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FLEROV LABORATORY OF NUCLEAR REACTIONS

RESEARCH ACTIVITIES IN 1997

Report to the 83rd Session
of the Scientific Council of JINR
January 15–16, 1998

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The Flerov Laboratory of Nuclear Reactions carries out research in heavy ion physics in three main directions. They include the synthesis of heavy and exotic nuclei with ion beams of stable and radioactive isotopes, studies of nuclear reactions, accelerator technology, studies of matter with heavy ions and other applied research. They were grouped in 14 projects and were performed in wide international collaboration using the accelerators of the Laboratory and other scientific centers.

Unfortunately, in 1996-1997, due to the financial difficulties of the Institute, our accelerators (U-400 and U-400M) worked for experiments only 30% of the planned beam-time, which resulted in a considerable reduction in the programme of experimental investigations with the use of the heavy ion beams of our accelerators.

In 1997 the Laboratory organized four international conferences devoted to different trends in research, including the International School-Seminar on Heavy Ion Physics, the International IGISOL Workshop and the International Workshop on Applied Physics Research.

The results obtained were published in more than 40 journal papers. More than 50 talks were presented at various international conferences.

The regular biannual Scientific Report of FLNR JINR (1995-1996) *Heavy Ion Physics* was published.

Heavy Elements

The theory of nuclear shell corrections predicted the existence of heavy and superheavy elements. As a result of the fission barrier emergence, which is determined by nuclear structure, the partial spontaneous fission half-lives of heavy nuclei turned out to be by ~10-20 orders of magnitude larger than the value predicted by the classical liquid drop model, and the isotopes of the heaviest elements undergo α-decay.

Past years brought certain achievements in this direction. Experiments on the synthesis of new elements in hot fusion were carried out by the FLNR-LLNL (Livermore) collaboration at the U-400 cyclotron and those in cold fusion - by the GSI (Darmstadt)-FLNR collaboration at the UNILAC accelerator. Both series of experiments resulted in the synthesis of the new heaviest nuclei. The values of cross sections of the hot fusion reactions resulting in 4n and 5n evaporation from the compound nuclei with $Z=104\div110$ were measured. The new data quantitatively confirmed the predictions of the macro-microscopic theory that there is a significant stabilization shell effect in the region near $N=162$ and $Z=108$.

This allows the mass predictions made by the theory for spherical nuclei near Z=114 and N=174÷180 to be the most realistic. The ^{232}Th, ^{238}U and $^{244}Pu+^{48}Ca$ reactions are considered to be suitable for the synthesis of the isotopes of elements 110÷114 with a neutron excess as maximal as possible (Z=175, 174).

In 1997 the electronic and detector systems of the separators DGFRS and VASSILISSA were upgraded. These modernization's allowed one to use a 16-strip position sensitive detector at the separator's focal plane, 4 backward detectors and to obtain an energy resolution better than 25 KeV for 5,5 MeV α–particles, a position resolution better than 0,5mm for the reaction products implanted into a detector and a total registration efficiency of no less than 85% for the α–particles emitted from the studied nuclide.

The work has been performed on preparing experiments on synthesis of superheavy nuclei with Z=110 in the complete fusion reaction $^{232}Th+^{48}Ca$. According to the latest theoretical predictions by A. Sobiczewski et al., the partial half-lives in respect to the alpha decay and spontaneous fission of the ^{268}Sg (Z=106) nucleus are 2-3 hours, whereas the half-life of the daughter spontaneously fissile nuclide ^{264}Rf (Z=104) is estimated to be a few seconds. The ^{268}Sg nuclide should be formed as a result of two short alpha decays of the $^{274}110$ nucleus, which is a product of evaporation of 4 neutrons from the compound $^{280}110$ nucleus. The lifetimes of the daughter products of the 3-neutron evaporation reaction, i.e. of odd ^{269}Sg and ^{265}Rf isotopes are estimated with less certainty. However, it is expected that the nuclide ^{269}Sg must undergo an α-decay with a half-life of about one-hour, after which spontaneous fission of the isotope ^{265}Rf (or the daughter nuclide ^{265}Rf) should take place in several hours. The planned scheme of the experiments consists in accumulating the long-lived ^{268}Sg nuclide in a collector during the irradiation of a ^{232}Th target by the ^{48}Ca beam, subsequent chemical separation of the 106 element fraction and measurements of the α and SF activities in the off-line regime.

As a result of the experiments, the properties of the most heavy $^{268,269}Sg$ (Z=106) and $^{264,\ 265}Rf$ (Z=104) nuclides near the N=162 shell can be studied and the level of the superheavy nuclei formation cross sections can be determined in the complete fusion reactions between ions of ^{48}Ca and the actinide target nuclei.

