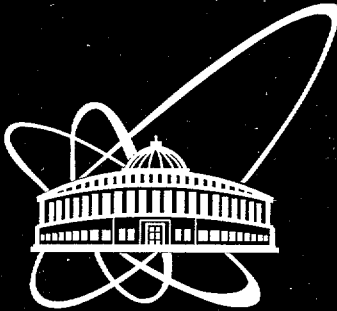




XJ0100089



**ОБЪЕДИНЕННЫЙ  
ИНСТИТУТ  
ЯДЕРНЫХ  
ИССЛЕДОВАНИЙ**

**Дубна**

E15-2000-295

**FUSION-FISSION OF SUPERHEAVY NUCLEI  
AT LOW EXCITATION ENERGIES**

The invited talk at the International Workshop  
«Fusion Dynamics at the Extremes», May 2000, Dubna, Russia

**32 / 30**

**2000**

M.G.Itkis, Yu.Ts.Oganessian, E.M.Kozulin, A.A.Bogatchev, I.M.Itkis, M.Jandel,  
J.Kliman, G.N.Kniajeva, N.A.Kondratiev, I.V.Korzyukov, L.Krupa,  
I.V.Pokrovski, V.A.Ponomarenko, E.V.Prokhorova, A.Ya.Rusanov,  
V.M.Voskresenski

*Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia*

F.Hanappe, B.Benoit, T.Materna

*Universite Libre de Bruxelles, 1050 Bruxelles, Belgium*

N.Rowley, L.Stuttge

*Institut de Recherches Subatomiques, F-67037 Strasbourg Cedex, France*

G.Giardina

*Dipartimento di Fisica dell' Universita di Messina, 98166 Messina, Italy*

K.J.Moody

*University of California, Lawrence Livermore National Laboratory, Livermore,  
California 94551, USA*

## 1 Introduction

Interest in the study of the fission process of superheavy nuclei interactions with heavy ions is connected first of all with the possibility of obtaining information, the most important for the problem of synthesis, on the production cross section of compound nuclei at excitation energies of  $\approx 15-30$  MeV (i.e. when the influence of shell effects on the fusion and characteristics of the decay of the composite system is considerable), which makes possible prediction on its basis of the probability of their survival after evaporating 1, 2 or 3 neutrons, i.e. in "cold" or "warm" fusion reactions. However, for this problem to be solved, there is a need for a much more penetrating insight into the fission mechanism of superheavy nuclei and for a knowledge of such fission characteristics as the fission - quasi-fission cross section ratio in relation to the ion-target entrance channel mass asymmetry and excitation energy, the multiplicity of the pre and postfission neutrons, the kinetic energy of the fragments and the peculiarities of the mass distributions of the fission and quasi-fission fragments etc. Undoubtedly all these points are of great independent interest to nuclear fission physics.

In this connection this work presents the first preliminary results of the experiments on the fission of superheavy nuclei in the reactions  $^{208}\text{Pb}+^{48}\text{Ca}\rightarrow^{256}\text{No}$ ,  $^{248}\text{Cm}+^{22}\text{Ne}\rightarrow^{270}\text{Sg}$ ,  $^{248}\text{Cm}+^{26}\text{Mg}\rightarrow^{274}\text{Hs}$ ,  $^{238}\text{U}+^{48}\text{Ca}\rightarrow^{286}112$ ,  $^{244}\text{Pu}+^{48}\text{Ca}\rightarrow^{292}114$ ,  $^{248}\text{Cm}+^{48}\text{Ca}\rightarrow^{296}116$ ,  $^{208}\text{Pb}+^{58}\text{Fe}\rightarrow^{266}\text{Hs}$ ,  $^{248}\text{Cm}+^{58}\text{Fe}\rightarrow^{306}122$ ,  $^{208}\text{Pb}+^{86}\text{Kr}\rightarrow^{294}118$  carried out at FLNR JINR in the last year. The choice of the indicated reactions has undoubtedly been inspired by the results of the recent experiments on producing the nuclides  $^{283}112$ ,  $^{287}114$ ,  $^{289}114$  at Dubna [1,2] and  $^{293}118$  at Berkeley [3] in the same reactions.

## 2 Experiment

The experiment was carried out on the extracted beam of  $^{22}\text{Ne}$ ,  $^{26}\text{Mg}$ ,  $^{48}\text{Ca}$ ,  $^{58}\text{Fe}$  and  $^{86}\text{Kr}$  ions of the FLNR JINR U-400 accelerator, using a set-up that included:

- the two-armed time-of-flight reaction products spectrometer CORSET built with the use of microchannel plates (MCP);
- 24 detector time-of-flight neutron spectrometer DEMON using scintillation modules [4];
- a 4 detector scintillation  $\gamma$ -quanta multiplicity spectrometer.

The reaction fragments spectrometer allows one to obtain the mass energy and angular distributions of fission fragments and scattered particles. It is based on 2 identical movable time-of-flight arms. The start detectors used MCP amplifiers equipped with an electrostatic mirror for the electrons knocked out by a particle passing through a  $25 \times 35$  mm thin  $120 \mu\text{g}/\text{cm}^2$  gilded mylar foil placed at 30 mm from the target.

As stop detectors, 4 coordinate sensitive MCP modules of  $40 \times 60$  mm operating zone were used in each arm, the modules being placed at 180 mm from the target. The detectors were installed symmetrically relative to the beam at an angle of about  $60^\circ$  depending on the reaction type.

The spectrometer was calibrated and adjusted with the use of  $^{226}\text{Ra}$   $\alpha$ -particle sources, the fission fragments of  $^{252}\text{Cf}$  and elastic scattering peaks directly during the experiment. The following values were obtained for its main characteristics:

Time resolution	150-225 ps
Measuring range of the angles of divergence of reaction products for each arm:	
- in the reaction plane $\Theta$	$44^\circ$
- beyond the $\Psi$ -plane	$28^\circ$
Angular resolution	$0.1^\circ$
Solid angle of one arm	370 mst
Mass resolution	$\approx 3$ amu

The spectrometer for  $\gamma$ -ray multiplicity consisted of four  $63 \times 63$  mm NaJ(Tl) detectors, which were placed in lead collimators and installed in the lower hemisphere at 35 cm from the target. The threshold of  $\gamma$ -quanta registration was 100 keV. To reduce the accidental coincidences, the time between pulses from fission fragments and  $\gamma$ -rays were measured. The time resolution of the  $\gamma$  ray detectors was 7 ns.

The neutron spectrometer detectors (built with the use of a Ne213 liquid scintillator) arranged in groups of three were located at 130 cm from the target at angles of  $17^\circ$ ,  $0^\circ$ ,  $-17^\circ$  beyond the reaction plane and at angles of  $45^\circ$ ,  $65^\circ$ ,  $155^\circ$ ,  $-65^\circ$ ,  $-90^\circ$ ,  $-135^\circ$  in the reaction plane. Some detectors were located in the vertical plane along the beam axis at angles of  $10^\circ$ ,  $25^\circ$ ,  $74.5^\circ$ ,

90°, 105.5°, 163°. The signals due to neutrons and  $\gamma$ -radiation were separated by analysing the shape of the pulse generated by the photomultiplier.

The discrimination thresholds were set during calibrating  $^{22}\text{Na}$ ,  $^{88}\text{Y}$ ,  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ ,  $^{226}\text{Ra}$ . To ensure the stability of the energy scale, the calibration was repeated several times during the experiment.

