

International Workshop
on
Dynamical Aspects of Nuclear Fission
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Programme & Abstracts



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PRELIMINARY PROGRAMME

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THURSDAY V & VI SESSION	9 ³⁰ I. OHTSUKI BINARY FISSION CONFIG. IN LIGHT ACTINIDES H. NAKAHARA BINARY FISSION IS ESSENTIALLY TWO-MODE	C. YTHIER NEW POINTS OF VIEW ON THE SYMMETRIC FISSION OF ²³⁸ U M. ASGHAR LOW ENERGY FISSION DYNAMICS	M. ITRIS SHELL EFFECTS IN THE MASS AND ENERGY DISTR. OF FRAGMENTS FROM FISSION OF THE LEAD TO FERMIUM	A. RUBEN DISSIPATIVE ENERGY IN NUCL. FISSION - PHENOMEN. ANALYSIS	J.P. THEQBALD THE ²⁴¹ Am (2n, f) REACTION	W.I. FURMAN FISSION CHANNELS AND MODES IN (n, f) REACTIONS	
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Cold Deformed Fission

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By far the major contribution to the fragment kinetic energy observed in nuclear fission is due to the Coulomb repulsion between the nascent fragments at scission. Hence, large or small kinetic energy releases correspond to compact or deformed scission configurations, respectively. Compact scission configurations, with very large kinetic energies of the fragments, have been studied in the past for some thermal neutron induced and spontaneous fission reactions. For a rather broad range of fragment masses the high energy tail of the experimental kinetic energy distributions comes surprisingly close to the total available energy, i.e. the Q -value of the reaction. Since no excitation energy is left, the fragments have to be born in a cold state. The phenomenon has, therefore, become known as cold (compact) fission. A further signature for cold fission of even Z compound nuclei are pronounced odd-even effects in the nuclear charge yields of the fragments, with even Z fragments being favored in yield compared to odd Z fragments. Furthermore, closely linked to the charge odd-even effect, the fragment mass distributions exhibit a marked fine structure. It turns out that these by-effects of cold fission may be traced back to the systematics of the Q -value, viz. its dependence on the (A, Z) -fragmentation. Not unexpectedly, for the most compact scission configurations approaching the limits of allowable phase space, the fissioning compound should be sensitive to any structure in the available energy Q .

Recently mass and charge measurements of fission fragments have been pushed to the opposite extreme of very low kinetic energies for the thermal neutron reactions $^{232}\text{U}(n,f)$, $^{235}\text{U}(n,f)$ and $^{239}\text{Pu}(n,f)$. The experiments were performed on the Cosi fan tutte spectrometer of the Institut Laue-Langevin in Grenoble. Similar to the situation at high kinetic energies, it could be shown for the first time that also at very small fragment kinetic energies a strong odd-even effect in the charge yields turns up. This discovery is corroborated by the observation of fine structure in the mass yields. It is noteworthy that upon moving from high to low energies the peak positions of mass fine structure are shifted in accordance with what is known on neutron emission from the fragments as a function of their mass and energy. Large neutron emission number at low fragment kinetic energies, surprisingly, do not spoil the fine structure. This points to small variances in the number of emitted neutrons in spite of large average numbers.

The characteristics of both the charge and mass distributions demonstrate that, besides for cold compact fission at high kinetic energies, also for deformed scission configurations with low kinetic energies the fission fragments at the scission point appear to be cold. In contrast to cold compact fission the phenomenon may be called cold deformed fission. Discussing cold deformed fission in terms of a scission point model, the total energy available at the scission point has in this limit to be entirely tied up as potential Coulomb and, in addition, deformation energy. This feature could explain why the fissioning system becomes again sensitive to the structure in the Q -systematics.

COLD FRAGMENTATION PROPERTIES

A CRUCIAL TEST FOR THE DYNAMICS OF FISSION

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Summary

Very often in the literature the descent from saddle to scission in the low energy fission of even-even actinides is given as an example of a process in which a large scale collective rearrangement of nuclear matter is realized without (or with a very low) dissipation of the collective kinetic energy into quasi-particle excitation. As a matter of fact, a systematic and strong odd-even effect in fragment charge distributions as well as fine structures in mass distributions have been interpreted as a evidence that the system breaks up preferentially into two even-even nuclei. In other words the initial superfluidity of these fissioning systems known to be completely paired at the saddle-point should be, to a large extent, preserved up to scission.

In order to get an experimental confirmation of this interpretation, we have measured the yields of individual primary fragments in the "cold fragmentation region" (namely the region of high kinetic energy fission events giving birth to fragments so weakly excited that neither can emit any prompt neutrons so that the primary masses are directly observed). We have used the traditional set-up of two Frisch gridded ionisation chambers placed on both sides of an exceedingly thin target. In the cold region, a perfect identification of each individual fragmentation was obtained.

The data show quite similar characteristics for the four studied systems: thermal neutron induced fission of ^{233}U , ^{235}U , ^{239}Pu and spontaneous fission of ^{252}Cf :

- All the energetically allowed fragmentations into two even-even, even-odd, odd-even, odd-odd nuclei are in competition up to the highest TKE values; there is no preference for fragmentations into even-even nuclei excepted the trivial selection imposed by the Q-values; even more, the coldest fragmentations (the TKE_{max} 's approaching the Q-values) correspond systematically to odd-odd fragmentations.

- The odd-even effect in the charge distributions reaches its maximum value in the cold region but it is not at all connected to any preponderance of fragmentations into two even-even nuclei. It only results from the summation on the isotopic mass distributions which systematically are observed to be much larger for the even-Z ones than for the odd-Z ones.

- This difference between even-Z and odd-Z mass distributions is quite well explained from the systematics of the Q-values; it tends progressively to decrease when the available energy ($Q - \text{TKE}$) increases. Thus, the amplitude of the odd-even effect appears to be closely related to the smallness of the available energy at scission.

Starting from the experimental observation of a very high probability of nucleon pair breaking, even in the coldest fragmentations, arguments are presented in favour of a strong dissipation of the collective energy of the fission mode into quasi-particle excitations.

LOW ENERGY FISSION DYNAMICS

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The fission dynamics is expected to show up in the region between the last saddle point and the scission point and in the rupture of the fissioning nucleus into binary fragments. The simplest way to look at this dynamics is to know as to what happens to the collective energy freed in this region. One can calculate reasonably well the value of this energy which depends on the fissioning nucleus considered.

The fission observables define a probability surface $Y(M, Z, E)$. As a rule, the production probability of these observables should reflect the influence of this dynamics. However, it is difficult to unveil this influence save for the observables whose initial state, before the dynamics is turned on, can be defined. The nuclear charge yields, $Y(Z, E|M)$ and the quantities derived from them such as charge variance $\frac{\sigma^2}{Z}(Z|M)$ for even-even fissioning nuclei, are such parameters.

Over the years, we have done extensive, systematic and correlated measurements on all the fissioning systems from Th to Cf that could be obtained. These data for (n_{th}, f) and (s, f) rule out the possibility of qp-excitations at the saddle point for all these fissioning systems. The analysis shows that the fast rupture of a relatively thick neck at the exit point - the physical scission point, where the Raleigh instability sets in, is a major source of a qp-excitations. The source of energy for these qp-excitations is the collective energy pre-scission energy present in the fission degree of freedom. All the data including those coming from other sources will be considered together in an effort to have a coherent view of the problem.

Fine structure in fission fragments mass-energy distributions for thermal neutron fission of actinides.