Test experiments on elaborating the procedure of chemical separation of the 106 element fraction - the product of α-decay of $^{276,277}110$ nuclei, have been performed. The experiments revealed a high degree of separation of the 106 element fraction from the background Th (≥3x10^5), Bi and Pb (≥3x10^4) products.

The first series of six experiments on synthesizing $^{276,277}110$ nuclei using the ^{48} Ca ion beam of the U-400 cyclotron has been performed with a subsequent chemical separation of the 106 element fraction.

Chemical samples were deposited on carbon foils of the ~40 mg/cm^2 thickness and placed between pairs of semiconductor detectors for the activity registration in the off-line regime. After the irradiation, part of the thorium targets containing complete fusion products were placed between the layers of solid track detectors for the registration of spontaneous fission fragments.

The intensity of the ^{48} Ca beam was of up to 4x10^{12} particles per second. The total dose of ~3x10^{17} of ^{48}Ca ions was accumulated during the 56 hours of the experiment. At present, measurement of the samples is still in progress, the results of the experiments are being processed and analysed. The dependence curve of the upper limit of the formation cross sections of $^{276,277}110$ nuclei has been obtained as a function of half-lives of the daughter $^{268,269}Sg$ or $^{264,265}Rf$ nuclides (Fig. 1).

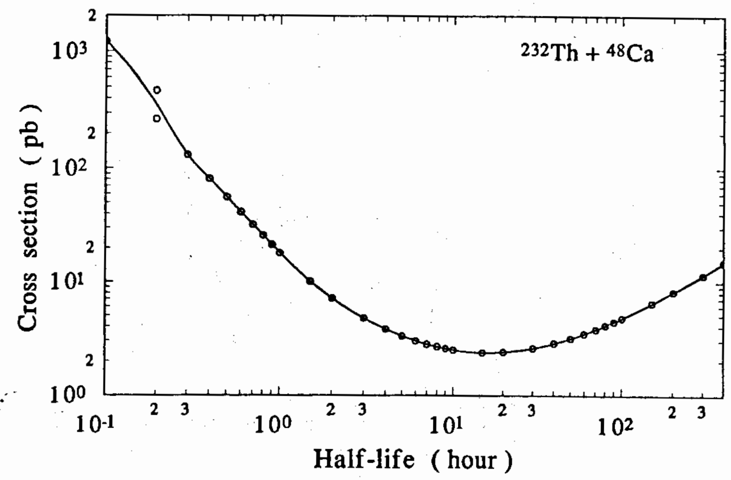

Fig. 1

The sensitivity of the experiment was ~3 pb (10^{-36} cm ^{2}). The experiments on synthesising $^{276,277}110$ nuclei and observing the daughter products of their α-decay, $^{268,269}Sg$ or $^{264,265}Rf$, are scheduled to be continued in March 1998 using the reaction $^{232}Th+^{48}Ca$. At the intensity of the ^{48}Ca beam of up to $3x10^{12}$ particles per second, the sensitivity of the experiment will be 1 pb.

Chemistry of Transactinides

Some years ago, at FLNR, comparative studies of the tetrachloride and tetrabromide compounds of element 104 and hafnium were performed using the thermochromatographic method. The data indicated that the volatility of the compounds of element 104 is higher than that of hafnium. This results from the relativistic effects in chemical properties. Recently, at U-400, in collaborative experiments with groups from PSI (Switzerland) and RC (Rossendorf, Germany), the chromatographic behavior of the tetrachlorides of the two elements, as well as that of the oxodichlorides of these elements, was compared. The fraction of radioactive atoms that had survived after the passing through the column was measured at the exit of the column as a function of the column temperature. This fraction is an accurate measure of the "retention time", which depends on the compound volatility and on the column temperature. For the first time, the nuclides to be compared had equal half-lives, which made it possible to quantitatively characterize the difference in the properties of similar elements. (Fig. 2.)

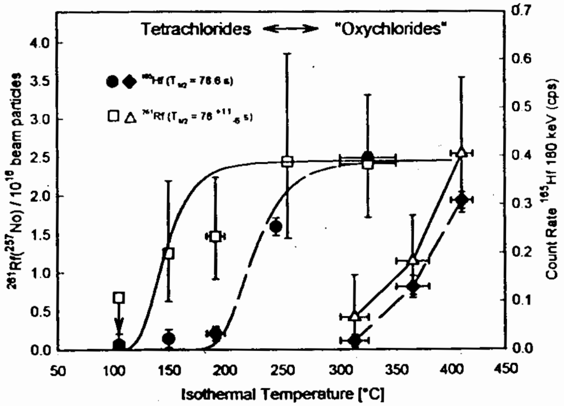

Fig. 2

Nuclear Fusion and Fission

New evidence of the influence of nuclear shells on the nuclear fission dynamics was found for spontaneous and induced fission in recent

experiments carried out at FLNR in collaboration with several groups.

