JOINT INSTITUTE FOR NUCLEAR RESEARCH

99-327

M. G. Itkis

FLEROV LABORATORY OF NUCLEAR REACTIONS

RESEARCH ACTIVITIES IN 1999

Report to the 87th Session
of the JINR Scientific Council
January 13–14, 2000

Dubna 1999

M. G. Itkis

FLEROV LABORATORY OF NUCLEAR REACTIONS

RESEARCH ACTIVITIES IN 1999

Report to the 87th Session
of the JINR Scientific Council
January 13–14, 2000

Dubna 1999

The scientific activity of the FLNR in the field of heavy-ion physics traditionally has been developing in three main directions. They include experiments on the synthesis of heavy and exotic nuclei using ion beams of stable and radioactive isotopes and studies of nuclear reactions, acceleration technology, heavy ion interaction with matter and applied research.

In 2000-2002 in the field of nuclear physics, we will continue to undertake these investigations grouped in 11 projects in the framework of two themes and one all-Institute project - DRIBs:

- Synthesis of New Nuclei and Study of Nuclear Properties and Heavy Ion Reaction Mechanisms (8 projects);
- Development of the FLNR Cyclotron Complex for Producing Intensive Beams of Accelerated Ions of Stable Isotopes (3 projects).
- Development of the U400+U400M+MT25 cyclotron-microtron complex for producing radioactive ion beams (DRIBs – project).

These activities will be performed in a wide international collaboration using both the accelerators of the Laboratory and of other scientific centers.

Heavy Elements

A fundamental outcome of macro-microscopic theory is the prediction of an "island of stability" of superheavy elements. This intriguing hypothesis, proposed more than 30 years ago and intensively being developed during all this time, seems to have recently received an experimental confirmation in FLNR.

An important achievement of the Laboratory in 1994 -1998 was the experimental confirmation of a sharp increase in the superheavy nuclei stability to spontaneous fission near the neutron shell N=162.

Experiments carried out by the Dubna – Livermore (USA) collaboration at the U400 cyclotron, resulted in the synthesis of new isotopes of the elements Sg (Z=106), Hs (Z=108) and Z=110 in ^{22}Ne+^{248}Cm, ^{34}S+^{238}U and ^{34}S+^{244}Pu reactions. Within the framework of the GSI (Germany) - FLNR collaboration at the UNILAC accelerator new elements with Z=110, 111 and 112 were synthesized in ^{62,64}Ni + ^{208}Pb, ^{64}Ni + ^{209}Bi and ^{70}Zn + ^{208}Pb cold fusion reactions.

According to calculations carried out in different theoretical models, the nuclei with Z = 114 and N = 174, 175 should have a spherical shape in their ground state; the stabilizing effect of the strong neutron shell N = 184 should noticeably manifest itself.

The use of ^{48}Ca ions as projectiles in production of the heaviest elements is of special interest. Their neutron-excess makes it possible to gain access to compound nuclei whose neutron numbers are close to the predicted magic neutron numbers. The doubly magic structure (Z=20, N=28) of ^{48}Ca allows one to form relatively cold compound nuclei at energies close to the fusion barrier.

The experiments to search for new isotopes of element 112 in the ^{48}Ca+^{238}U reaction were performed at the electrostatic recoil separator VASSILISSA in 1998 and the results were reported at the 85th session of the JINR Scientific Council.

The production of an intense ion beam of the rare and extremely expensive isotope ^{48}Ca was the cornerstone in our attempts to synthesize superheavy elements. In order to achieve this aim it was necessary to carry out a modernization of the U400 accelerator, which included the development of a new external multi-charge ion source (ECR-4M) and an axial injection channel for a low-energy $^{48}Ca^{5+}$-beam (E_p = 60 keV) to the center of the accelerator chamber. Due to these improvements, an internal ^{48}Ca-beam with an intensity of 1.5÷2.0 pμA was obtained at a rate of material consumption equal to about 0.3 mg h^{-1}. The average intensity of the ^{48}Ca-beam on the target was about $4 \cdot 10^{12}$ pps.

In the $^{48}Ca + ^{244}Pu$ fusion reaction, isotopes of element 114 with maximum neutron excess can be synthesized. Such isotopes will most closely approach the peak of the "island of stability". In this reaction, at a bombarding energy close to the Coulomb barrier, we expect a maximum yield for the 3n- and 4n-evaporation channels.