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At the time-of-flight fission fragments MEFHI spectrometer (1) the mass-energy distributions were studied for the thermal neutron fission of ^{233}U , ^{235}U , $^{242\text{m}}\text{Am}$. The total statistics for each measurements was about 10^6 - 10^7 events. In the two-dimensional difference spectra for U targets obtained by subtracting the smoothed spectrum from the measured one, a fine structure in the form of linear ridges can be observed. First mentioned in(2). The additional measurements and performed analysis allow to suppose that the ridges are close to the $A_p(E_k)$ -lines, where A_p is the most probable mass of the isotope distribution for even charges and E_k is the light fragment kinetic energy. Assuming A_p not depending on E_k in the primary (before neutron emission) distributions one can estimate mean number of neutrons $\nu(Z, E_k)$, $\nu(A)$ for isotope distributions and fragments with the primary mass A. For mass region 95-100 amu ($Z=38-40$) a fair agreement in $\nu(A)$ values is observed. For odd-proton $^{242\text{m}}\text{Am}$ a better mass resolution is needed to resolve different ranges for all, but not only for even charges.

1.A.A.Alexandrov, et al. NIM 1991, in press.

2.A.A.Alexandrov, et al., Abstr.Int.Conf. "50 years of Nuclear Fission", Leningrad, 1989, p.127.

DYNAMICS OF THE FISSION-LIKE PROCESSES

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Gross properties of fission could be understood in terms of the shape dependence of the surface, electrostatic and rotational energies. Consequently an accurate knowledge of nuclear shape and its dependence on inertial, dissipation and viscosity parameters becomes essential for interpretation of fission phenomena.

According to the conventional TSM theory the effective moment of inertia of saddle point configuration may be deduced from TSM analysis of angular distribution of fission fragments. RLD model provides unified function for effective moment of inertia in the effective fissility parameter X space. Saddle point configurations at sufficiently high effective fissility may be approximated by spheroidal shapes. This feature is used here to derive the method to discriminate between the different types of fission-like processes comparing the semi-empirical unified function predictions for the effective moments of inertia with experimental values deduced from angular distributions of symmetric fragments as well as to derive the scaling factors for geometrical formulae and relationships that are relevant for description of the saddle point properties and fission decay and/or neutron emission time scale. Significant deviations of experimental results from standard RLD model predictions are observed previously. Semi-empirical method, based on further evolving of the basic hypothesis of TSM theory, is used here to include the angular momentum and nuclear dissipation effects. It is found that experimentally deduced variance of statistical distribution of projection K of total spin J along the symmetry axis of the fissioning nucleus does not reflect only the statistical features of transition state at saddle point configuration, but of all of the states through which the K distribution i.e. nuclear deformation evolves. Effective elongation of the fissioning nucleus may be represented in the form of the unified function for all reaction systems. Unified function enables to determine the eccentricity of spheroidal saddle point shapes and consequently: stiffness and hydrodynamic mass parameters, viscosity and dissipation coefficients and significant number of other parameters relevant in describing fission dynamics may be easily obtained through the application of appropriate formulae. Fission like events may be classified as: true fission, fast fission and quasi fission events according to their mean reaction spin values. The true fission events are found to lie inside an error of 5% about the unified function. The values of critical elongations for fast fission events lie below .95 of the predicted values while those for quasi fission and $X \geq 1$ events are larger than 1.05 of the predicted values for true fission events at the same relative angular momentum value. These features are used to discriminate between different types of fission like events, providing the information about the attained level of equilibration of composite reaction system.

NEW POINTS OF VIEW ON THE SYMMETRIC SPONTANEOUS FISSION OF ^{258}Fm

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An attempt is made to interpret the symmetric spontaneous fission of ^{258}Fm according to the general scheme developed by the authors in the case of asymmetric fission ¹. This attempt leads to observations suggesting that this kind of symmetric fission occurs for nuclei in which the initial formation of a cluster within the valence shells of the fissioning nucleus yields an energy higher than the threshold for formation of a pion, and that this mode of fission could be related to a phase change of nuclear matter.

1. G. Mouze and C. Ythier, Nuovo Cimento 103 A (1990) 617-624.

DO SHELL AND PAIRING EFFECTS INFLUENCE TERNARY FISSION ?

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Abstract :

The experimental data base for this paper is mainly formed by the results of a systematic study of the triton and alpha-emission in the thermal neutron induced ternary fission of the actinides. The isotopes discussed are : ^{233}U , ^{235}U , ^{239}Pu and ^{241}Pu (Phys. Rev. C33 (1986) 943), ^{231}Pa (Nucl. Phys. A285 (1977) 32), ^{237}Np (Nucl. Phys. A369 (1981) 1) and ^{229}Th , ^{241}Am and ^{243}Am (new results). This data base is completed by recent results on the alpha-emission in the ternary photofission of ^{230}Th , ^{232}Th , ^{233}U , ^{234}U , ^{235}U , ^{238}U , ^{237}Np and ^{242}Pu (M.Verboven, Ph.D.Thesis, Univ. of Gent, 1988) and by spontaneous fission results going from ^{240}Pu up to ^{257}Fm (mainly data from Wild et al., Phys. Rev. C32 (1985) 488).

A combination of all these results gives evidence for the presence of neutron shell effects in the ternary alpha yield. On the other hand, the proton number seems to determine the ternary triton emission.

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The Dynamical Model of Ternary Fission.

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The principal propositions and the consequences of the dynamic theory of the ternary fission of the heavy nuclei are presented. Assuming that light particles are formed as a result of two random neck ruptures the ternary fission probabilities and the light particle mass and charge distributions are calculated. The results of theoretical calculations are in good agreement with the experimental data. It is shown that the ternary fission probability is determined by the dynamic properties of the nucleus at the descent from saddle point and by the local properties of the nuclear matter in the neck near the scission point. The light particle mass and charge distributions are strongly governed by the nuclear exchange dynamics in the ternary nuclear system. The new model of the trajectory calculation which takes into account the nucleon exchange and also the nuclear and dissipative forces is discussed.

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Binary Fission in Light Actinides

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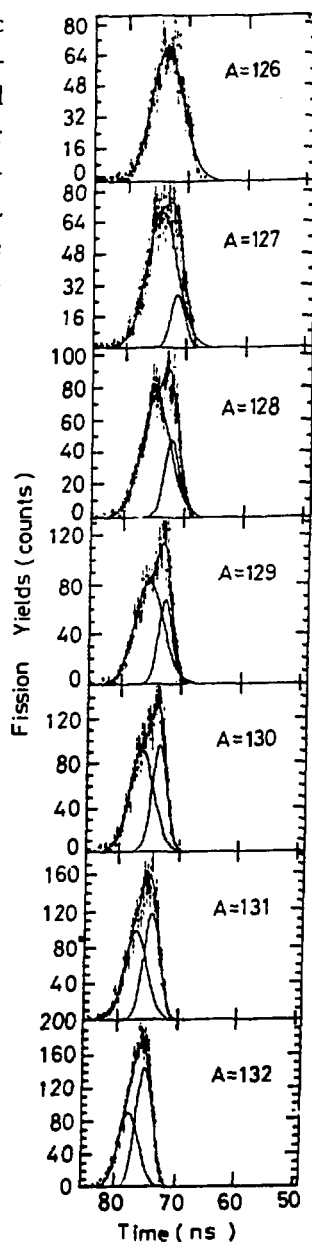
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The correlation between fragment mass and total kinetic energy has been studied for the proton-induced fission of actinides by means of a double-arm TOF spectrometer constructed at the JAERI tandem accelerator facility. The start detector was composed of a carbon foil (30 $\mu\text{g}/\text{cm}^2$ thick) and a micro-channel plate, and the stop signal was delivered by a large-area parallel-plate avalanche counter (PPAC). The flight paths were about 82.0 cm and 60.7 cm and the laboratory angles of detectors were at 45° and -133.5° with respect to the beam direction. The target of ^{232}Th evaporated onto a 10 $\mu\text{g}/\text{cm}^2$ carbon foil was bombarded with a 13 MeV proton beam. The calibration of fragment velocity was carried out using a ^{252}Cf source.