The multidetector set-up "CORSET+DEMON" (large-angle fission fragment detectors and a 4π neutron array) and the FOBOS spectrometer were used to measure the spontaneous fission of ^{248}Cm with the aim of studying the phenomenon of cold compact and cold deformed fragmentation and searching for the cluster decay modes.

An analysis was made of the fine and gross-structure of the primary mass-energy distribution of the fission fragments produced in the spontaneous fission of ^{252}Cf. An evidence was found of the fission modes being determined by the clusterization of a fissioning system. In Fig. 3 a two-dimensional P(M/E*) plot is presented. The two fission modes, which are distinguishable as hills, can differ in the location where scission predominantly takes place: close to the light cluster ^{106}Mo or to the heavy cluster ^{128}Sn (inserts A and B).

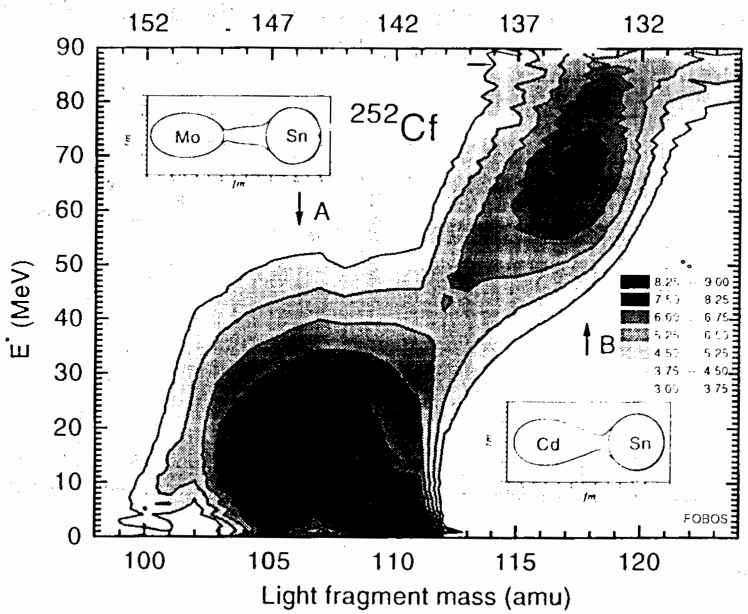

Fig. 3

It has been recognized for a long time that the study of the fragment angular momentum can provide insights into the fission dynamics. However, until the present time a little progress was achieved in this direction due to the difficulties in obtaining the experimental information.

In 1997 entirely new data about the fragment angular moments were obtained by the Dubna-Vanderbilt collaboration where the prompt multiple γ-rays were investigated. Spectroscopic measurements of the coincident γ-rays of the ^{252}Cf spontaneous fission were carried out with the Gammasphere facility. The angular momentum of the primary Ba-Mo and Ce-Zr fragments was determined in more than 70 cases. The general conclusion, which was derived from the analysis of the obtained data, is that the fragment angular momentum does not increase regularly with the rise of the fragment scission point deformation (see Fig.4a). A comparison of the experimental values with the results of theoretical calculations shows that such a behavior is caused by the decrease of the collective transverse oscillation temperature. For the first time a correlation was observed between the yields of the fragment pairs and the values of the angular momentum (see Fig.4b). Such correlation gives a clear indication that there is a strong coupling between two collective degrees of freedom, i.e. between transverse and dipole oscillations.

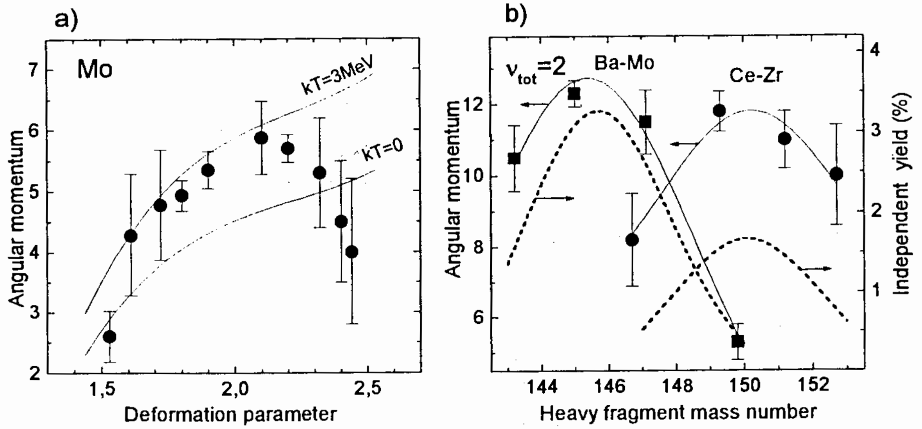

Fig.4

The multiparameter (mass-energy-angle) correlations for the fission fragments in coincidence with neutron and γ-quanta were measured in the reaction ^{18}O+^{208}Pb at energies lower than the Coulomb barrier. For the first time the experimental data were obtained on the emission of a pre-scission neutron for individual fission modes (symmetric and asymmetric). The results of the analysis showed that in this case the dependence of ν_{pre} on the fragment mass differs drastically from that at higher excitation energies, when the shell effects disappear and there are no fission modes.