The experiments on the synthesis of these nuclei were carried out at the Gas-Filled Recoil Separator. The target consisted of the enriched isotope ^{244}Pu (98.6 %). The projectile energy in the middle of the target was chosen equal to 236 MeV, and the excitation energy of the compound nuclei should be in the range 34 to 38.5 MeV. In these conditions two experiments were carried out.

In the first run, with a beam dose of $5.2 \cdot 10^{18}$ ions we found out the chain of sequential decays, which is shown in Fig. 1a.

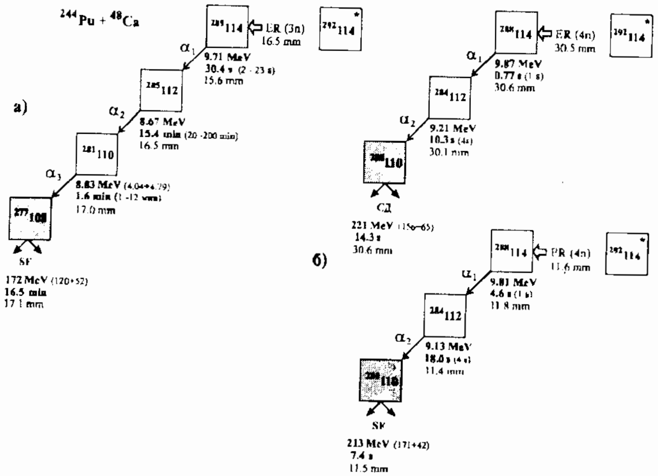

Fig. 1. Sequential decay chains, obtained in the $^{48}Ca + ^{244}Pu$ reaction. For the spontaneous fission fragments the values of the energies deposited in the front and side detector are indicated. For all registered signals the position coordinates are also indicated

An α-particle with an energy $E_{\alpha 1}$=9.71 MeV was emitted 30.4 s after the implantation of the heavy nucleus with a residual energy E_r=6.1 MeV and a $E_{\alpha 2}$=8.67 MeV, was observed after 15.4 min. A third α-particle was emitted 1.6 min later in the backward hemisphere: it deposited 4.04 MeV in the front detector and was absorbed in the side detector ($E_{\alpha 3}$=8.83 MeV). Finally, after 16.5 min the already mentioned above spontaneous fission was observed.

Indeed, such a scenario is expected for the decay of the superheavy nuclei of element 114. Considering the conditions of performing the experiment and the decay characteristics, the origin of the decay chain is most probably found in the isotope ^{289}114, which has been produced in the 3n-evaporation channel. The observed event corresponds to a cross section of about 1 picobarn.

In the second experiment, carried out in June – October 1999, the total beam dose amounted to $1.1 \cdot 10^{19}$ ions. Here two more α-decay sequences, terminating in spontaneous fission, were observed (Fig. 1b).

All 4 signals (EVR, α_1, α_2, SF) in both chains "a" and "b" have been found within a position interval of 0.5 mm, which gives evidence of a strict correlation between the observed decays. Within the limits of the energy resolution of the detectors (ΔE~50 keV) and the statistical uncertainty in the times of α-decays, both events coincide by all the 11 measured parameters, and thus belong to the decay of one and the same nucleus. The probability of random coincidences of the signals imitating correlated events in the observed decay chains is about $5 \cdot 10^{-17}$.

Finally, the granddaughter nucleus ^{280}110 undergoes spontaneous fission with a half-life $T_{SF} = 7.5^{+13.7}_{-3}$ s. The energy deposition in the detectors from the spontaneous fission fragments of this nucleus is E_{tot}=217 MeV. According to the calibration of the detectors with the ^{252}No ($\overline{TKE}$=190 MeV) spontaneous fission fragments, such high energy deposition corresponding to TKE~225 MeV can only be observed in the decay of a very heavy nucleus with $Z \geq 110$.

The projectile energy corresponds to an excitation energy of the compound ^{292}114 nucleus equal to E_x=38±2 MeV. At this energy the most probable 4n-evaporation channel leads to the formation of the isotope ^{288}114.

The isotope of element 114 with N=173 - ^{287}114 - can be synthesized via the 3n-evaporation channel in the $^{48}Ca + ^{242}Pu$ reaction. It should predominantly undergo α-decay to the daughter nucleus ^{283}112, which has been found in the $^{48}Ca + ^{238}U$ reaction.