The primary mass (before neutron emission) of a fission fragment was obtained from the ratio of the velocities of the pair fragments with assumptions that no neutron was emitted from the compound nucleus prior to fission and that neutrons from the primary fragment were isotropically emitted and did not alter the initial fragment velocity. The time distributions of each of fragment masses are shown in the Fig.1. The binary structure is clearly seen for the fragment mass 128-130. The slower component and the faster one are equivalent to the lower total kinetic energy (TKE) component and higher one, and the former corresponds to an elongated shape associated with the symmetric mass division and the latter a compact associated with the asymmetric, respectively. In the spontaneous fission of the heavier actinide region, the existence of two TKE components has been reported by Hulet et al[1]. and interpreted as a mixture of liquid-drop-like deformed scission point configuration and fragment-shell-directed compact one. The present result indicates that similar scission point configurations exist in the fission of light actinide region.

[1] Hulet et al., Phys. Rev. Lett. 56 313(1986).

Fig.1 Time distributions in the fragment mass region $A=126 \sim 132$.



Proton odd-even effects in the photofission of ^{238}U with bremsstrahlung energies between 6.1 and 12 MeV.

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Proton and neutron odd-even effects in the yields of fission fragments have been studied extensively for the fission of several actinides. While most of the results were obtained for thermal neutron induced fission (Lohengrin, Coxi Fan Tutte), our experiments revealed for the first time strong odd-even effects in photon induced fission. Unlike with neutrons, working with bremsstrahlung easily allows an intensive beam at any energy desired. In particular the 14 MeV linac of the Ghent university provides a high electron current and hence a high bremsstrahlung intensity in an energy region of 4-14 MeV (e.g. 1mA at 7 MeV). This advantage is crucial for a thorough study of the odd-even effects as a function of the excitation energy.

Up to now, we obtained the results for the photofission of ^{238}U with six different bremsstrahlung endpoint energies, varying between 6.1 and 11 MeV. The odd-even effects were calculated based on the yields of fragments in the heavy mass group only; i.e. the difference between the normalized total yield of fragments with an even charge number Z and fragments with odd Z number for masses between 130 and 149. The needed independent yields of the fission products were measured by means of mass spectrometry on the β -decaying fission products.

In the table below, (preliminary) results on the proton odd-even effect in the photofission of ^{238}U are presented for 5 bremsstrahlung energies :

bremsstrahlung energy	average excitation energy	odd-even effect
6.12 MeV	5.66 MeV	29.3% $\pm 2\%$
6.44 MeV	5.84 MeV	28.9%
7.33 MeV	6.23 MeV	29.1%
8.35 MeV	6.68 MeV	30.0%
9.31 MeV	7.19 MeV	26.5%

Taking into account the excitation energy spectrum associated with each bremsstrahlung energy, these data seem to suggest a constant value of the odd-even effect (about 29%) for energies below 8.4 MeV (=about 2.7 MeV above the fission barrier), followed by a steep decrease towards 0%. These facts lead to the conclusion that the fission of ^{238}U is fairly adiabatic and that pair breaking seems to occur during the final stages of the fission process (i.e. the neck rupture) or at the (last) saddle point, when there is energy available to excite the paired nucleus above the pairing gap.

Comparing with other U-isotopes, the odd-even effect for ^{238}U seems to be rather high. But, when comparing with the results for Th, Pu and Cf, the value of 29% is very reasonable assuming an exponential behaviour of the odd-even effect as a function of the fissility parameter Z^2/A . The neutron odd-even effect is much smaller (about 3%) and doesn't show a significant systematic behaviour with changing excitation energy. Again the value of 3% is compatible with other results when plotted as a function of Z^2/A .

ODD-EVEN EFFECTS IN NEUTRON INDUCED FISSION OF ^{235}U AND
FISSION NEUTRON SPECTRUM

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In deducing an energy dissipated during the descent from second saddle of fission barrier to scission point proton odd-even effect δ_p is widely used. The origin of neutron odd-even effect δ_N is not yet settled. To clear up this question an inverse problem has been solved. The value of δ_N before a neutrons emission has been calculated from the experimental isotope yields $Y(A,Z)$.

The probability of neutron emission has been calculated in the framework of statistical approach with pre-equilibrium correction. The chain deexcitation of primary fragment was taken up to the emission of three neutrons. The γ -deexcitation of nuclei in the chain was taken in the account using Brink-Axel hypothesis.

The excitation energy of primary fission fragments has been generated by Monte-Carlo method.

The solution of system of coupled linear equations for the isotope yields $Y(A,Z)$ gives a possibility to calculate a primary neutron odd-even effect δ_N , i.e. the δ_N before the neutrons emission. The typical results are displayed in Figs. 1 and 2.

The value of this δ_N is approximately 34% which is comparable to the value of proton odd-even effect $\delta_p \sim 36\%$.

This result confirms that the origin of odd-even effect for neutrons and protons is similar.

The calculated pre-neutron isotope yields have been used as input data for the calculation of fission neutron spectrum. Remarkable large correction ($\sim 3\%$) has been obtained for neutrons emitted in the energy range (100-500) keV.

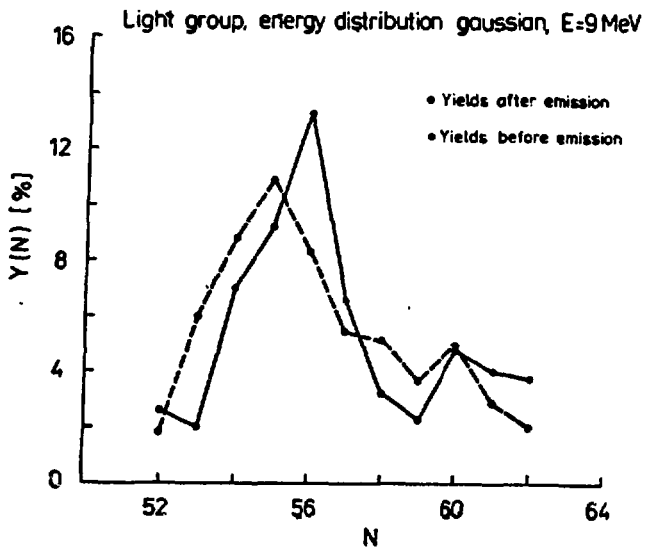


Fig. 1

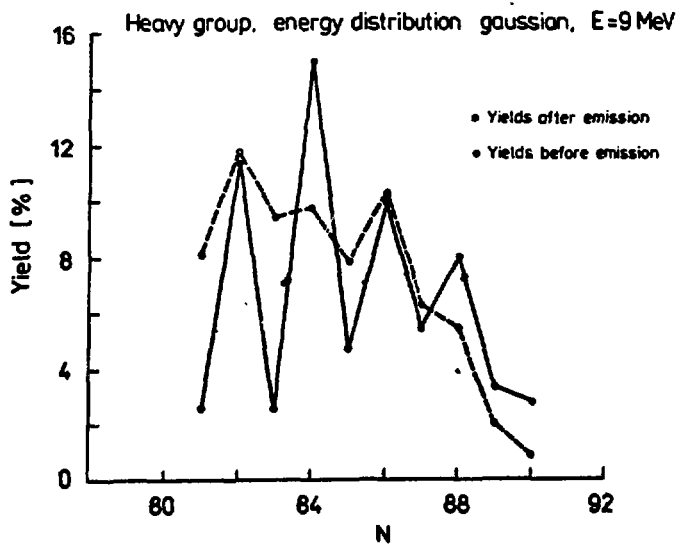


Fig. 2

First results concerning the proton odd-even effect for the photofission of ^{235}U as a function of the excitation energy.