For the first time, the characteristics of the fission fragments (mass-energy correlation's) in coincidence with neutron and γ-quanta were measured for the compound nuclei of the element with Z=110 produced in the asymmetric reaction ^{249}Cf+^{24}Mg. The preliminary analysis of the experimental data showed that this method allows one to describe the fusion-fission cross-sections for superheavy nuclei with small excitation energy. (Fig. 5)

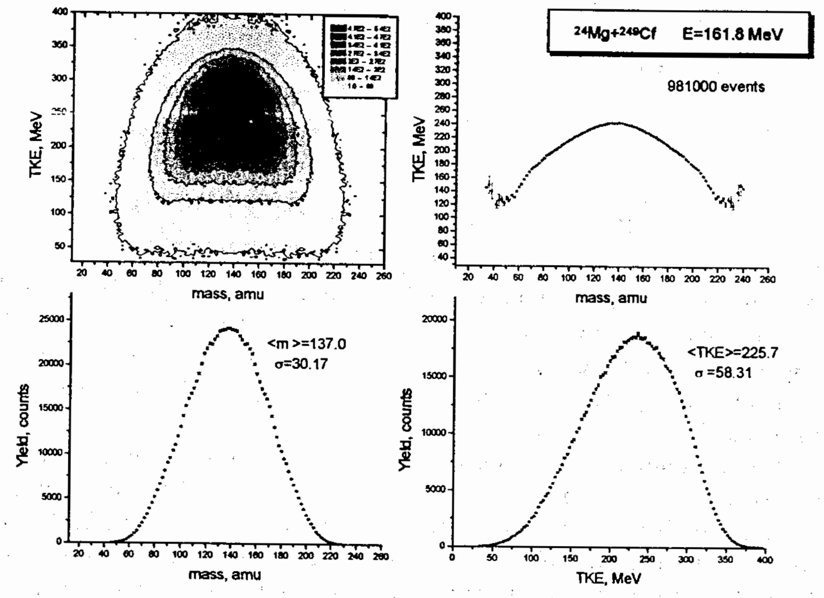

Fig. 5

In 1997 using the kinematic separator VASSILISSA and heavy ion beams accelerated at the U-400 cyclotron, the experiments were continued which resulted in the study of the fusion probability and fissility of excited heavy compound nuclei. The de-excitation process of highly excited compound nuclei and the evaporation of protons, α-particles and up to 8 neutrons for Fm compound nuclei were studied. Systematic information on the competition between the different channels of compound nuclei at temperatures of up to 1,8 MeV was obtained.

The neutron-to-total width ratios ($\hat{a}_n/\hat{a}_{tot}$) were measured for $^{254-256}$Fm at E^*=60-80 MeV (Fig. 6.). The fission barrier values for the neutron deficient nuclei of Fm were extracted after an analysis with the use of statistical model calculations.

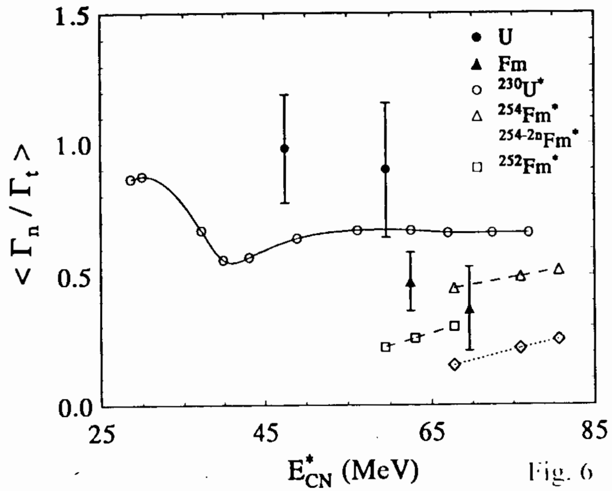

Fig. 6

Experiments were performed to study the limitations of the fusion at the entrance channel for the reactions ^{16}O+^{206,208}Pb $\rightarrow$ ^{222,224}Th. The evaporation residue cross sections were measured in the region of the excitation energy of compound nuclei extending to 10 MeV below the fusion barrier.

