAI e.V.), Tech. Univ. Dresden, Mommsenstr. 13, O-8027 Dresden, Germany

Quantum Phenomena at Fast Modulation of a Neutron Wave

D.V.Amandzolova, A.I.Frank, V.G.Nosov †

†Institute of General and Nuclear Physics RRC "Kurchatov Institute", Moscow

In a number of papers quantum phenomena are considered that are related to a fast periodic influence exerted on a neutron beam. Periodical chopping of neutron beam is the simplest case. The following wave function is found in [1],[2] for a periodic chopper:

$$\psi(x,t) = \frac{1}{2}e^{i(kx-\omega t)} + \frac{i}{\pi}\sum_{s=-\infty}^{\infty}\frac{e^{i(k_s x-\omega_s t)}}{2s-1}, \qquad \Omega = 2\pi/T, \tag{1}$$

where $\omega_s = \omega + \Omega(2s-1), k_s = k\left[1+(2s-1)\gamma\right]^{1/2}, \gamma = \Omega/\omega \ll 1$. Thus, the state in the semi-space to the right represents a non-stationary superposition of waves, each of which has an energy $\hbar\omega_n$ and a corresponding wave number k_n.

To obtain a state with a discrete energy spectrum it is not necessary to chop the neutron beam simultaneously over the whole of its cross section. Periodic chopping at each point of the beam cross section, even changing the moment of chopping from point to point, will do the job quite well. In this way we come to the problem of the motion of a periodic structure, a grating, across a beam [2],[3].

The wave function of the difracted neutron in the laboratory reference system is found by subsequent application of the Galilean transformation to the neutron wave function in a moving reference system connected with the grating. In the limit, when the grating has a high velocity and its period, one readily arrives at the formula (1), given above. In the same way was a solution found, also, for the phase grating.

It has been shown in [5],[4] that the problem can be solved without invoking the precise solution of the Schrödinger equation with the corresponding time-dependent potential. If the action of some device located at $x = 0$ being a periodic variation of the amplitude or phase of the initial plane wave then as was obtained for $x > 0$:

$$\psi(x,t) = \sum_{n=-\infty}^{\infty} C_n e^{i(k_n x-\omega_n t)} \qquad \omega_n = \omega + n\Omega, \qquad k_n = k(1+n\gamma)^{1/2} \tag{2}$$

where C_n are the Fourier coefficients of the modulation function $f(t)$.

It was found in [2],[4] that the transmitted wave exhibits a structure characteristic of space beats with a large-scale period of $L = (vT)^2/\pi\lambda$.

In the case of phase modulation it is possible to reconstruct the initial monoenergetic state with the aid of a second modulator. Here modulators act like a coherent splitter and combiner of neutron waves. The possibility is considered of creating a neutron interferometer with beams coinciding in space and based on this idea.

The above arguments make it easy to obtain a solution of the problem for neutrons reflected from an oscillating (magnetic, for example) potential barrier. In the stationary case, the amplitude r of the wave reflected from a potential U is given by the usual solution of the stationary Schrödinger equation. In the case of a time-dependent potential the amplitude $r(t)$ is also readily found by formal substitution of the quantity $U(t)$ into the corresponding expression for the amplitude. The state characterizing the reflected wave is a superposition of coherent waves, the amplitudes of which are the Fourier coefficients of the function $r(t)$. Consequently, reflected waves corresponding to various satellites will exhibit different reflection angles and energies. The picture that arises can be illustrated by Fig.1.

Figure 1: Quantum reflection

It was estimated, that angular distribution of reflected waves may be quite within the range of resolutions exhibited by ordinary reflectormeters.

A number of experiments is proposed and now in a preparation for testing the theory.

References

[1] V.G.Nosov, A.I.Frank. VI Int. School in Neutron Phys. (Alushta, 1990), **1**, 313.

[2] A.I.Frank,V.G.Nosov. *Quasi-energy of Ultracold Neutrons* JINR, E4-92-457.

[3] A.I.Frank and V.G.Nosov. Phys.Lett. A (1994) (in print)

[4] A.I.Frank and V.G.Nosov. Yadernaya Fizika (1994) (in print). (1994).