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Mass and charge distributions have been measured for $^{235}\text{U}(\gamma, f)$ using bremsstrahlung with 6.5, 7 and 8.4 MeV endpoint energy. The independent yields of the fission products were measured by means of γ -spectrometry on the β^- -decaying fission products. We combined the results of two experimental methods: the catcherfoil technique and the direct γ -spectrometry using a rabbit system. In the catcherfoil technique, the fission fragments with sufficient kinetic energy escape from the ^{235}U -target and are trapped in nearby Al-foils. After irradiation, these foils are placed in front of a HPGe-detector and the yield of every product is determined from the relative intensity of its typical γ lines in a series of consecutively measured spectra. This method works well for products with half-lives $T_{1/2} > 3\text{min}$. Very unstable fragments have to be detected by direct γ -spectrometry of the target. In this method, the irradiated target sample together with the fission fragments are transported between the irradiation site and the detector by means of a rabbit system. Transportation time could be reduced to 1.5 s and one is able to obtain yields of fragments with $T_{1/2} > 1\text{s}$.

From the calculated yields we derive the proton odd-even effect as a function of the excitation energy. Together with the intensive work on $^{238}\text{U}(\gamma, f)$ done in our laboratory and the results already appeared in literature we hope to be able to prove the Z^2/A dependence of the proton odd-even effect for $\text{U}(\gamma, f)$. First results indicate an odd-even effect for ^{235}U somewhere between the figures for ^{232}U and ^{238}U and we intend to present the exact figures for at least one energy.

ISOMERIC YIELDS OF ^{130}Sb , ^{132}Sb , ^{134}I , AND ^{136}I
IN THE THERMAL NEUTRON FISSION OF ^{235}U

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Isomer yield ratios of ^{130}Sb , ^{132}Sb , ^{134}I and ^{136}I isomers formed in the thermal neutron fission of ^{235}U have been experimentally determined. The iodine and antimony fractions formed in fission were rapidly separated and the decay of γ -rays belonging to each isomer pair were followed using Ge(Li) detectors and a multi-channel analyser. The isomer ratios were calculated from growth and decay considerations of these γ -rays.

The results are compared with the recently published values obtained with an on-line isotope separator and with those from model calculations. Angular momenta of fission fragments corresponding to the measured isomer yields have also been calculated.

NEUTRON EMISSION IN THE FISSION OF HIGHLY EXCITED NUCLEI

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Recently intensive studies of neutron emission in the fission of excited nuclei have been carried out. The analysis of the angular and energy distributions of neutrons emitted at different angles with respect to fragments flight allows one to divide the neutron multiplicity into the prefission, ν_{pre} , and postfission, ν_{post} , components. So far the ν_{pre} and ν_{post} measurements were done mainly for compound nuclei with $A \leq 200$. At the same time, it is of interest to study neutron multiplicity for the excited transuranium nuclei produced in heavy ion-induced reactions. This is due to the fact that in these nuclei the descent from the saddle point to scission plays an essential role whereas neutron multiplicity studies enable one to obtain information on the time characteristics of this process and on the excitation energy of the system at scission.

In addition, there is a hope that the use of differential characteristics for fission neutrons will make it possible to discriminate between compound-nucleus fission with the time 10^{-19} - 10^{-20} s and the processes of fast fission or quasi-fission types, where the times range from 10^{-21} - 10^{-20} s. For this purpose systematic studies of ν_{pre} and ν_{post} are begun in the transuranium region.

The experiments on studying the neutrons member appearing at fission of the excited nuclei with the same values Z, A and E^* , but forming in different asymmetry of access duct are of essential interest.



From the analysis of these reactions one can obtain the additional information of what $\Delta \nu_{pre}$ fraction is bound with neutrons emission from the compound nucleus and what fraction is bound with the nucleus descent phase from saddle to decay point.

Measuring simultaneously ν_{pre} and the angular distribution of the fission fragment of separated mass the angle of rotation of system with a process time can be bound and the information about the dynamical reactions characteristics of fast fission is

NEUTRON AND GAMMA-RAY MULTIPLICITIES AS
A PROBE OF THE FISSION PROCESS

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ABSTRACT

The gamma-ray and the neutron multiplicities associated with fission have been studied in a variety of light and heavy ion induced reactions. The angular variation observed in the γ -ray multiplicities together with the angular distributions of the fragments yield information on the K-state populations and thus provide rather restrictive tests of the statistical theory of nuclear fission. In related experiments the neutron multiplicity distributions for several reactions have been investigated using a recently completed 4π neutron detector. Because of the strong correlation between neutron multiplicity and linear momentum transfer, it is possible to separate the contributions from complete and incomplete fusion reactions. Results obtained with low energy heavy ions provide additional constraints on models of fission angular distributions while measurements with medium energy projectiles yield new insights into the mechanism of the fusion process.

STATISTICAL ASPECTS OF EXCITED NUCLEI FISSION

Yu.A.Muzychka, B.I.Pustyl'nik

Recently, dynamical models have been widely used in the analysis of experimental data on the excited nuclei fission and this is natural since nuclear fission is a complex dynamical process during which the nuclei are undergoing maximum collective reconstructions in comparison with other nuclear processes.

At the same time, for subsequent development of dynamical approaches those effects that can not be explained by the traditional statistical model of nuclear fission are to be separated. In classical transition state model it is assumed that the main characteristics of the excited compound nuclei decay are mainly determined by the level densities in the compound state and the saddle configuration. The main model parameters were selected from the analysis of fission cross sections and evaporation residues' yields, and also from the fission fragments angular distributions.

It is supposed that no changes in process characteristics during the transition from saddle to scission occur in such model.

However, the last results of measurements of the mean number of prescission and postscission neutrons showed that the time of descent of heated nuclei from the saddle configuration to scission point is essentially longer than expected and the total fission time is estimated to be equal $\sim 10^{-20} - 10^{-19}$ s. This time depends weakly on Z^2/A . The initial excitation energy of the fissioning nucleus. The excitation energy of the heated nuclei in the scission point appeared to be practically constant, equal to $\sim 30 - 50$ MeV in a wide range of Z^2/A and initial excitation energies.

Thus, one can expect that with increasing Z^2/A and angular momentum and in the presence of high nuclear viscosity, the statistical equilibrium for the collective degree of freedom will be not only in the saddle but also in the scission point. In this case, a set of characteristics of fission process will be determined by nuclear parameters in the scission point, i.e. it will be necessary to use the statistical scission point model. The detailed analysis of available data on angular, mass and energy distributions of fission fragments of the excited compound nuclei formed in complete and incomplete fusion reactions of heavy ions with nuclei should be carried out within this model. Thereby, one

can clarify the role of the dynamical effects in the formation of mass and energy distributions of fission fragments or show that all these characteristics may be determined by nucleus thermodynamical properties in the scission point.

The dependence of the main critical parameters of the statistical fission model on the excitation energy, angular momentum and the influence of shell effect on decay characteristics of the compound nuclei should be also investigated.

EMISSION OF FRAGMENTS IN THE DECAY
OF EXCITED NUCLEI

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Recent experimental data suggest that a noticeable fraction of fragments with $Z > 2$ formed in nuclear reactions induced by high-energy heavy ions and protons is due to the decay of excited nuclei. In considering new possible mechanisms of fragment formation it is necessary to have a notion of what part of these fragments may be associated with the conventional statistical model of the decay of excited nuclei, which is usually used to describe nucleon emission or fission probability. In the statistical model two different approaches correspond to these extreme situations. The evaporation model is based on the principle of detailed equilibrium and the decay probability is related to the density of states in residual nuclei. At the same time, the fission proba-

bility is determined by the level density at the saddle point. In ref/1/ the fragment decay probability was described under the assumption of very asymmetric binary fission.