As the target, 120-170  $\mu\text{g}/\text{cm}^2$   $^{208}\text{Pb}$ ,  $^{238}\text{U}$ ,  $^{248}\text{Cm}$  and  $^{244}\text{Pu}$  spectrometric layers deposited on a 40- 50  $\mu\text{g}/\text{cm}^2$  carbon backing were used.

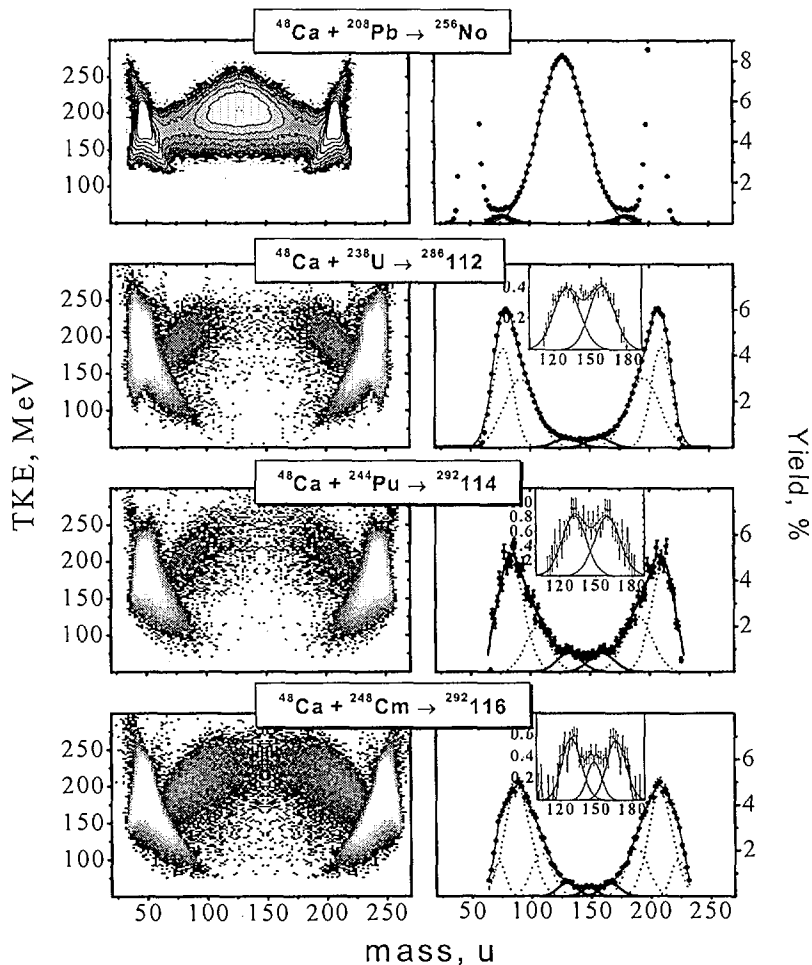
The ion beam energy was periodically measured with an accuracy of  $\pm 1$  MeV with use of a semiconductor detector, using its scattering by tantalum and gold foils, and constantly monitored with a semiconductor monitor immediately in the reaction chamber, using the scattering of the beam nuclei by the target. The total ion current that had passed through the target was measured with the help of a Faraday cup, taking account of the dead time of the collecting system and its rest time.

The data processing was carried out with the use of traditional techniques, assuming the process under study to be a two-body process. The losses of the energy of the fragments in the target, backings and start detectors were taken into account. Special attention was paid to the angular folding correlations of the fragments both in and beyond the reaction plane. Only those events were selected and then analyzed that corresponded to the two-body process of complete momentum transfer. The neutron energy and angular distributions for selected masses and energies of fragments were obtained using a JUNO data visualization and analysis program.

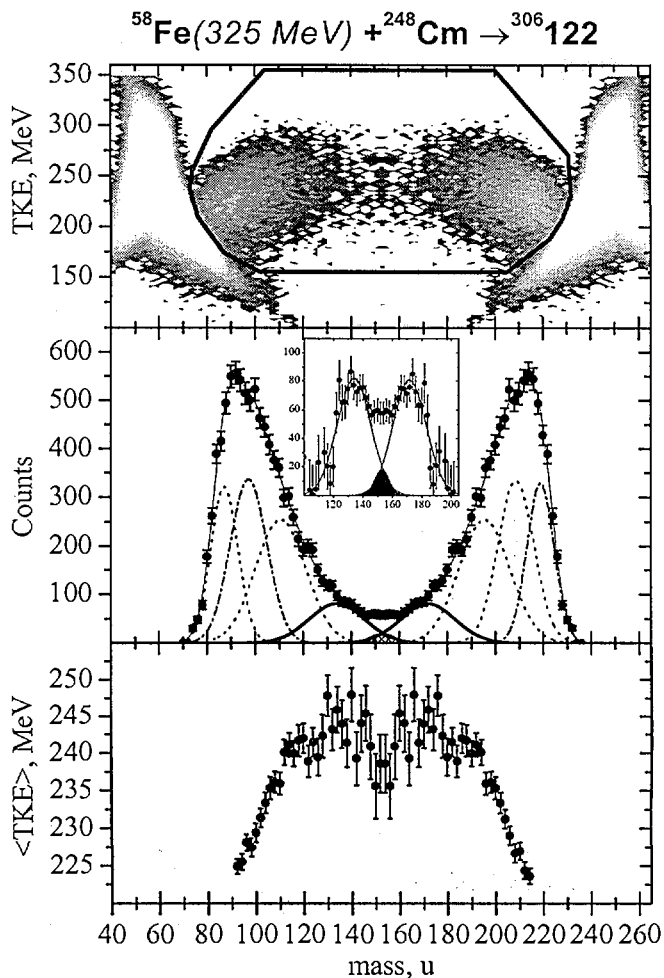
### **3 Characteristics of mass and energy distributions of SHE fission fragments**

Fig.1 shows the data on mass and energy distributions of fission fragments of  $^{256}102$ ,  $^{286}112$ ,  $^{292}114$  and  $^{296}116$  nuclei produced in the reactions with  $^{48}\text{Ca}$  at one and the same excitation energy  $E^* \approx 33$  MeV. The main peculiarity of the data is the sharp transition from the predominant compound nucleus fission in the case of  $^{256}102$  to the quasi-fission mechanism of decay in the case of the  $^{286}112$  nucleus and more heavy nuclei. It is very important to note that despite a dominating contribution of the quasi-fission process in the case of nuclei with  $Z=112-116$ , in the symmetric region of fission fragment masses ( $A/2 \pm 20$ ) the process of fusion-fission of compound nuclei, in our opinion, prevails. It is demonstrated in the framings (see the right-hand panels of Fig.1) from which it is also very well seen that the mass distribu-

tion of fission fragments of compound nuclei is asymmetric in shape with the light fission fragment mass = 132-134.