The experimental conditions of the experiment, performed in March and April 1999, were practically identical to the ones for the synthesis of the isotope ^{283}112 in the $^{48}Ca + ^{238}U$ reaction. The rotating 0.2 mg/cm^2 thick ^{242}Pu target was bombarded by a 235 MeV ^{48}Ca-beam with a total beam dose of $7.5 \cdot 10^{18}$ ions. The most probable deexcitation channel of the compound nucleus ^{290}114 ($E_x \approx$33.5 MeV), corresponding to the emission of 3 neutrons, leads to the formation of the even-odd isotope ^{287}114 (N=173).

The spontaneous fissions were observed as two coincident signals (two fission fragments) with TKE=195 MeV for the first event; and with TKE=165 MeV for the second event. The search for α-decays preceding the spontaneous fission events led to the discovery of the two decay chains presented in Fig. 2.

As the total energy E_α for the second event is not determined, obviously we can assume that the α-decay in both cases proceeds from one and the same state of the parent nucleus. The half-life of the latter, derived on the basis of the two events, amounts to $T_\alpha = 5.5^{+10}_{-2}$ s. The detected daughter nuclei undergo spontaneous fission. Their decay properties are comparable with the ones of the spontaneously-fissioning nuclide produced earlier in the $^{48}Ca + ^{238}U$ reaction. Moreover, all four spontaneous fission events, observed in these two experiments, within the experimental error, can be described by the same half-life $T_{SF}=3.0^{+2.8}_{-1.0}$ min and can be attributed to the decay of one and the same nucleus.

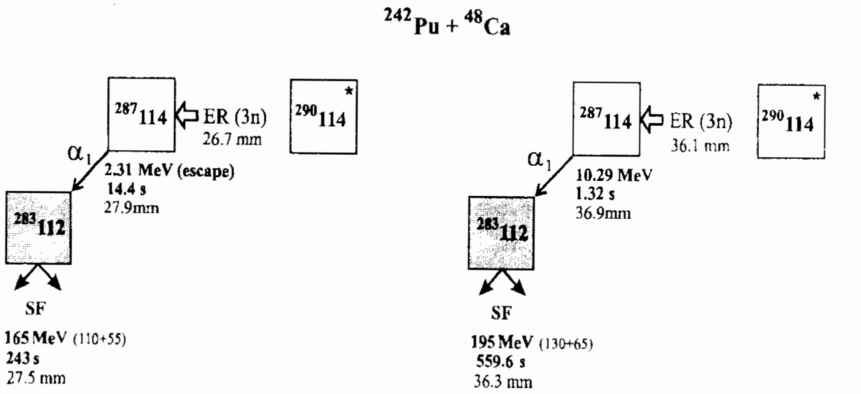

Fig. 2. Sequential decays observed in the ^{48}Ca (235 MeV)+^{242}Pu reaction

In the $^{48}Ca+^{238}U$ reaction this nuclide was produced directly as an EVR in the 3n-evaporation channel, while in the $^{48}Ca+^{242}Pu$ reaction it is the daughter of the α-decay of the parent $^{287}114$ nucleus (E_α=10.29 MeV). The production cross section of the new isotope of element 114 amounts to about 2 pb. Its half-life and the decay sequence are shorter than the ones of the previously observed heavier isotope $^{289}114$, formed in the reaction $^{48}Ca+^{244}Pu$ through the 3n-evaporation channel and the intermediate even-even isotope $^{288}114$ (Fig. 1). Such a trend is expected, according to theory, with the decrease of the neutron number of the superheavy nucleus, or in other words with moving away from the closed N=184 shell.

Summarizing the results of the three experiments performed using the ^{48}Ca-beam with a total beam dose of about $2.2\cdot10^{19}$ we come to the following conclusions.

The spontaneous fission events (TKE~200 MeV) are related to the decay of heavier and considerably long-lived nuclei (T_{SF} ~10÷1000 s). In the $^{48}Ca+^{238}U$ (Z_{CN} = 112) reaction they are formed as parent nuclei, while in the experiments with the $^{242,244}Pu$ targets (Z_{CN} =114) they are daughter nuclei of heavier products.