In our work /2/ the possibilities of evaporation of fragments with $Z > 2$ from excited nuclei were analysed on the basis of the Weisskopf's statistical theory. The calculations were done in the cascade evaporation model for the cross sections of forming fragments with $Z = 3-20$ in the decay of excited nuclei produced in the reactions $p(480 \text{ MeV}) + \text{Ag}, {}^3\text{He} + \text{nat Ag}, {}^{12}\text{C} + {}^{232}\text{Th}, {}^{52}\text{Cr} + {}^{181}\text{Ta}$ and ${}^{40}\text{Ar} + (\text{Ag}, \text{Sm}, \text{Au})$.

The final formula used to calculate the cross sections of fragment evaporation from the excited nucleus produced in heavy-ion reactions, taking into account several stages of the neutron evaporation cascade, can be presented in the following form:

$$\sigma_{\nu} = \sum_{l=0}^l \sigma_c^l \sum_{l=0}^m \frac{\Gamma_{\nu, l}^{(1)}}{\Gamma_{f, l}^{(1)} + \sum_{n, p} \Gamma_{n(p), l}^{(1)} + \sum_{\nu} \Gamma_{\nu, l}^{(1)}} \prod_{k=0}^{l-1} \frac{\Gamma_{n, l}^{(k)}}{\Gamma_{f, l}^{(k)} + \sum_{n, p} \Gamma_{n(p), l}^{(k)} + \sum_{\nu} \Gamma_{\nu, l}^{(k)}}$$

In the case of the reactions induced by high-energy protons the calculations were carried assuming two stages: a fast one after which, as a result of fast particle emission, heated nuclei remain with certain distributions on Z , A and excitation energy E^* , and a slow stage during which the decay of the compound nuclei formed takes place.

If the fragment may also have the excited states, the total available excitation $E^* = E - E_{\nu} - E_{\text{rot}}^l$ may be partitioned between the fragment and residue and we may write Γ_{ν} as

$$\Gamma_{\nu}^l(E^*) \approx (2l + 1)(2s_{\nu} + 1)\mu_{\nu} \int_0^{E^*} \sigma_{\nu}(\epsilon) d\epsilon \cdot \int_0^{E^* - \epsilon} \rho_2(E^* - E' - \epsilon) \rho_1(E' + 0) dE'$$

where ρ_1 and ρ_2 are the density of

final states for the fragment and residue, respectively, s_{ν}, E_{ν} and μ_{ν} are the spin, the binding energy and reduced mass of the ν particle, $\sigma_{\nu}(\epsilon)$ is the cross section of the inverse reaction of capture of particle ν with energy ϵ . As usual $\rho(E)$ was taken according to the Fermi gas model and the level density parameter phenomenologically takes shell effects into account.

The analysis of the available experimental data has shown that within the framework of our model qualitative agreement has been obtained for the cross sections of forming fragments. As an example the calculated charge and mass yields of the evaporated fragments from the reactions $p_3 + {}^{108}\text{Ag}$ (calculated $E^* = 135 \text{ MeV}$) and ${}^3\text{He} + {}^{108}\text{Ag}$ ($E = 139 \text{ MeV}$) are shown in Fig. 1 in comparison with the experimental data.

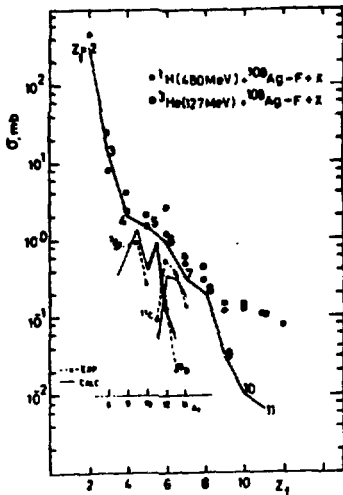


Fig. 1.

The same behaviour of the total cross sections of fragment formation in these two reactions and agreement between the calculation (solid lines) and experimental data (including those for the isotopic yields) indicate that the formation of fragments in the reactions $^3\text{He} + \text{Ag}$ and $p + \text{Ag}$ is governed by the common mechanism, namely the evaporation one.

The calculations have shown: a) that a substantial fraction ($\approx 30\%$) of the cross section is due to emission of fragments following the evaporation of several neutrons; b) that several isotopes make comparable contributions to the yield of fragments with a given Z value; c) that the results are most sensitive to the level density parameter (and therefore to the shell effects in the level density of the residues) and to the quantity r_0 that enters into the formula

for the Coulomb barrier of the interaction of clusters with the residual nucleus. At the same time the results depend on the collective effects due to the changes in the equilibrium deformation and in the angular momentum of the residual nucleus.

The experimental data have shown that substantial difference between the forms of the fragment's distributions in reactions induced by the lightest ions (^3He , ^{12}C) and by heavy-

er ones (with $A \geq 40$) exist. Fig. 2 compares the yields of the fragments with $Z=3-16$ in the reactions $^{12}\text{C} + ^{232}\text{Th}$ and $^{52}\text{Cr} + ^{181}\text{Ta}$.

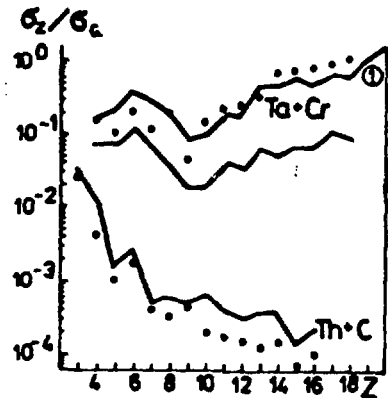


Fig. 2.

The dots show the experimental data /3/. The full lines represent the results of calculations /4/. One can see, that satisfactory agreement has been obtained, but there is a qualitative difference in fitting to the experimental results for these two reactions. In the case of the reaction with carbon ions one must choose the r_0 value to be equal 1.23 fm, whereas for the ^{52}Cr -ion induced reaction $r_0 = 1.3$ fm (the line 1 in Fig. 2). This difference can be explained assuming that in the latter reaction the deformation of residual nuclei increases, or only 10-20% of the equilibrium fragment yield is due to compound nucleus decay, the rest being formed as a result of the deep inelastic interaction of the nuclei.

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Influence Of Angular Momentum On Fission Fragments Mass And Energetic Distributions

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The influence of the angular momentum on mass and energetic distributions of excited compound nuclei with $Z=84$ and 104 , obtained in reactions with heavy ions at different incident energies and different projectile-target combinations have been investigated.

On the basis of experimental data the energetic balance of the investigated reactions are obtained. The systematics of the mass and energetic distributions in dependence of the excitation energy and angular momentum of the compound nucleus have been constructed.

ISOMERIC YIELD RATIO OF ^{134}I IN THE PHOTOFISSION OF ^{232}Th AND ^{238}U

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The isomeric yield ratios for ^{134}I , for the photofission of ^{232}Th and ^{238}U with 25-MeV bremsstrahlung has been determined using radio chemical techniques and gamma spectrometry. From the measured isomeric yield ratios, the corresponding root-mean-square values of the primary angular momenta (J_{rms}) were calculated using a statistical model analysis for the deexcitation of the fission fragments as discussed by Huizenga and Vandenbosch[1].

The values of isomer yield ($Y^m/(Y^m+Y^s)$), angular momentum (J_{rms}) and neutron number of complementary fragment (N_c) are given in the Table.