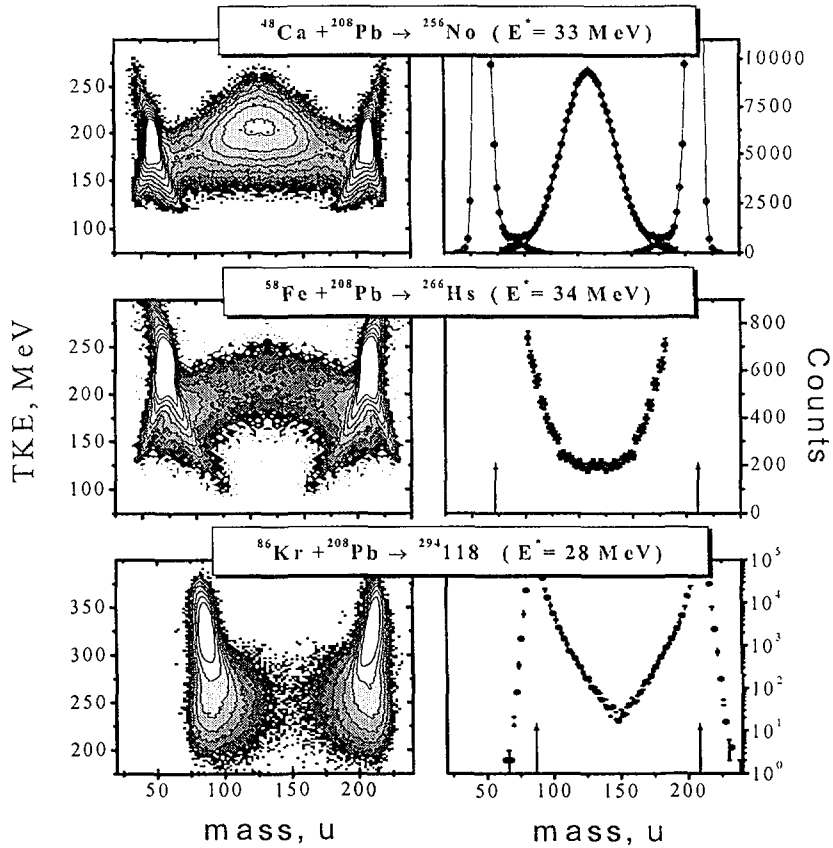
**Figure 1.** Two-dimensional TKE-Mass matrices (left-hand side panels) and mass yields (right-hand side panels) of fission fragments of  $^{256}102$ ,  $^{286}112$ ,  $^{292}114$  and  $^{296}116$  nuclei produced in the reactions with  $^{48}\text{Ca}$  at the excitation energy  $E^* \approx 33$  MeV.



**Figure 2.** A two-dimensional TKE-Mass matrix, the mass yield and average TKE as a function of the mass of  $^{306}\text{122}$  fission fragments.

Fig. 2 shows similar data for the reaction  $^{58}\text{Fe} + ^{248}\text{Cm}$  leading to the formation of the heaviest compound system ever studied by us, namely,  $^{306}\text{122}$  ( $N=184$ ), i.e., to the formation of the spherical compound nucleus, which agrees well with theoretical predictions [5]. As seen from Fig.2, in

this case we observe an even stronger manifestation of the asymmetric mass distribution of  $^{306}122$  fission fragments with the light fragment mass 132. The corresponding structures are also well seen in the dependence of the TKE on the mass (the lower panel of Fig.2).



**Figure 3.** Two-dimensional TKE-Mass matrices and mass yields of fission fragments for the reactions  $^{208}\text{Pb} + ^{48}\text{Ca}$ ,  $^{208}\text{Pb} + ^{58}\text{Fe}$ ,  $^{208}\text{Pb} + ^{86}\text{Kr}$  at an excitation energy of  $\approx 30$  MeV.

Fig.3 shows mass and energy distributions of fission fragments for compound nuclei  $^{256}\text{No}$ ,  $^{266}\text{Hs}$  and  $^{294}118$  formed in the interaction between a  $^{208}\text{Pb}$  target and  $^{48}\text{Ca}$ ,  $^{58}\text{Fe}$  and  $^{86}\text{Kr}$  ions at the excitation energy of  $\approx 30$  MeV. It is important to note that in the case of the reaction  $^{208}\text{Pb} + ^{86}\text{Kr}$



the ratio between the fragment yields in the region of asymmetric masses and that in the region of masses  $A/2$  exceeds by about 30 times a similar ratio for the reactions with  $^{48}\text{Ca}$  and  $^{58}\text{Fe}$  ions. It signifies to that fact that in the case of the  $^{208}\text{Pb} + ^{86}\text{Kr} \rightarrow ^{294}118$  reaction in the region of symmetric fragment masses the mechanism of quasi-fission prevails.

Figures 4, 5, 6 show similar data for the reactions  $^{208}\text{Pb} + ^{58}\text{Fe} \rightarrow ^{266}\text{Hs}$ ,  $^{244}\text{Pu} + ^{48}\text{Ca} \rightarrow ^{292}114$  and  $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow ^{296}116$  obtained at different excitation energies.

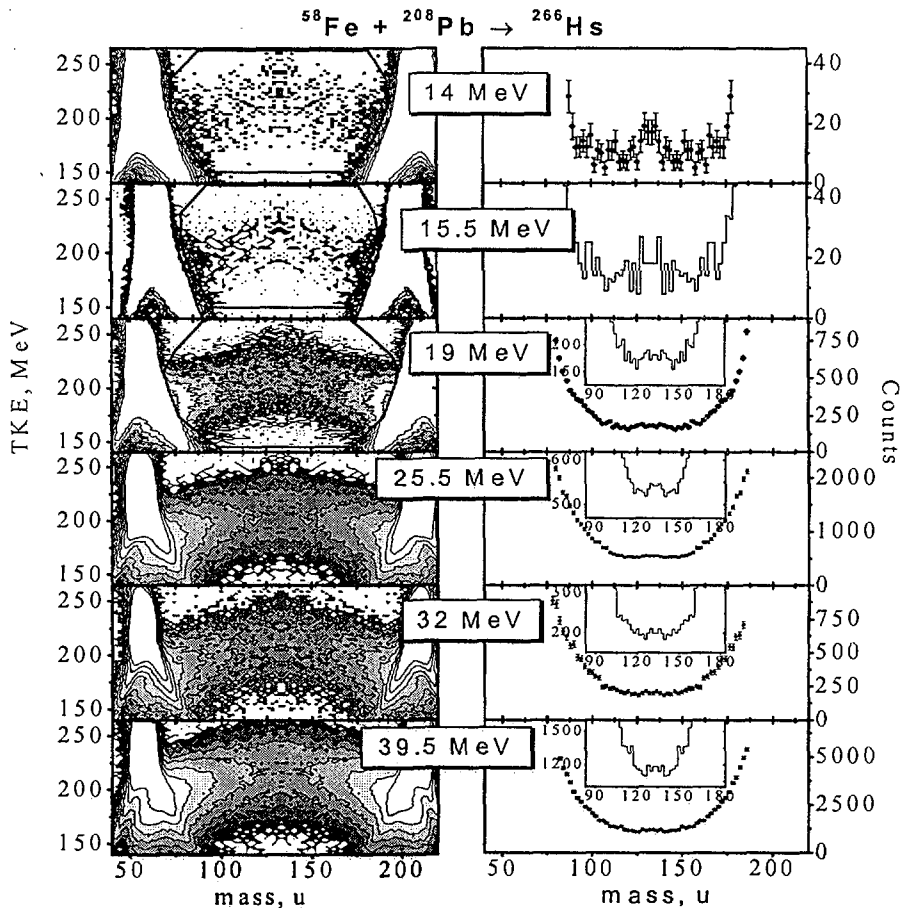
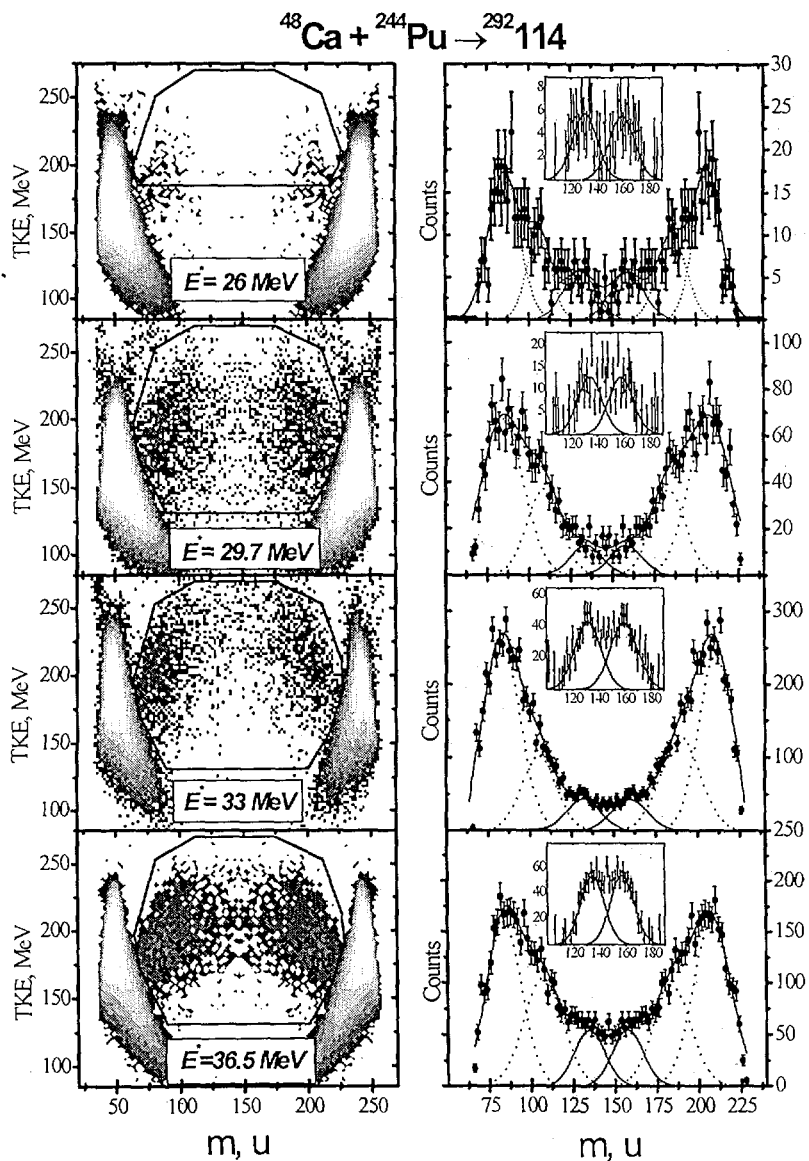