For a number of reactions, the effect of the closed neutron shells of the reactants for the reaction ^{16}O + ^{206,208}Pb (N=8 and 126 respectively), for the reaction ^{86}Kr + ^{136}Xe (N=50 and 82 respectively) and the effect of the closed neutron shells of the compound nucleus for the reaction ^{86}Kr + ^{130}Xe (N=126) on the evaporation residue excitation functions near the barrier energies were investigated.

The results of the analysis showed that the set of experimental data connected with the decay of the ^{222,224}Th compound nuclei can be described well within the framework of the statistical model of the compound nucleus deexcitation realized by the code HIVAP. The results obtained for the ^{222}Th compound nucleus (^{86}Kr+^{136}Xe reaction) showed that the shift of the fusion barrier resulting from the predicted extra push energies is not observed. These results will allow the study of the "cold" fusion reaction mechanisms, the subbarrier fusion of heavy nuclei will open new possibilities for the synthesis of superheavy nuclei.

For 1998 it is planned to continue the investigation of the channel peculiarities of the fusion in the following reactions being of great interest to the synthesis of the heaviest elements: ^{136}Xe+^{124}Sn $\rightarrow$ ^{260}104*, ^{136}Xe+^{136}Xe $\rightarrow$ ^{272}108* and ^{86}Kr+^{208}Pb $\rightarrow$ ^{294}118*.

For this aim, for 1998 it is planned to continue the upgrading of the VASSILISSA separator, to increase the electrostatic field strength by a factor of two and to transform the VASSILISSA separator now operating as an energy filter to a velocity filter.

Exotic Nuclei

For a long time the neutron rich nucleus of ^{6}He has attracted much attention from both experimental and theoretical points of view. The theory describes ^{6}He as a three-body system and can give accurate predictions. In particular, the "di-neutron" and "cigar-like" configurations predicted for ^{6}He are waiting for experimental verification. The available experimental data do not permit one to draw certain conclusions about the details of the neutron halo structure in ^{6}He. It is well known that transfer reactions provide a good opportunity to study the structural parameters and spectroscopic factors of nuclear configurations. Therefore it appears to be natural to conduct such a test of the ^{6}He internal wave function. In the case of collision partners, which ^{6}He and ^{4}He could be, there could be two-neutron transfer, i.e. an exchange effect that should be observed in the center-of-mass frame as elastic scattering in backward direction.

A high quality, intense secondary beam of exotic ^{6}He ions was produced by fragmentation of a 32 MeV/n ^{7}Li beam on a thick ^{9}Be target of a thickness of 225mg/cm^2. The ions of ^{6}He were separated using the ACCULINNA facility recently commissioned at the U-400M cyclotron. The beam energy spread (FWHM) and transverse emittance made up ±2% and 30π mm*mrad respectively. With this quality, the ^{6}He beam intensity made up to about 2x10^5 pps at the intensity of the primary ^{7}Li beam of 1x10^{12}pps. The helium gas target was cooled to 78 K by liquid nitrogen and, at a pressure of 5 atm, the resulting thickness of the ^{4}He target was equal to 5.6x10^{20} atoms/cm^2. The experimental setup involved two silicon detector telescopes mounted on two independently movable arms. The energy resolution of each detector used in the telescopes was better than 100 keV for the 5.5 MeV alpha line of ^{238}Pu and made up ≈ 0.6% for the 150 MeV ions of ^{4}He. The solid angle of each of two telescopes made up ≈ 75 msr in the laboratory system.

The resulting angular dependence of the differential cross-section $d\sigma/d\Omega$ is presented in Fig.7. (The closed circles stand for the estimated cross-section values, the horizontal bars with downward arrows - for the upper limits). The differential cross-sections calculated for the $^6He+^4He$ system with the optical model (OM) potential are shown by the dotted line. Within the angular range of $122° \leq \vartheta cm \leq 155°$ the calculated elastic scattering cross-section varies between 5×10^{-4} and 5×10^{-6} mb/sr, whereas the experimental points lie in this range at the level that is by 10^2-10^4 times higher.

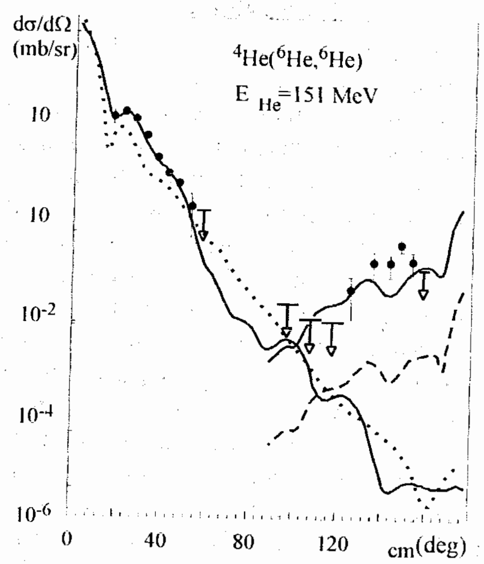

Fig.7

As it was expected, there is not any reasonable set of OM parameters that can reproduce the yield of ^6He nuclei observed in the backward direction. This definitely means that the ^6He scattering events observed in this angular region are in fact the result of two-neutron exchange.