Fissioning nuclide	$\frac{Y^m}{(Y^m + Y^s)}$	J_{rms} [h]	N_c	References
$^{232}\text{Th}(\gamma, f)$	0.57 ± 0.06	10.3 ± 0.8	60	Pres.work
$^{235}\text{U}(\gamma, f)$	0.53 ± 0.03	9.4 ± 0.6	61	[2]
$^{238}\text{U}(\gamma, f)$	0.52 ± 0.06	8.8 ± 0.6	65	Pres.work

The odd-Z fragment (e.g. ^{135}I) have higher angular momenta than neighbouring even-Z ones (like $^{131,133}\text{Te}$ [2]). The odd-even fluctuation is quite significant.

The table shows J_{rms} for ^{134}I in all three fissioning nuclides as a function of the probable neutron number (N_c) of the complementary fragments. In the calculation it is assumed that the excitation energies in these nuclides are comparable and that the number of prompt neutrons emitted at mass ≈ 134 in all cases is ≈ 1 . It is seen that the fragment angular momenta gradually decrease as N_c approaches the 66 neutron deformed shell configuration. Therefore, the fragment complementary to ^{135}I becomes increasingly deformed in passing from ^{232}Th to ^{238}U .

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ON THE NATURE OF THE 721.6 eV RESONANCE OF THE ^{238}U

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ABSTRACT. The results of a recent capture γ -ray spectra measurements for resonances of ^{238}U are presented. The most interesting are those at 721.6 eV and 1211.4 eV. It was concluded from the analysis of fission and capture cross section measurements that these resonances are predominantly class II levels by nature. Because the secondary well in ^{239}U is ~ 2 MeV shallower than the primary well, the γ -ray spectrum for resonances of this type must be much softer than that of the ordinary class I resonances. To date, the experimental situation is contradictory: Browne observed a much softer γ -ray spectrum for 721.6 eV resonance, whereas Weigmann at el. observed no difference.

Our experiment was performed after the manner of Weigmann utilizing the TOF-facility GNEIS at Gatchina. It was found that the ratio of resonance area for upper γ -ray bias B2 and low bias B1 has different dependence on the value of B2 for resonances in question. The experimental ratios for 721.6 eV are in agreement with assumption that this resonance is essentially class II state, whereas 1211.4 eV one is pure class I state. It means that the relations between fission barrier parameters E_a and E_b are different for 721.6 eV and 1211.4 eV. Consequently, it could manifest the existence of the different fission modes for neighboring sub-barrier clusters.

CURRENT AND DENSITY ALGEBRA APPROACH TO LOW-ENERGY
HEAVY ION COLLISIONS

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A many-fermion system with the general-type Hamiltonian, expressed in terms of the current and density operators, is considered. On its basis the Hamiltonian expressed via collective and intrinsic variables is found. The problem is solved in a partly self-consistent way, describing the average density of the dinuclear system phenomenologically but determining all other quantities microscopically.

The formalism developed can be applied as to heavy-ion collision as to fission.

PROMPT GAMMA-RAY EMISSION FROM FISSION OF ^{239}Pu
BY RESONANCE NEUTRONS

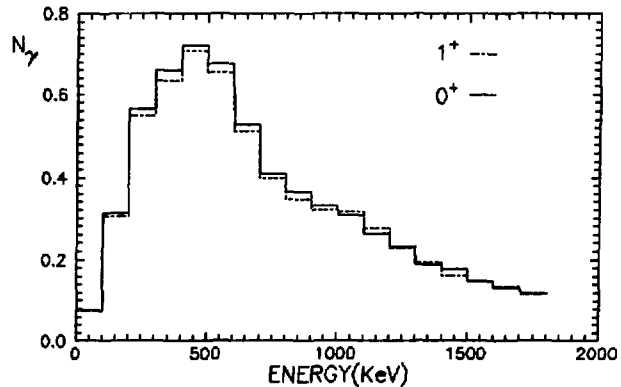
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The spectrometry of the prompt gamma rays from the fission of ^{239}Pu by resonance neutrons has been carried out on the IBR-30 pulse reactor beams. The fast ionization chamber, containing 1.6 g enriched to 99.9% ^{239}Pu isotope and Ge(Li) detector with volume 100cm^3 were operating in coincidence. The multidimensional technique has been applied from the data analysis. The gamma ray multiplicity, total and mean energy have been obtained for neutron energy range from 0.2 to 220eV. The distribution

of multiplicity as a function of gamma ray energy for $J^\pi = 0^+$ and 1^+ compound nucleus resonances are shown in figure.

The independent yields of the even-even fission fragments have been determined on the

bases of the gamma ray yields from the prompt decay of the relevant first excited states. The variance isobaric distribution and those value of the odd-even effect has been analysed in the framework of several models. The internal and collective temperature, intrinsic excitation and dissipation energy are discussed.



ABOUT A INTERPLAY BETWEEN BOHR'S CHANNELS AND MASS MODES
IN FISSION

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Fluctuations in the anisotropy of angular distribution of fission fragments, their total kinetic energy, independent yields and ratios of asymmetric to symmetric fission for individual resonances of the compound nucleus ^{236}U are considered. From the multi-level two-channel analysis by Moore, et al., of the spin separated cross-sections of ^{235}U (n,f) reaction, we have obtained the weights of A.Bohr's fission channels for neutron resonances with $J^\pi = 4^-$ at neutron energies from 0.7 to 35eV. For this set of resonances significant correlations between the fluctuations of the above mentioned fission characteristics and the weights of fission channels are found.

A model that unifies a concept of A.Bohr for fission channels and an idea of available paths of fission - fission modes, has been proposed. This model gives the explanation of the physical source of the revealed correlations and permits the conclusion that only Bohr's fission channels are randomly mixed in the individual compound resonances, whereas different modes of fission dynamical structure of A.Bohr's ones.

Evaluation of Fission Yields for ^{239}Pu in the Neutron Resonance Region

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An evaluation of fission yields was performed for $J^\pi=1^+$ neutron resonances of ^{239}Pu numbered by λ (with total fission width $\Gamma_{f\lambda}$) on the basis of a multimode model [1]. Channel effects on the relative population $W_{d\lambda}$ of fission mode d were neglected because there is only one fission channel [2]. If considering the $(n,\gamma f)$ process with an average width $\bar{\Gamma}_{\gamma f}$ as a second channel, the fission characteristics \bar{X}_λ as total fragment kinetic energy $\overline{\text{TKE}}$, average number of neutrons $\bar{\nu}$, total number of γ -rays \bar{N}_γ , average total energy of γ -rays \bar{E}_γ , and the ratio peak/valley P/V can be expressed by

$$\bar{X}_\lambda = \frac{\bar{\Gamma}_{\gamma f}}{\Gamma_{f\lambda}} \sum_d W_d^\gamma \bar{X}_d^\gamma + \left(1 - \frac{\bar{\Gamma}_{\gamma f}}{\Gamma_{f\lambda}}\right) \sum_d W_{d\lambda} \bar{X}_d,$$

where W_d^γ is the relative population of mode d in the case of $(n,\gamma f)$ process. The mass yield of fission mode d is represented by a Gaussian. According to Brosa et al., three standard modes and one superlong mode are considered. Their parameters were deduced from experimental fission yields [3,4]. Experimental fission characteristics (fragment kinetic energy and neutron multiplicity) as function of fragment mass number for thermal-neutron induced fission were used to define the parameter of energy partition at scission point [5]. In the case of $(n,\gamma f)$ process the excitation energy at scission point is reduced by the average γ -ray energy, whereas the total number of γ -rays increases by 1. Using experimental data for $\overline{\text{TKE}}_\lambda$, $\bar{\nu}_\lambda$, $\bar{E}_{\gamma\lambda}$, $\bar{N}_{\gamma\lambda}$, and P/V_λ we fitted the relative populations $W_{d\lambda}$ and W_d^γ .