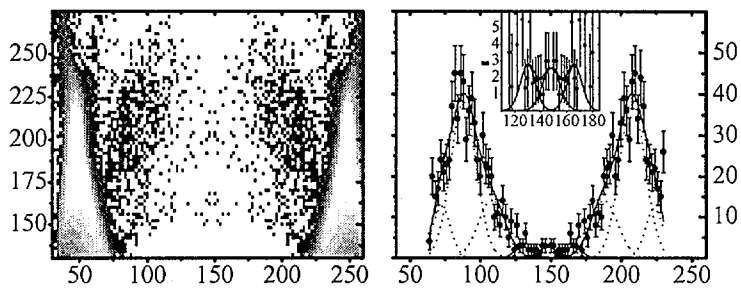
Figure 4. Two-dimensional TKE-Mass matrices and mass yields of fission fragments for the reaction  $^{208}\text{Pb} + ^{58}\text{Fe} \rightarrow ^{266}\text{Hs}$  at different excitation energies.



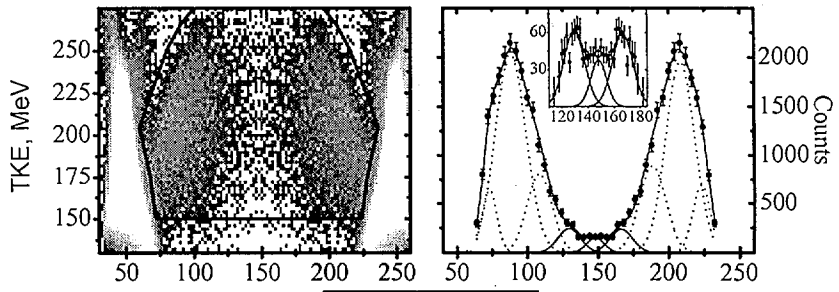
**Figure 5.** Two-dimensional TKE-Mass matrices and mass yields of fission fragments for the reaction  $^{244}\text{Pu} + ^{48}\text{Ca} \rightarrow ^{292}\text{114}$  at different excitation energies.



$E_{\text{lab}} = 234 \text{ MeV}$



$E_{\text{lab}} = 238 \text{ MeV}$



$E_{\text{lab}} = 245 \text{ MeV}$

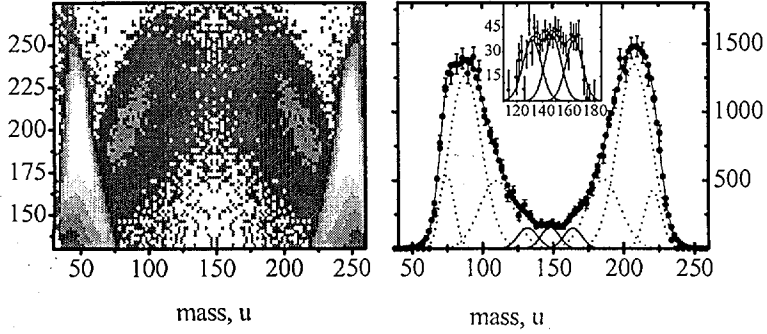


Figure 6. Two-dimensional TKE-Mass matrices and mass yields of fission fragments for the reaction  $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow ^{296}\text{116}$  at different excitation energies.