The theoretical estimations done within the three-body model (α+n+n) predict two sufficiently distinct spatial components for the ^6He state wave function: (1) - a "di-neutron" component in which two neutrons are located close to each other ($r_{nn} \approx 1$ fm), with their center of mass being rather far from the ^4He core ($R_{nn} \approx 4$ fm), and (2) - a "cigar-like"

component ($r_{nn} \approx 4$ fm, $R_{nn} \approx 1$ fm). After normalizing the model ^6He wave function the contributions of the above mentioned two components to the two-neutron exchange effect were studied. The solid line shows the two-neutron transfer cross section calculated with the full, two-component model wave function. It is evident that the calculated cross section values are close to the experimental points. The dashed line shows the results of the calculation done with the model wave function from which the "di-neutron" component was eliminated. One can see the deficit of two-order of magnitude in the cross section values shown in Fig. 7 allows one to state that the contribution of the close located, "cigar-like" component to the two-neutron transfer cross section is rather small. It means that it is the "di-neutron" configuration of ^6He that is mainly responsible for the two-neutron exchange. The fact that the calculated cross sections obtained with the full, normalized wave function are close to the experimental data implies that the spectroscopic factor of the two-neutron cluster in the ^6He nucleus is close to one.

An analysis of the data shows that the rise in the cross section at the backward CM angles is by about 100% due to the "di-neutron" configuration of the ^6He halo nucleus. So, the long-standing problem of proving the strict principal conclusion of the theory of halo nuclei about the ^6He structure is solved.

At the U-400M cyclotron, the multidetector set-up MULTI was put in full operation. It consists of a 19-module plastic-BG0-spectrometer, multiwire proportional chamber and multilayer Si and plastic telescopes. It also includes a 4π-BG0-ball. The new set-up was created jointly by FLNR, LNP (JINR), LANCE (Los Alamos), INP (Rez), YeIPh (Yerevan) and MEPhI (Moscow). The beams of the proton-rich nuclei of ^7Be, ^9C and ^8B were produced at the beam line of the U-400M cyclotron. The first experiment on studying the ^8B nucleus structure (a proton "halo" candidate) was performed. The preliminary analysis showed that the increase in the root-mean proton radius of ^8B compared with the radii of ^7B and ^9C may be interpreted as evidence of a proton "halo" in the nucleus of ^8B.

The production rates of different nuclei far from stability with $6 \leq Z \leq 14$ in $^{32,34}S$ induced reactions of energies up to 20 MeV/n were measured with the MSP-144 spectrometer. The data obtained were compared with the similar data from experiments performed at GANIL (Caen) at 75 MeV/A . The results give evidence of the contribution of multinucleon transfer reactions at various energies up to 30÷40 MeV/n.

The conclusion was drawn that transfer reactions have some advantages compared with fragmentation reactions used for the synthesis of radioactive nuclei (Fig. 8). This is important when selecting reactions to be used for the production of radioactive nucleus beams.

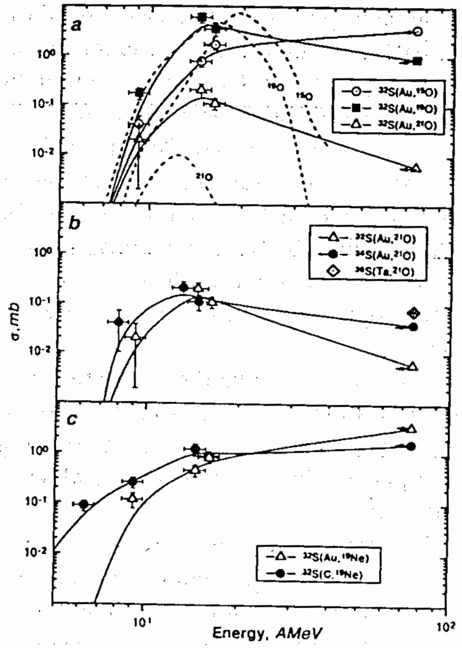

Fig. 8

The properties of very neutron-rich isotopes in the region of the neutron shells with N=20, 28 were studied within the framework of the GANIL - FLNR and FLNR - RIKEN collaboration.

The masses of nuclei close to the dripline were measured with high precision ($\frac{\Delta M}{M}$~10^{-6}). Evidence of the particle instability of ^{28}O, ^{33}Ne and ^{36}Na was found.