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PROMPT GAMMA-RAY YIELDS AT INDIVIDUAL FISSION RESONANCES OF
 ^{239}Pu

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Gamma-rays of primary fission products were measured by Ge(Li) detector in coincidence with fission chamber on the flight path of the IBR-30 reactor.

Neutron resonances from 0.2 eV up to 74 eV have been resolved. A multilayer fission chamber (19 sections) was employed as a sample and fast detector of fission fragments with a time window of 32 ns.

The independent yields of the light and heavy fragments as a function of A and Z were determined for all stronger neutron resonances. From these data on the independent yields and the gamma-ray spectra several observations can be made:

- the variance of charge distribution $\sigma_z^2 = 0.38 \pm 0.03$ is in a good agreement with value of $\sigma_z^2 = 0.4 \pm 0.05$ obtained in the mass-spectrometry measurement,
- there is an indication of a difference between γ -spectrum measured for resonance with large value of fission width Γ_f (e.g. 10.9 eV, $\Gamma_f=149.5$ MeV) and small value of Γ_f (e.g. 44.5 eV, $\Gamma_f=4.2$ MeV), configuration of both γ -spectra is shown in Fig.1,
- there is generally good agreement between our yields and the independent yields from the thermal neutron fission.

This general rule does not apply to all neutron resonances. In some cases systematic dispersion of yields is observed. The yield of several fragments can be correlated with the fission width of relevant neutron resonance, e.g. ^{142}Ba , ^{94}Sr . This

correlation is shown in Fig's 2 and 3.

Similar correlation is well-known from the study of $(n,\gamma f)$ reaction.

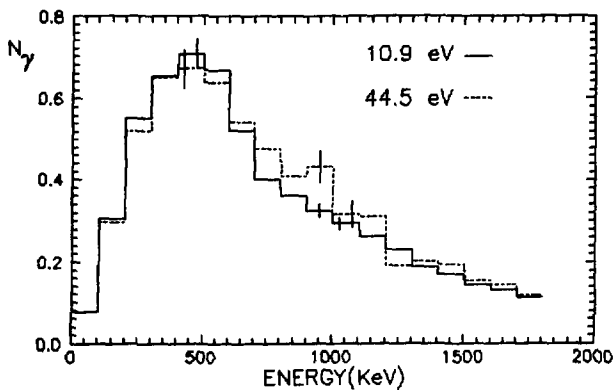


Fig. 1

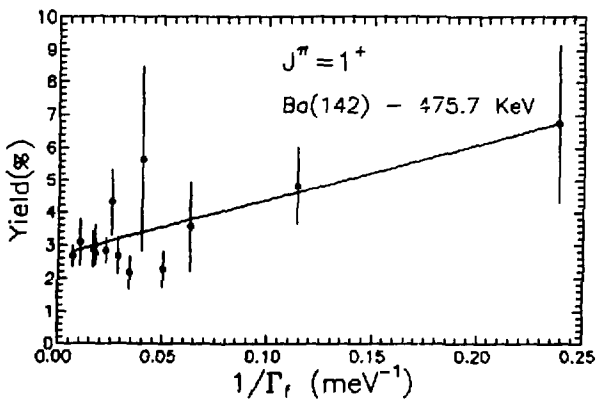


Fig. 2

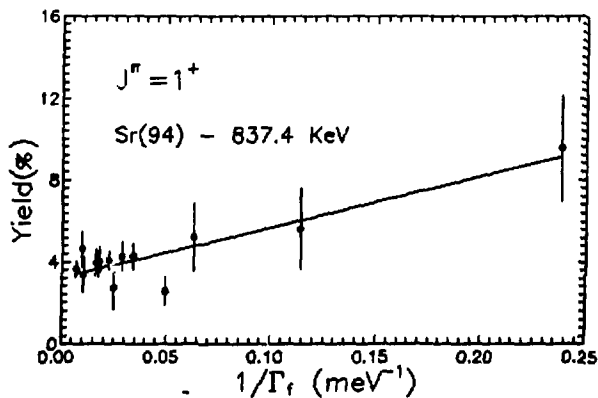


Fig. 3

DISCOVERY OF A NEW REGION OF BETA-DELAYED NUCLEAR FISSION

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Beta-delayed fission (i.e. fission from excited nuclear states populated via beta-decay) was first discovered in 1966 at Dubna for neutron-deficient transuranium nuclei (see ref.¹⁾ for a review). Subsequently it was realized^{1,2)} that this phenomenon should also take place for nuclei of *considerably lighter* elements, e.g., for ultra-neutron-deficient nuclei of Pb or Hg. Our exploratory experiments performed in 1986 fully corroborated these expectations: a striking delayed fission activity was observed in the $^{144}\text{Sm}+^{40}\text{Ca}$ reaction and explained as being due to beta-delayed fission of ^{180}Hg . A short account of these first experimental results was published in ref.³⁾ (see also ref.⁴⁾). Later on the experiments were continued. Reported below are improved experimental data on beta-delayed fission around ^{180}Hg as well as new experimental results revealing another example of this phenomenon in the region of preactinide nuclei.

For producing ultra-neutron-deficient preactinide nuclei we employed fusion-evaporation reactions induced by projectiles from ^{35}Cl to ^{48}Ti on isotopically enriched Sm targets, in particular, ^{144}Sm and ^{147}Sm ; targets of ^{151}Eu and $^{\text{nat}}\text{Eu}$ were also used. Bombarding energies were close to the fusion barrier. The experiments were carried out at the U-400 cyclotron by using the technique described in refs.^{3,5)}. Until now 12 different reactions were tried out in searching for delayed fission effects in this nuclear region. The most noticeable effect was repeatedly observed in the reaction $^{144}\text{Sm}+^{40}\text{Ca}$. In this reaction some 600 delayed fission events were detected as a result of five irradiations with the total ^{40}Ca beam dose of $3.5 \cdot 10^{18}$ particles. The half-life of this fission activity was determined to be $0.97^{+0.09}_{-0.08}$ s whereas its yield was found to correspond to a cross section of 60 ± 30 pb. The 0.97-s fission activity was not seen in the ^{40}Ca -induced reactions on targets of ^{147}Sm , ^{150}Sm and ^{154}Sm ; in irradiating ^{144}Sm by ^{35}Cl and ^{40}Ar projectiles it was not revealed either. In all of the above reactions the yields of any fission events with $T_{1/2} \geq 0.1$ s decrease by 10 to 100 times as compared to the $^{144}\text{Sm}+^{40}\text{Ca}$ case. As argued in refs.^{3,4)}, the most probable origin of the 0.97-s fission activity seems to be beta-delayed fission occurring in the decay chain

$^{180}\text{Tl} \xrightarrow[0.97 \text{ s}]{\text{EC}(\beta^+)}$ $^{180}\text{Hg}^*$. The probability of beta-delayed fission in this chain (i.e. the probability of fission of the daughter nucleus ^{180}Hg per one event of $\text{EC}(\beta^+)$ decay of the precursor ^{180}Tl) can be estimated to be $F_{\beta\text{df}} \approx 3 \cdot 10^{-(7 \pm 1)}$.