# Mass asymmetry in binary fission

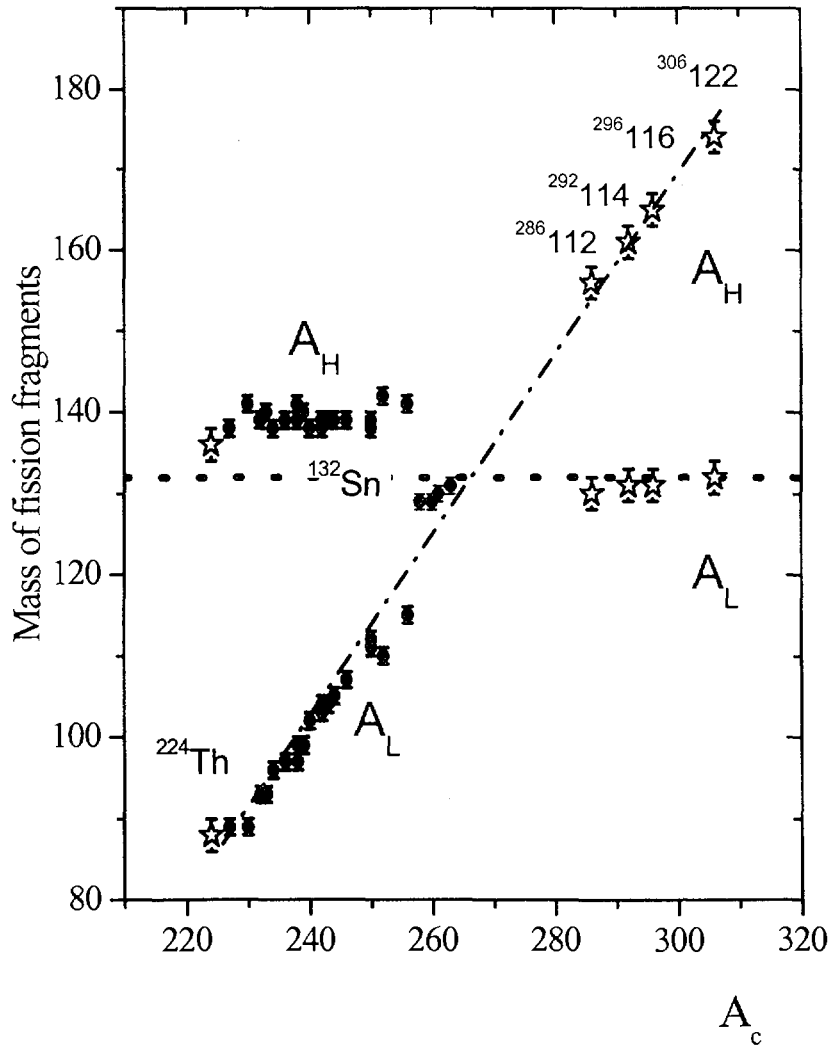
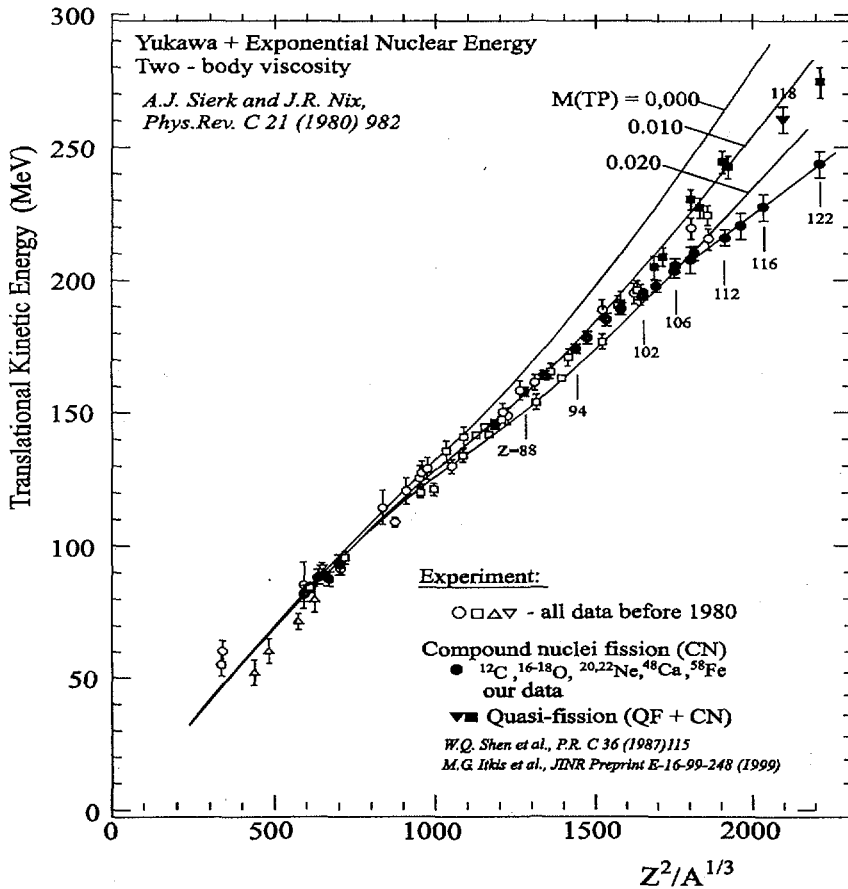


Figure 7. The dependence of the light and heavy fragment masses on the compound nucleus mass.

**Fission Fragment Total Kinetic Energy  
in Heavy Ion Induced Reactions**



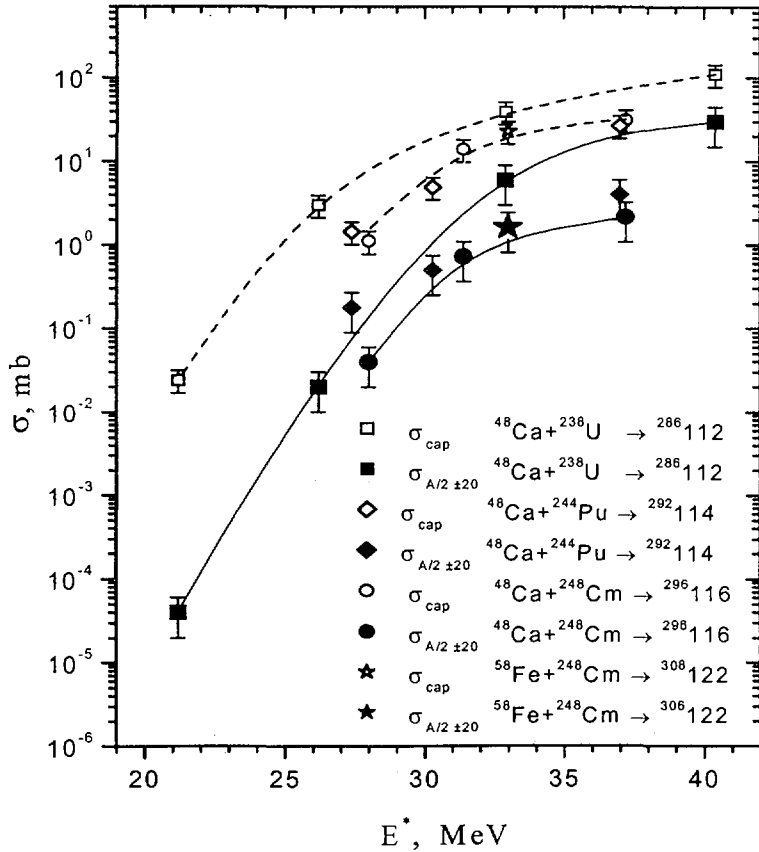
**Figure 8.** The dependence of TKE on the Coulomb parameter  $Z^2/A^{1/3}$ .

In analyzing the data presented in Figs. 1-6 one can notice two main regularities in the characteristics of mass and energy distributions of fission fragments of superheavy compound nuclei:

1. Fig. 7 shows the dependence of the light and heavy fragment masses on the compound nucleus mass. It is very well seen that in the case of superheavy nuclei the light spherical fragment with masses 132-134 plays a stabilizing role, in contrast to the region of actinide nuclei.