[5] A.I.Frank, V.G.Nosov *Quasi-Energy of Cold Neutrons and Neutron Time Interferometry.* To be published in: F.De Martini, A.Zeilinger (Eds.) **Quantum Interferometry,** World Scientific, Singapore, 1993.

[6] A.I.Frank, D.B.Amandzolova. *Neutron Quantum Refraction,* JINR E3-93-418.

INTERACTION OF WAVES AND PARTICLES WITH LAYERED MEDIA
(all media can be considered to be layered)

V.K.Ignatovich
Joint Institute for Nuclear Research, Dubna, Russia

The results presented here are related to two topics: 1)interaction of particles with a periodic potential and 2)a model of the ball lightning.

Periodic potential

Usually to solve one-dimensional Shrödinger equation with an arbitrary potential u means to find the reflection and transmission amplitudes. It is shown in [1, 2], that the physical problem is not changed if the potential is split by an infinitesimal gap in two parts at any point. But the reflection R_{12} and transmission T_{12} amplitudes of the whole potential are now represented through the amplitudes of its parts:

$$R_{12} = R_1 + \frac{T_1^2 R_2}{1 - R_1 R_2}, \qquad T_{12} = \frac{T_1 T_2}{1 - R_1 R_2} \tag{1}$$

The equations (1) are very useful when we consider semi infinite periodic potential. Here we can cut off one period from remaining part (fig.1),

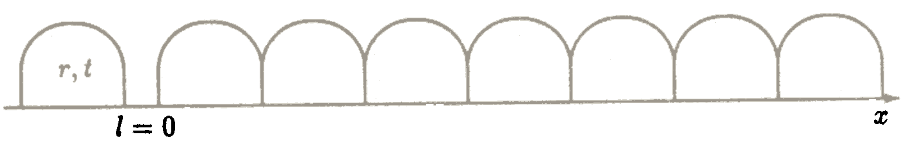


fig.1

and if the reflection, r, and transmission, t, of a single period are known, then the reflection R_∞ of the whole potential is represented by the solution of the algebraic equation:

$$R_\infty = r + tR_\infty(1 - rR_\infty)^{-1}t. \tag{2}$$

For a scalar wave propagation the solution of (2) is

$$R_\infty = \frac{\sqrt{(1+r)^2 - t^2} - \sqrt{(1-r)^2 - t^2}}{\sqrt{(1+r)^2 - t^2} + \sqrt{(1-r)^2 - t^2}}, \tag{3}$$

which contains all the features related to the Bragg structure of the reflection spectrum.

It is not difficult to obtain also the Bloch phase factor

$$\exp(iql) = \frac{\sqrt{(1+t)^2 - r^2} - \sqrt{(1-t)^2 - r^2}}{\sqrt{(1+t)^2 - r^2} + \sqrt{(1-t)^2 - r^2}},$$

where l is the length of the period and q is the Bloch wave number.

To get the reflection and transmission amplitudes for a periodic potential with a finite number of periods it is necessary to note that the potential with a period l is periodic also with the period $L = nl$. The result is

$$T_n = \frac{(1 - R_\infty^2)\exp(iqL)}{1 - R_\infty \exp(iqL) R_\infty \exp(iqL)}, \quad R_n = \frac{R_\infty - \exp(iqL) R_\infty \exp(iqL)}{1 - R_\infty \exp(iqL) R_\infty \exp(iqL)} \tag{4}$$

The equation (1) is applicable also to vector fields of any dimension. This gives a way for generalization to 3-dimensional space. In particular, it is possible to get a new method for the dynamical diffraction of waves on three-dimensional single crystals [1].

The same approach is applicable to any linear equation of mathematical physics of second order (see, for example, [3, 4]).

The ball lightning

The model for ball lightning was constructed during consideration of ultracold neutrons interaction with matter. This interaction is described by the potential $u_0 = 4\pi N_0 b$, where N_0 is atomic density and $b > 0$ is coherent scattering amplitude. If $b < 0$ the potential is attractive. So the substance is represented by a potential well, where bound levels for neutrons are possible.

It is important to notice that not only the well holds the particle, but the particle also holds the well, i.e. it compresses the substance as is illustrated in fig. 2.