In further experiments a significant effect of beta-delayed fission was found in the $^{147}\text{Sm} + ^{45}\text{Sc}$ reaction where 140 fission events were detected as a result of three irradiations with the total ^{45}Sc beam dose of $2.6 \cdot 10^{18}$ particles. The time distribution of these events corresponds to a half-life of $0.40^{+0.08}_{-0.06}$ s; the appropriate cross section is 40 ± 20 pb. A delayed fission activity with a similar half-life, $T_{1/2} = 0.33^{+0.05}_{-0.04}$ s, and a comparable yield was detected in the $^{\text{nat}}\text{Eu} + ^{40}\text{Ca}$ reaction; this activity was also observed in the reaction $^{151}\text{Eu} + ^{40}\text{Ca}$. Again, a delayed fission activity with $T_{1/2} = 0.32^{+0.12}_{-0.07}$ s was revealed in irradiating ^{144}Sm by ^{48}Ti projectiles. The yield of the latter was twice as low as compared to that in the $^{147}\text{Sm} + ^{45}\text{Sc}$ case. At the same time, no fission activity with $T_{1/2} \approx 0.3 - 0.4$ s was found in the reactions $^{144}\text{Sm} + ^{45}\text{Sc}$ and $^{147}\text{Sm} + ^{48}\text{Ti}$. An analysis of the whole evidence accumulated so far suggests that the fission activity with $T_{1/2} \approx 0.3 - 0.4$ s produced by the reactions $^{147}\text{Sm} + ^{45}\text{Sc}$, $^{\text{nat}}\text{Eu} + ^{40}\text{Ca}$, $^{151}\text{Eu} + ^{40}\text{Ca}$ and $^{144}\text{Sm} + ^{48}\text{Ti}$ is associated with the decay chain $^{188}\text{Bi} \xrightarrow[0.3-0.4 \text{ s}]{\text{EC}(\beta^+)}$ $^{188}\text{Pb}^*$ (see also ref. 4).

Thus, our experiments have proved the existence of a new region of $\text{EC}(\beta^+)$ -delayed fission far outside the transuranium part of the nuclear chart. This finding opens up a way¹⁻³⁾ to unique information about fission barrier heights of cold nuclei lying extremely far from the beta-stability line.

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HEAVY ELEMENT RESEARCH AT DUBNA: TODAY AND TOMORROW

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Exploring nuclei near the limit of nuclear stability traditionally represents one of the main research directions of the JINR Laboratory of Nuclear Reactions at Dubna. A good deal of remarkable findings were obtained here during the past three decades¹⁾. In the nineties heavy element research at Dubna is expected to be pursued on a large scale. Given below is an outline of the future heavy element research programme for the Dubna 4-meter isochronous heavy-ion cyclotron U400.

I. THE HEAVIEST NUCLEI

1. New elements

- Element 110 by U+Ar and/or Pb+Ni reactions
- Superheavy elements by ⁴⁸Ca-induced fusion on ²⁴⁸Cm or ²⁴⁴Pu

2. New nuclides with Z>100

- Neutron rich species near the newly predicted subshell N=162, e.g., ²⁶⁶106 by the ²⁴⁸Cm+⁴⁸Ca reaction
- Neutron poor species via both cold fusion on Pb and Bi targets and high xn-evaporation channels in fusion on actinide targets

3. The probability and dynamics of spontaneous fission (SF)

- Ground-state SF systematics
- SF from various spin isomeric states

II. EXOTIC PREACTINIDE NUCLEI AND THEIR FISSION

1. New nuclides of Z≈70-90 near the proton drip line

2. Beta-delayed fission around ¹⁸⁰Hg and ¹⁸⁸Pb

- Fission barriers: macroscopic properties of cold nuclei
- Fragment distributions: low-energy fission (and fusion) mechanism

3. Ground-state (or shape isomeric) SF of Rn-Ra-Th nuclei with A≈200

4. Other studies: superdeformation and high-spin fissioning isomers, ground-state and beta-delayed cluster emission from exotic nuclei

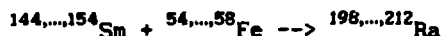
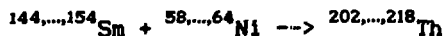
III. THE PROBABILITY AND DYNAMICS OF FUSION. STRUCTURAL AND DYNAMICAL FEATURES IN THE DECAY OF INTERMEDIATE NUCLEAR SYSTEMS FORMED BY FUSION OF TWO COMPLEX NUCLEI

1. Fusion-evaporation reactions leading to transfermium nuclei

- Dynamics of neutron-to-fission competition in the decay of barrierless composite systems: ²³²Th, ..., ²⁴⁹Cf + ¹⁸O, ..., ⁴⁰Ar

-Further cold fusion studies, $A \geq 40$

2. Cold fusion studies near the closed $N=126$ shell



-Influence of the fission stability (B_f) of the composite system on the fusion process

-Influence of the $N=126$ shell on the decay pattern of cold and hot composite systems

3. Formation and decay of nuclear systems with high nuclear temperature.

For the above studies, the main experimental facility will be a gas-filled recoil separator²⁾ (GFRS) recently built and put into operation at Dubna; a variety of simpler techniques including radiochemistry will also be used. The GFRS employs a D-Q-Q scheme (a dipole magnet and a quadrupole doublet). It shows excellent features for fusion-evaporation reactions induced by ${}^{40}\text{Ar}$ and heavier projectiles. In these cases we have a 40 to 60% efficiency for collecting evaporation residues on an area of $30 \times 70 \text{ mm}^2$ in the focal plane. The suppression of full-energy beam projectiles and target-like products is stronger than 10^{15} and 10^4 , respectively. Also, a considerable progress was made in optimizing the GFRS for fusion-evaporation reactions induced by "light" heavy ions, e.g., ${}^{18}\text{O}$ or ${}^{22}\text{Ne}$. For the highly asymmetric model reactions ${}^{238}\text{U} + {}^{18}\text{O}$ and ${}^{235}\text{U} + {}^{22}\text{Ne}$, an efficiency of 3 to 8% was reached for collecting evaporation residues on a focal plane area of $40 \times 120 \text{ mm}^2$. Although in these cases the collection efficiency is fairly low, the net sensitivity of experiments can be significantly improved by applying very intense beams of the lighter projectiles. In fact, the intensity of ${}^{18}\text{O}$ or ${}^{22}\text{Ne}$ beams from U400 reaches $(3+4) \cdot 10^{13}$ pps. To accept such intense beams, the GFRS is equipped with beam wobbling systems, fast rotating entrance windows, rotating target wheels, etc.

First experiments with the GFRS are now under way. These aim at producing new isotopes of element 106, in particular, ${}^{258}106$ and ${}^{266}106$, to probe the SF stability of the $Z=106$ nuclei in a wide range of N . The experiments to produce ${}^{266}106$ in the ${}^{248}\text{Cm} + {}^{22}\text{Ne}$ reaction are performed in collaboration with the group by E.K. Hulet (LLNL, Livermore, USA).

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FISSION GAMMA-RAY MULTIPLICITY VARIATION IN ^{235}U LOW ENERGY FISSION RESONANCES

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Abstract

Time-of-flight measurements of the fission gamma-ray yields R in low energy fission resonances of ^{235}U were performed using the Dubna $IBR-30$ pulsed reactor based neutron source. A large 6-section liquid scintillation detector and ^{235}U loaded multiplate fission chamber FC were used for detecting 3 or more fission gamma-quanta in coincidence with a FC pulse.

It was found that there is no statistically significant difference between the $R(3^-)$ and $R(4^-)$ values for both resonance spin groups. Considering the spin $J^\pi = 4^-$ resonance group we found a positive correlation between the $R(4^-)$ values and the branching values of $P = \Gamma_f(4^-, K = 1) / \Gamma_f(4^-, K = 1) + \Gamma_f(4^-, K = 2)$. A positive correlation between the R and TKE values is consistent with the negative one for the R and ν_α values.

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