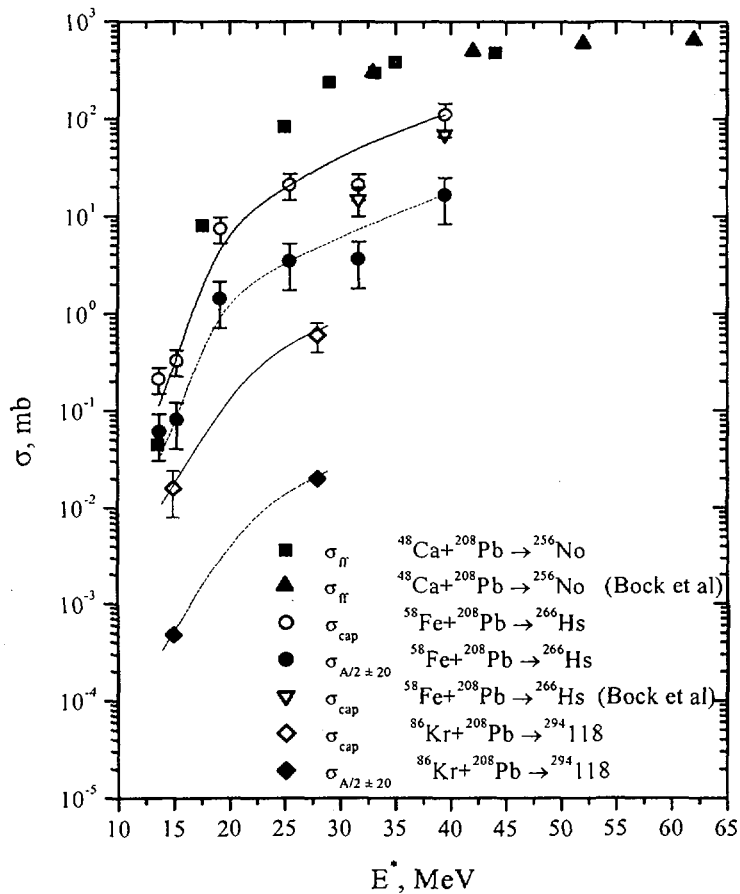
2. Fig. 8 shows the TKE dependence on the Coulomb parameter  $Z^2/A^{1/3}$ , from which it follows that for the nuclei with  $Z > 100$  the TKE value is much smaller in the case of fission as compared with the quasi-fission process.

#### 4 Capture and fusion-fission cross sections



**Figure 9.** The capture cross section  $\sigma_c$  and the fusion-fission cross section  $\sigma_{ff}$  for the reactions  $^{48}\text{Ca} + ^{238}\text{U}$ ,  $^{244}\text{Pu}$ ,  $^{248}\text{Cm}$ , and  $^{58}\text{Fe} + ^{248}\text{Cm}$  as a function of the excitation energy.

Figures 9 and 10 show the results of measurements of the capture cross section  $\sigma_c$  and the fusion-fission cross section  $\sigma_{ff}$  for the studied reactions as a function of the initial excitation energy of the compound systems.



**Figure 10.** The capture cross section  $\sigma_c$  and the fusion-fission cross section  $\sigma_{ff}$  for the reactions  $^{48}\text{Ca}$ ,  $^{58}\text{Fe}$ ,  $^{86}\text{Kr} + ^{208}\text{Pb}$  as a function of the excitation energy.

Comparing the data on the cross sections  $\sigma_{ff}$  at  $E^* \approx 14$ -15 MeV (cold fusion) for the reactions  $^{208}\text{Pb} + ^{58}\text{Fe}$  and  $^{208}\text{Pb} + ^{86}\text{Kr}$ , one can obtain the following ratio:  $\sigma_{ff}(108)/\sigma_{ff}(118) \geq 10^2$ . In the case of the reactions from  $^{238}\text{U}$

+  $^{48}\text{Ca}$  to  $^{208}\text{Cm}$  +  $^{58}\text{Fe}$  at  $E^* \approx 33$  MeV (warm fusion) the value of  $Z$  changes by the same 10 units as in the first case, and the ratio  $\sigma_{\text{ff}}(112)/\sigma_{\text{ff}}(122)$  is  $\approx 4-5$  which makes the use of asymmetric reactions for the synthesis of spherical superheavy nuclei quite promising.

Another interesting result is connected with the fact that the values of  $\sigma_{\text{ff}}$  for  $^{256}102$  and  $^{266}108$  at  $E^* = 14-15$  MeV are quite close to each other, whereas the evaporation residue cross sections  $\sigma_{\text{xn}}$  [6] differ by almost three orders of magnitude ( $\sigma_{\text{ff}}/\sigma_{\text{xn}}$ ) which is evidently caused by a change in the  $\Gamma_f/\Gamma_n$  value for the above mentioned nuclei. At the same time, for the  $^{294}118$  nucleus formed in the reaction  $^{208}\text{Pb} + ^{86}\text{Kr}$ , the compound nucleus formation cross section is decreasing at an excitation energy of 14 MeV by more than two orders of magnitude according to our estimations ( $\sigma_{\text{ff}} \approx 500$  nb is the upper limit) as compared with  $\sigma_{\text{ff}}$  for  $^{256}102$  and  $^{268}108$  produced in the reactions  $^{208}\text{Pb} + ^{48}\text{Ca}$  and  $^{208}\text{Pb} + ^{58}\text{Fe}$  at the same excitation energy. But when using the value of  $\approx 2.2$  pb for the cross section  $\sigma_{\text{ev}}(1n)$  from work [3], one obtains the ratio  $\sigma_{\text{xn}}/\sigma_{\text{ff}} \approx 4 \cdot 10^{-6}$  for  $^{293}118$ , whereas for  $^{266}108$  the ratio is  $\sigma_{\text{xn}}/\sigma_{\text{ff}} \approx 10^{-6}$ .

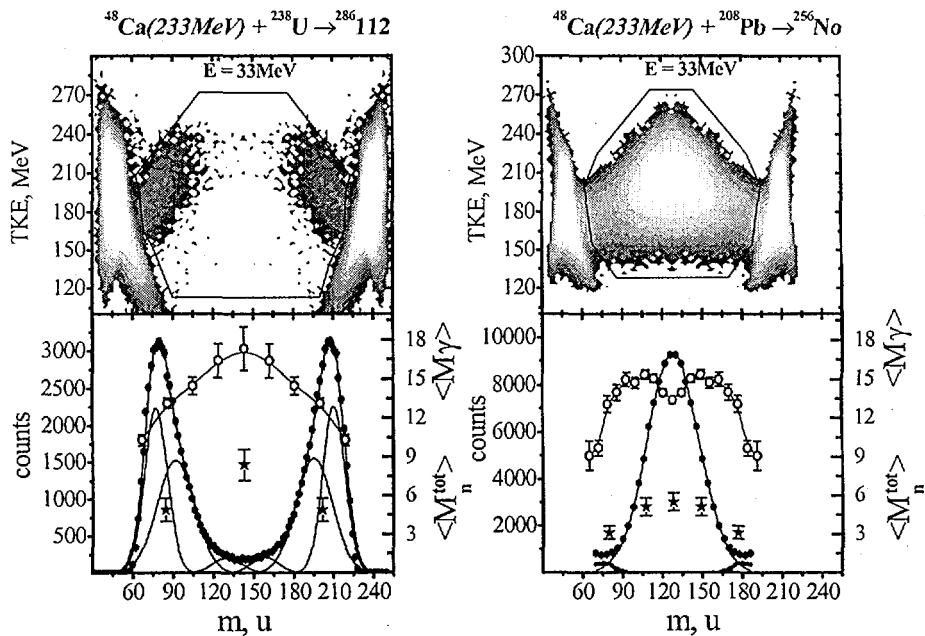
In one of recent works [7] it has been proposed that such unexpected increase in the survival probability for the  $^{294}118$  nucleus is connected with the sinking of the Coulomb barrier below the level of the projectile's energy and, as a consequence, leads to an increase in the fusion cross section. However, our data do not confirm this assumption.