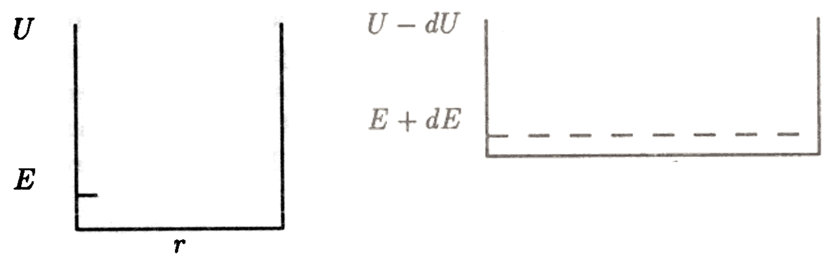


fig.2

The compression force can be very important in neutron stars. But the most interesting is to consider an analogy with γ-quanta. They are Bose particles, can be accumulated on a single level in any number and their compression force can be arbitrary high.

This leads to a model of the ball lightning [5]. It can be visualizer as a shock wave of a point explosion in an excited gas with a laser discharge at its front. The discharge photons with their electrostrictive force may stop the shock wave. So the ball lightning is a frozen spherical thin skin filled with a great number of photons.

References

[1] V.K.Ignatovich. Multiwave Algebraic Darwin Method In Dynamic Theory Of Diffraction. Kristallografiya 37(5):1100-1112, 1992. (see Sov. Phys. Crystallography)

[2] V.K.Ignatovich. An Algebraic approach to the propagation of waves and particles in layered media. Physica B 175(1-3):33-38, 1992.

[3] V.K.Ignatovich. Propagation of Acoustic Waves in Layered Elastic Media. Acoustic Journal 38(1):70-78, 1992. (see Sov. Physics Acoustics-USSR 38(1):34-39, 1992.)

[4] V.V.Golikov, V.K.Ignatovich, E.N.Kulagin. Measurement of the loss coefficient of UCN in Beryllium powder. Yad.Fiz 55(3):608-616, 1992. (see Sov. J. Nucl. Phys.-USSR 55(3):337-341, 1992.)

[5] V.K.Ignatovich. The Ball Lightning. Laser Physics v. 2, n. 6, p. 991-6, 1992.

PROMISING AND CRUCIAL EXAMPLES OF CLUSTER RADIOACTIVITY PROCESSES

S.G.Kadmensky
Voronezh State University, Russia
W.I.Furman
Frank Laboratory of Neutron Physics, JINR, Dubna
Yu.M.Tchuvil'sky
Moscow State University

The general problems of the cluster radioactivity study: an adiabatic or nonadiabatic character of the process, its connection with fission and α-decay, even-odd effects, the fine structure, heavy and light cluster mass limits etc., are discussed. Special attention is paid to the experiments, that might help finding an optimal theoretical approach to the description of the above characteristics of the process. The wide-scale search for the new examples of such experiments was carried out using our theoretical scheme[1]. Not many cases of cluster decay in the traditional $A > 208$ parent nucleus mass region are the prospective objects of a crucial experiment. Most of them are presented in the table.

No.	Decay	$log(T^{theor}_{1/2x}(sec)$	$-log(\Gamma_x/\Gamma_\alpha$	Note
	$^{220}Ra \rightarrow ^{12}C$	11.1	≥ 12.7	$T_{1/2\alpha} \geq 1sec$
2	$^{221}Ra \rightarrow ^{13}C$	14.7	13.2	short-lived*(sl)*
3	$^{221}Fr \rightarrow ^{14}C$	16.2	13.7	sl
4	$^{223}Ac \rightarrow ^{14}C$	14.3	12.2	sl
5	$^{224}Ac \rightarrow ^{14}C$	17.4	12.4	$\frac{\Gamma_{\beta(\epsilon)}}{\Gamma_\alpha} \approx 10.2sl$
6	$^{224}Th \rightarrow ^{14}C$	12.8	12.8	$T_{1/2x} \approx 1sec$
7	$^{226}Th \rightarrow ^{14}C$	17.5	14.2	
8	$^{226}Th \rightarrow ^{18}O$	18.5	15.2	
9	$^{230}U \rightarrow ^{22}Ne$	19.6	13.3	
10	$^{232}Th \rightarrow ^{26}Ne$	30.1	12.5	long-lived *(ll)*
11	$^{235}U \rightarrow ^{25}Ne$	30.1	13.8	1. and other clusters 2.*ll*
12	$^{236}U \rightarrow ^{30}Mg$	29.1	14.4	*ll*
13	$^{237}Np \rightarrow ^{30}Mg$	29.3	15.5	*ll*
14	$^{234}Pu \rightarrow ^{26}Mg$	21.1	15.4	$\frac{\Gamma_{\beta(\epsilon)}}{\Gamma_\alpha} \approx 17$
15	$^{236}Np \rightarrow ^{28}Mg$	28.7	14.7	*ll*
16	$^{240}Cm \rightarrow ^{32}Si$	21.3	14.9	