For the four events of sequential α-decay, terminated by spontaneous fission, the energies and decay probabilities obey the basic rule of Geiger-Nuttall, which connects the α-decay energy Q_α and the half-life T_α. The values of the energies and decay probabilities imply decays of nuclei with large atomic numbers (Z=110÷114). According to the conditions of the experiment the parent nuclides are formed in fusion reactions in 3n- or 4n-evaporation channels. The cross sections for these reaction channels amount to one or several pb.

During the period of 2000-2002, the investigations will be aimed at the synthesis of nuclei with Z ~110-116 in the ^{232}Th, $^{236,238}U$, ^{237}Np, $^{242,244}Pu$, $^{241,243}Am$, $^{246,248}Cm+^{48}Ca$ reactions. It is noteworthy that the even-odd and the odd-odd isotopes, which can be produced in reactions with ^{237}Np, ^{243}Am or ^{249}Bk targets, may happen to be even more long-lived.

Both facilities - VASSILISSA and Gas-Filled Recoil Separator (GFRS) - will be used in these experiments. For 2000 it is planned to continue the upgrading and reconstruction of the GFRS (electronic and detector systems) and of the VASSILISSA (improvement of the mass-resolution, electronic and detector systems).

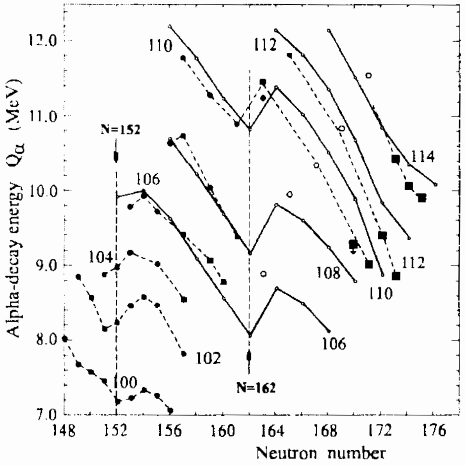

Fig. 3. The α-decay energy – Q_α as a function of the number of neutrons for the isotopes with Z=100÷114 (these are denoted in the Figure). The solid lines denote the calculated values, the black points – the experimental values, the black squares – the results obtained in ^{48}Ca-induced reactions, the open circles – the results of V.Ninov et al. ($^{86}Kr+^{208}Pb$). The dashed lines are drown through the experimental points to guide the eye.

Experiments will be carried out in collaboration with LLNL (Livermore, USA), GSI (Darmstadt, Germany), Comenius University (Bratislava, Slovakia), University of Messina (Italy), RIKEN (Japan).

Chemistry of Transactinides

The investigation of chemical properties of new elements is one of the traditional FLNR research programs. A series of collaborative experiments was conducted in the FLNR together with scientists from Switzerland, Germany and Poland. New results on the properties of Rf and Sg were obtained.

In 1999 - 2000 it is supposed to measure some physico-chemical properties of volatile compounds of elements with Z ≥106 by gas (thermo) chromatography and to study their complexation in solutions by ion exchange and extraction techniques and the upgraded setup KIT.

The relatively long half-lives of the isotopes with Z =108÷14, obtained in ^{48}Ca-induced reactions, open new opportunities for investigation of the chemical properties of these elements. A question arises as to whether these isotopes are homologues of the heavy metals Os ÷ Pb. This strongly depends on the relativistic effect of the heavy-atom electron structure, which influences their chemical properties. This question is a fundamental one for modern chemistry.

Element 108 (hassium) is expected to be a chemical homologue of Ru and Os. There are good prospects for selective separation of hassium from the transactinoid and actinoid elements with Z<108 making use of the unique chemical group property of Ru, Os, and Hs –formation of very volatile stable tetroxides, $Os(Ru)O_4$. We found that Os atoms rapidly form OsO_4 in a $Ar+O_2$ mixture at 800-900°C.

The final test experiments were done with short-lived alpha-active $^{171-174}Os$ produced in the reaction $^{158}Dy+^{20}Ne$. With the help of the Ar/O_2 carrier gas, the thermalized recoil atoms were transported into a hot cell and then to a quartz chromatographic column (see Fig. 4).

The volatile compound of Os passed through the column, while the less volatile oxides of interfering elements were deposited on the walls of the gas duct. When the gas stream was mixed with a Pb aerosol, OsO_4 attached to the Pb particulates, which could be transported through a 10 m long capillary to a counting room in a few seconds. Here, the aerosol was repeatedly collected for 20 s by impact on a tape, which then was stepped. An overall yield (chemical conversion, transportation, deposition) of 50 - 60% was achieved.