## 5 Neutron and gamma-ray multiplicities in the fission of superheavy nuclei

Emission of neutrons and gamma-rays in correlation with fission fragments in the decay of superheavy compound systems at excitation energies of near or below the Coulomb barrier had not been properly studied before this publication. At the same time such investigations may be extremely useful for an additional identification of fusion-fission and quasi-fission processes and thus a more precise determination of the cross sections of the above mentioned processes in the total yield of fragments. On the other hand, the knowledge of the value of the fission fragment neutron multiplicity may be used in the identification of SHE in the experiments on their synthesis.



The first results of such investigations are presented in Figs. 11-12 for the reactions  $^{208}\text{Pb} + ^{48}\text{Ca} \rightarrow ^{256}\text{No}$ ,  $^{238}\text{U} + ^{48}\text{Ca} \rightarrow ^{286}\text{112}$ ,  $^{244}\text{Pu} + ^{48}\text{Ca} \rightarrow ^{292}\text{114}$  and  $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow ^{296}\text{116}$  at energies near the Coulomb barrier. As seen from the figures, in all the cases the total neutron multiplicity  $M_{\text{tot}}$  is considerably lower (by more than twice) for the region of fragment masses where the mechanism of quasi-fission predominates as compared with the region of fragment masses where, in our opinion, the process of fusion-fission prevails (in the symmetric region of fragment masses). Another important peculiarity of the obtained data is the large values of  $M_{\text{tot}} \approx 9$  and  $10.5$  for the fission of  $^{292}\text{114}$  and  $^{296}\text{116}$  compound nuclei, respectively. As well as for  $M_{\text{tot}}$  noticeable differences have been observed in the values of  $\gamma$ -ray multiplicities for different mechanisms of superheavy compound nucleus decay.



**Figure 11.** Two-dimensional TKE-Mass matrices (top panels) and the mass yields (the solid circles), neutron (the stars) and gamma ray (the open circles) multiplicities in dependence on the fission fragment mass (bottom panels) for the reactions  $^{238}\text{U} + ^{48}\text{Ca} \rightarrow ^{286}\text{112}$  and  $^{208}\text{Pb} + ^{48}\text{Ca} \rightarrow ^{256}\text{No}$ .

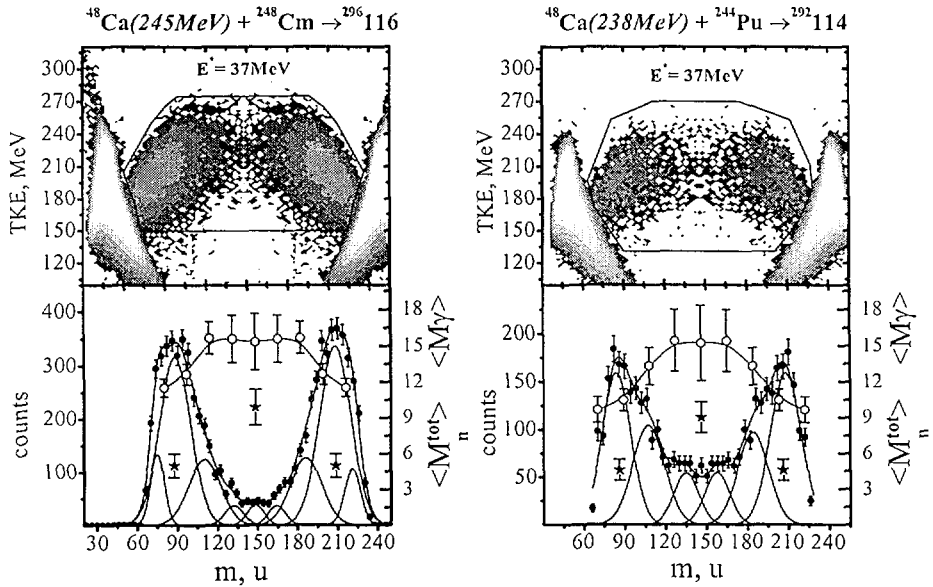


Figure 12. The same as in Fig.11, but for the reactions  $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow ^{296}\text{116}$  and  $^{244}\text{Pu} + ^{48}\text{Ca} \rightarrow ^{292}\text{114}$ .

## 6. CONCLUSIONS

As a result of the experiments carried out, for the first time the properties were studied of the fission of the compound nuclei  $^{256}\text{No}$ ,  $^{270}\text{Sg}$ ,  $^{266}\text{Hs}$ ,  $^{271}\text{Hs}$ ,  $^{274}\text{Hs}$ ,  $^{286}\text{112}$ ,  $^{292}\text{114}$ ,  $^{296}\text{116}$ ,  $^{294}\text{118}$  and  $^{306}\text{122}$ , produced in reactions with ions  $^{22}\text{Ne}$ ,  $^{26}\text{Mg}$ ,  $^{48}\text{Ca}$ ,  $^{58}\text{Fe}$  and  $^{86}\text{Kr}$  at energies close to and below the Coulomb barrier.

On the basis of those data a number of novel important physics results were received:

- it was found, that the mass distribution of fission fragments for compound nuclei  $^{286}\text{112}$ ,  $^{292}\text{114}$ ,  $^{296}\text{116}$  and  $^{306}\text{122}$  is asymmetric one, whose nature, in contrast to the asymmetric fission of acti-

nides, is determined by the shell structure of the light fragment with the average mass 132-134. It was established that TKE, neutron and  $\gamma$ -ray multiplicities for fission and quasi-fission of superheavy compound nuclei are significant different;

- b) the dependence of the capture ( $\sigma_c$ ) and fusion-fission ( $\sigma_{ff}$ ) cross sections for nuclei  $^{256}\text{No}$ ,  $^{266}\text{Hs}$ ,  $^{274}\text{Hs}$ ,  $^{286}\text{112}$ ,  $^{292}\text{114}$ ,  $^{296}\text{116}$ ,  $^{294}\text{118}$  and  $^{306}\text{122}$  on the excitation energy in the range 15–60 MeV has been studied. It should be emphasized that the fusion-fission cross section for the compound nuclei produced in reaction with  $^{48}\text{Ca}$  and  $^{58}\text{Fe}$  ions at excitation energy of  $\approx 30$  MeV depends only slightly on reaction partners, that is, as one goes from  $^{286}\text{112}$  to  $^{306}\text{122}$ , the  $\sigma_{ff}$  changes no more than by the factor 4–5. This property seems to be of considerable importance in planning and carrying out experiments on the synthesis of superheavy nuclei with  $Z > 114$  in reaction with  $^{48}\text{Ca}$  and  $^{58}\text{Fe}$  ions. In the case of the reaction  $^{86}\text{Kr} + ^{208}\text{Pb}$ , leading to the production of the composite system  $^{294}\text{118}$ , contrary to reactions with  $^{48}\text{Ca}$  and  $^{58}\text{Fe}$ , the contribution of quasi-fission is dominant in the region of the fragment masses close to  $A/2$ ;
- c) the phenomenon of multimodal fission was first observed and studied [8,9] in the region of superheavy nuclei  $^{256}\text{No}$ ,  $^{270}\text{Sg}$ ,  $^{266}\text{Hs}$ ,  $^{271}\text{Hs}$  and  $^{274}\text{Hs}$ .

This work was supported by the Russian Foundation for Basic Research under Grant № 99-02-17981 and by INTAS under Grant № 11929.