Even the listed above cases are difficult to be measured. To achieve the goal it is necessary to measure the cluster decay of a short - (No. 2-5), a very short - (No. 1,6), and a long-lived (No. 10-13) isotope. Sometimes (No. 5,15), the β-decay influence is strong. In some cases it is difficult to have the parent nucleus obtained. Thus one may hope to have data measured for a few cases only. The most interesting of them are Nos. 1, 2, 8, 9-14 — where the new clusters are emitted, including the lightest (1, 2) and the heaviest (16) ones, as well as (5, 15), the cases of the decay of odd-odd nuclei.

In spite of the difficulty of performing measurements with other parent nuclei some of them are worth the effort of experimentalists. Even obtaining of the upper limit of the branching ratio for the emission of a very light cluster $^{8}Be(-log(\Gamma_x^{theor}/\Gamma_\alpha) = 14.3)$ from ^{218}Ra, or a very heavy cluster ^{34}Si from $^{240}Pu(17.6),^{241}Am(19.2),^{242}Cm(18.7)$ and a superheavy cluster ^{48}Ca from ^{249}Cf ($\sim$ 30 in accordance with our estimations) will give some indications of the cluster mass dependence of the branching ratios and will be an additional test of the known theoretical approaches.

Due to the difficulty of real measurements in the discussed mass area, it is useful to look for new regions of cluster radioactivity. The one, first indicated in [2], was confirmed by our approach. This region includes the processes with the daughter nuclei, close to ^{100}Sn, and relatively light clusters $^{12}C,^{16}O$, etc. The folding procedure of the cluster-nucleus potential evaluation was used. The initial potential was the same as we used for the $A > 208$ region [1].

The obtained results are strongly different from those for the $A > 208$ region. For example, in the case of the $^{114}Ba \rightarrow ^{12}C + ^{102}Sn$ decay the branching ratio is $log(\Gamma_x/\Gamma_\alpha) = -0.4$. The half-life of the ^{12}C-decay, $T_{1/2x} = 6 \times 10^3$ sec, and the ratio, $(\Gamma_x/\Gamma_{tot}) \approx 10^{-4}$, make this decay observable. The characteristics of another example, $^{118}Ce \rightarrow ^{16}O + ^{102}Sn, log(\Gamma_x/\Gamma_\alpha) = +3.7, T_{1/2x} = 8.8 \times 10^2, (\Gamma_x/\Gamma_{tot}) \approx 10^{-3} \div 10^{-4}$, are as good as previous ones. Other variants of cluster decay in this region do not have such good characteristics but may be preferred as giving the possibility of obtaining the parent nucleus.

It is interesting to note that other theoretical approaches [3,4] give the width values for the emission of the ^{12}C and ^{16}O clusters many (respectively $4 \div 8$ and $8 \div 12$) orders of magnitude lower than our calculation does. So, further experiments should be performed to test different theoretical approaches.

References

1. Zamyatnin Yu.S. et al. Sov. J. Part. Nucl., 1990, v.21(2), p.537.

2. Price P.B. Nucl.Phys., 1989, v.A502, p.41.

3. Poenaru D.N. et al. Atomic Data and Nucl. Data Tables, 1986, v.34, p.423.

4. Blendowske R. and Walliser H. Phys. Rev.Lett., 1988, v.61, p.1930.