In 1997 the fragment separator COMBAS was carefully tested with heavy ion beams of ^{14}N and ^{12}C up to 50 MeV/n energies. The large solid angle (6.4msr) high-acceptance (20%) separator is capable of effectively collecting extremely short-lived nuclei with ultrasmall yields, which are produced in intermediate energy massive transfer reactions with wide momentum and angular distributions. The high intense primary beams (up to 10^{13} pps) of the U-400M cyclotron in conjunction with the high efficient separator COMBAS determine the advantages of this set-up. The first experiments (December 1997) were carried out to study the reaction mechanisms of the production of heavy isotopes up to 14 in the reaction ^{18}O (45 MeV/n)+^{9}Be.

Nuclear Reactions at Intermediate Energies

The FOBOS Set-up

The FOBOS set-up was further upgraded. In 1997 a new experiment was performed using a forward array of 80-phoswich counters. The analysis of the previous experiments led to the observation of new phenomena. For the first time the effect of pre-scission cooling in the fission of hot nuclei was observed in the fragment mass dispersion at excitation energies of 100-250 MeV.

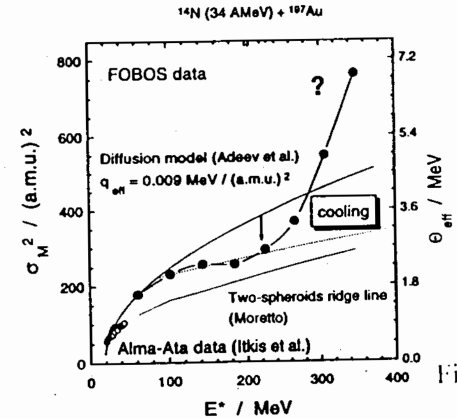

Fig. 9

It is ascribed to the creation of the mass distribution in a time around $4*10^{-20}$ s. Two-dimensional Langevin simulations reproduce the effect. A steep increase in the fission fragment mass width is found above excitation energy of 250 MeV. A decomposition of mass distributions reveals a rise in the additional broad component, which seems to be a switching on a new kind of a fast fission process. (Fig. 9).

The reactions ^{14}N (53 MeV/n)+^{197}Au and ^{232}Th were used to study the three-fold decay of hot heavy compound-like nuclei at excitation energies per nucleon < 3.5 MeV in competition with binary fission (Fig. 10).

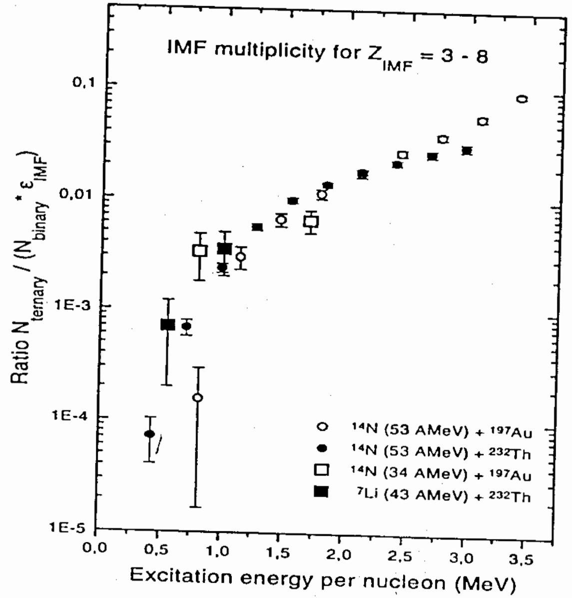

Fig. 10

Since the results for both targets are very similar, in central collisions decaying composite systems are mostly produced and the influence of the peripheral entrance channel can be neglected. The dominant three-fold decay mode is the sequential emission of an IMF from a target-like nucleus followed by the fission. Additionally, a simultaneous decay channel was identified from the observed Coulomb focusing effect of the lightest particle. The charge distribution of the lightest fragment group in this decay mode covers a large range up to the symmetric tripartition with a nearly constant yield for Z>10. The weaker dependence of the yield on induced E^* is in agreement with the description of this decay as a slow fission-like process. The relative velocities of the three fragments correspond with the collinear configuration of the tripartition. Based on these observations, we propose to interpret the measured data within the picture of the smooth transition from "neck"-emission to a symmetric

ternary fission process. The similar mode of tripartition, which is characterized by extremely low relative velocities and the isotropic emission of the third particle with respect to the fission axis, is interpreted as ternary fission accompanied by a delayed neck rupture.

A Russian-Chinese experiment was carried out on measuring the γ-ray, roentgen and proton spectra, and the yields of the nuclei formed in the reactions $^{92}Mo + ^{40}Ca$ and $^{97}Mo + ^{40}Ca$ at E_{lab} = 280MeV. Evidence was found for the new isotope ^{130}Sm being formed, which is the lightest nucleon-stable isotope of Sm. The reaction yields measured for more than 20 isotopes show that the channel of emitting only neutrons from the compound nucleus is suppressed. The compound nuclei of ^{132}Sm and ^{137}Sm formed in the reactions decay mainly emit protons and α-particles.