## References

1. Oganessian Yu.Ts. *et al*, *Eur. Phys. J. A* **5** (1999) 63.
2. Oganessian Yu.Ts. *et al*, *Nature*, 400 (1999) 242.
3. Ninov V. *et al*, *Phys. Rev. Lett.* 83 (1999) 1104.
4. Mouatassim S. *et al*, *Nucl. Instrum. Methods A* **359** (1995) 330;  
*A* **365** (1995) 446.
5. Patyk Z., Sobiczewski A., *Nucl. Phys. A* **533** (1991) 132.
6. Hofmann S., Münzenberg G., *Reviews of Modern Physics*, 72 (2000) №3.
7. Myers W. D. and Swiatecki W.J., *Phys. Rev. C*, **62** (2000) 044610.

8. Itkis M. G. et al, *Phys. Rev. C*, **59** (1999), 3172
9. Itkis M. G. et al, *Proc. 7-th Int. Conf. Clustering aspects of nuclear structure and dynamics (Cluster'99) Rab Island, Croatia, 1999* (WS, 2000) 386.

Received by Publishing Department  
on December 4, 2000.

**The Publishing Department  
of the Joint Institute for Nuclear Research  
offers you to acquire the following books:**

Index	Title
E1,2-97-79	Proceedings of the XIII International Seminar on High Energy Physics Problems. Relativistic Nuclear Physics and Quantum Chromodynamics. Dubna, 1996 (2 volumes, 364 p. and 370 p., in English)
D5,11-97-112	Proceedings of the 9th International Conference «Computational Modelling and Computing in Physics». Dubna, 1996 (378 p., in English)
E2-97-213	Proceedings of the V International Seminar on Interaction of Neutron with Nuclei «Neutron Spectroscopy, Nuclear Structure, Related Topics». Dubna, 1997 (446 p., in English)
E2,4-97-263	Proceedings of the Third International Conference «Renormalization Group'96». Dubna, 1996 (436 p., in English)
E10-97-272	Proceedings of the Data Acquisition Systems of Neutron Experimental Facilities (DANEF'97). Dubna, 1997 (325 p., in English)
D19-97-284	Proceedings of the International Symposium «Problems of Biochemistry. Radiation and Space Biology». Dubna, 1997 (2 volumes 284 p. and 405 p., in Russian and English)
E2-97-413	Proceedings of the VII Workshop on High Energy Spin Physics (SPIN'97). Dubna, 1997 (398 p., in English)
E15-98-57	Proceedings of the III International Workshop «Hyperfine Structure and Nuclear Moments of Exotic Nuclei by Laser Spectroscopy». Poznan, 1997 (200 p., in English)
D13-98-66	Proceedings of the XVII International Symposium on Nuclear Electronics. Varna, 1997 (242 p., in English and Russian)
E1,2-98-154	Proceedings of the XIII International Seminar on High Energy Physics Problems «Relativistic Nuclear Physics and Quantum Chromodynamics». Dubna, 1996 (2 volumes 300 p. and 282 p., in English)
E3,14-98-168	Proceedings of the German–Russian User Meeting «Condensed Matter Physics with Neutrons at IBR-2». Dubna, 1998 (126 p., in English)
E3-98-202	Proceedings of the VI International Seminar on Interaction of Neutrons with Nuclei Neutron Spectroscopy, Nuclear Structure, Related Topics. Dubna, 1998 (352 p., in English)
D1,2-98-215	Proceedings of the International Workshop «Relativistic Nuclear Physics: from MeV to TeV». Dubna, 1998 (384 p., in English and Russian)
E2-98-254	Proceedings of the International Workshop Hadronic Atoms and Positronium in the Standard Model. Dubna, 1998 (260 p., in English)

Index	Title
D9,11-98-273	Proceedings of the 4th International Workshop «Beam Dynamics and Optimization». Dubna, 1997 (162 p., in English and Russian)
E17,19-98-305	Proceedings of the International Workshop on Deuteration of Biological Molecules for Structural and Dynamic Studies. Applications to Neutron Scattering and NMR. Dubna, 1998 (100 p., in English)
E1,2-98-307	Proceedings of the International School–Seminar «Actual Problems of Particle Physics». Gomel, 1997, Belarus (2 volumes 304 p. and 220 p., in English)
E2-98-372	Proceedings of the III International Workshop «Classical and Quantum Integrable Systems». Erevan, 1998 (200 p., in English)
E9-99-26	Proceedings of the International Conference on High Energy Accelerators. Dubna, 1998 (432 p., in English)
E2-99-35	Proceedings of the XI International Conference on Problems of Quantum Field Theory. Dubna, 1998 (508 p., in English)
E5-99-38	Proceedings of the International Workshop «Self-Similar Systems». Dubna, 1998 (404 p., in English)
E9-99-92	Proceedings of the XVII International Conference on High Energy Accelerators HEACC'98. Dubna, 1998 (435 p., in English)

Please apply to the Publishing Department of the Joint Institute for Nuclear Research for extra information. Our address is:

Publishing Department  
 Joint Institute for Nuclear Research  
 Dubna, Moscow Region  
 141980 Russia  
 E-mail: [publish@pds.jinr.dubna.su](mailto:publish@pds.jinr.dubna.su).

Иткис М.Г. и др.  
Слияние–деление сверхтяжелых ядер  
при низких энергиях возбуждения

E15-2000-295

Представлены результаты исследования процесса слияния–деления сверхтяжелых ядер с  $Z=102-122$ , образованных в реакциях с ионами  $^{22}\text{Ne}$ ,  $^{26}\text{Mg}$ ,  $^{48}\text{Ca}$ ,  $^{58}\text{Fe}$  и  $^{86}\text{Kr}$  при энергиях вблизи и ниже кулоновского барьера. Эксперименты проводились на ускорителе У-400 Лаборатории ядерных реакций ОИЯИ с использованием времяпролетного спектрометра фрагментов CORSET и нейтронного мультidetектора DEMON. В результате проведенных экспериментов были изучены распределения масс и энергий фрагментов, сечения процессов деления и квазиделения, множественности нейтронов и  $\gamma$ -квантов и их зависимость от механизма образования и распада составных сверхтяжелых систем.

Работа выполнена в Лаборатории ядерных реакций им. Г.Н.Флерова ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2000

Itkis M.G. et al.  
Fusion–Fission of Superheavy Nuclei at Low Excitation Energies

E15-2000-295

The process of fusion–fission of superheavy nuclei with  $Z=102-122$  formed in the reactions with  $^{22}\text{Ne}$ ,  $^{26}\text{Mg}$ ,  $^{48}\text{Ca}$ ,  $^{58}\text{Fe}$  and  $^{86}\text{Kr}$  ions at energies near and below the Coulomb barrier has been studied. The experiments were carried out at the U-400 accelerator of the Flerov Laboratory of Nuclear Reactions (JINR) using a time-of-flight spectrometer of fission fragments CORSET and a neutron multi-detector DEMON. As a result of the experiments, mass and energy distributions of fission fragments, fission and quasi-fission cross sections, multiplicities of neutrons and gamma-rays and their dependence on the mechanism of formation and decay of compound superheavy systems have been studied.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 2000

Макет Т.Е.Попеко

Подписано в печать 26.12.2000  
Формат 60 × 90/16. Офсетная печать. Уч.-изд. листов 1,73  
Тираж 305. Заказ 52435. Цена 2 р.

Издательский отдел Объединенного института ядерных исследований  
Дубна Московской области