Physics and heavy-ion accelerator techniques

In 1997, due to the creation of an axial injection system for both U-400 and U-400M cyclotrons, new results concerning the intensity and quality of the accelerated beams were achieved. The most significant progress was achieved in accelerating Li(35 MeV/n) at the U-400M cyclotron, the beam intensity of the internal beam being 6 pmA and the beam intensity on the target being ~1 pmA. The modernization of the central part of the U-400M cyclotron and of the axial injection system elements was fulfilled. The creation of a buncher system allowed the beam intensity to be increased 2-3 times.

Experiments on producing intense beams of Ca and Li were performed with the ion sources DECRIS-14-2 and ECR4M at the test benches and axial injection systems. Significant progress in the production of metal ions was achieved by introducing a new microoven with a maximal temperature of up to 900 °C for evaporating metal samples. This microoven in combination with an additional tantalum sheet installed inside the discharge chamber allows one to produce $^{7}Li^{2+}$, $^{26}Mg^{3+}$ ion beams of more than 200 eμA.

Model experiments on producing intense beams of $^{48}Ca^{5+}$ using the efficient consumption of the working substances (Ca, CaO) were performed at the test benches and at the U-400 cyclotron. When the ECR4M source was operated in combination with the axial injection system of the U-400 cyclotron in the long-term mode at the intensity of the $^{40}Ca^{5+}$ beam equal to about 100 eμA, the consumption of ^{40}Ca was about 0,7 mg/h ($^{48}Ca^{5+}$, 30 μA, 0,2÷0,4 mg/h).

Ions of gases such as He, N_2, O_2 and Ar were successfully delivered from the DECRIS-14-2 source and accelerated at the U-400M cyclotron. The ion source showed good performances, especially for middle charge state ions (e.g. 600 eμA of Ar^{8+}), as well as high operational reliability.

Solid state radiation physics

Complex researches on the study of the radiation damage in semiconductors (Si, GaAs, monocrystal natural and artificial diamond, pirolitic graphite) and dielectric materials (LiF, Al_2O_3, mica) were performed. The investigations with irradiated polymers permitted one to elaborate new methods of manufacturing track membranes with ultra small pores and different pore shapes.

Detailed researches of the structure of the surface of the indicated above materials irradiated with 210 MeV Kr ions were carried out with the use of scanning electronic microscopy, tunnel and nuclear force microscopy of high resolution. For the first time it was shown that in the area where heavy ions enter the surface craterlike structures are formed and the removed material deposit on the intact surface. A new method of irradiating materials by high energy heavy ions was offered and realized, which allowed one to study the structure of the tracks of the ions focused along the surface.

The microstructure of defect zones was investigated, a new effect - the formation of the second peak of defects following the Bregg peak of displacement was found to occur in Si and GaAs as the ion fluency increases. The phenomenological model was advanced of the structure of the tracks of heavy ions with high specific ionization losses of energy in semiconductors and dielectric monocrystals.

On the basis of the advanced model of the track, investigation of the diffusion of impurities along heavy ions tracks was performed. It was shown that at the optimized temperatures of annealing the accelerated diffusion of impurity is observed. This will permit one to create conducting multilayers in materials.

Undoubtedly, the effects found has significant applied importance in the creation of new technology for electronic industry based on high-energy ion implantation.

Production of ultra pure radioisotopes for biomedical and ecological researches

The development of the methods was completed and for the first time monoisotope preparats of ^{237}Pu and ^{244}Pu with isotope cleanliness of 99,997% were obtained. These samples were used in the joint experiments with the Harwell Laboratory (Great Britain) on researching (in vivo) the plutonium metabolism in human body. This allowed one to perform a cycle of researches and to receive essentially new data.

A method for producing ^{178}W in the reaction ^{nat}Hf (4He, xn) at the FLNR U-200 cyclotron was developed. ^{178}W can be used as a generator of ^{178}W/^{178}Ta, which is used in nuclear medicine for cardiac diagnostics. It is especially perspective for children's cardiology because of the lowered radiating loading in comparison with widely used ^{99m}Tc, and also due to an opportunity of continuous, repeated and consecutive recurrence of functional inspections.

A high-sensitivity track method of the determination of ^{232}Th, U, ^{237}Np and Pu in earth, water, air, plants and biological objects was developed which uses the (γ, f)-reaction and has a limit of detection equal to $1\cdot10^{-13}$g, $5\cdot10^{-14}$g, $3\cdot10^{-14}$g and $1,5\cdot10^{-14}$g, accordingly, which is two order lower than that of known nuclear-physical methods of analysis. The given method was evaluated in more than 120 tests in the areas of northern Ukraine, Byelorussia and Ural.