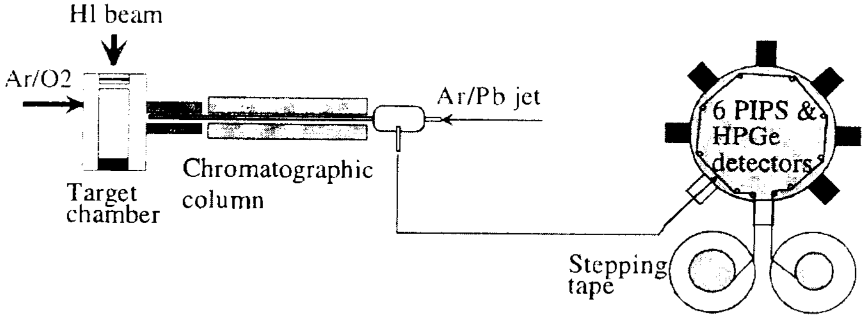

Fig. 4. Shematic view of the upgraded set-up KIT

Each aerosol spot was successively measured with 6 PIPS detectors for 120 s in 2π - geometry (Fig. 5). The spot was 3-4 mm in diameter and about 30 $\mu g/cm^2$ in thickness. With these parameters, the identification of the isotopes of element 108 from the bombardments of $^{248}Cm+^{26}Mg$ or $^{238}U+^{36}S$ are feasible. A 4π- geometry measurement device with a much higher efficiency for mother – daughter events will be provided by GSI for collaborative experiments.

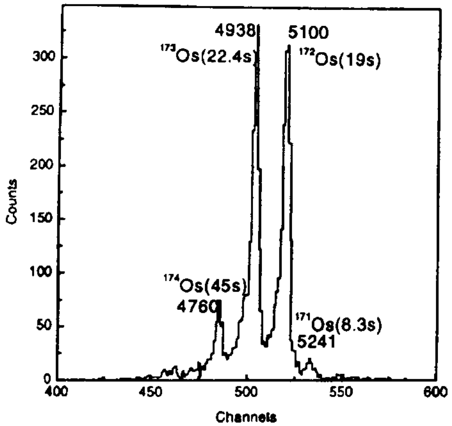

Fig. 5. Alpha-spectrum of the short-lived $^{171\text{-}174}Os$-isotopes produced in the test reaction $^{158}Dy+^{20}Ne$. The FWHM resolution is about 40 keV

Planned for 2000 is the on-line chemical isolation and identification of heavy isotopes of element with Z=112 produced in $^{238}U(^{48}Ca,3\text{-}4n)$ reactions with the detection of the α-decay and spontaneous fission.

Nuclear Fission

Interest in the study of the fission process of superheavy nuclei in reactions 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 ≈15÷30 MeV, 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 mutiplicity of the pre- and post-fission neutrons, the kinetic energy of the fragments and the peculiarities of the mass distributions of the fission and quasi-fission fragments etc.

In this connection experiments on the fission of superheavy nuclei in the reactions $^{208}Pb+^{48}Ca\rightarrow^{256}No$, $^{238}U+^{48}Ca\rightarrow^{286}112$, $^{244}Pu+^{48}Ca\rightarrow^{292}114$, $^{208}Pb+^{86}Kr\rightarrow^{294}118$ were carried out at FLNR JINR in 1999. 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 and $^{293}118$ at Berkeley in the same reactions.

The experiment was carried out on the extracted beam of ^{48}Ca and ^{86}Kr ions of the FLNR JINR U400 accelerator using the time-of-flight reaction products spectrometer CORSET, the 24 detector neutron spectrometer Demon and the 4 detector scintillation γ-quanta multiplicity spectrometer.

The reaction fragments spectrometer allows one to obtain the mass energy and angular distributions of fission fragments and scattered particles. The time resolution of the spectrometer was better than 150 ps and the mass resolution ≈3 amu.

Fig. 6 shows the TKE--M two-dimensional matrices for the studied reactions at the energy of ^{48}Ca ions E_{lab}=233 MeV and ^{86}Kr ions E_{lab}=453 MeV, which corresponds to the excitation energy of compound nuclei of ^{256}No, $^{286}112$ and $^{292}114$ $E^*\approx 33$ MeV, and of compound nuclei of $^{294}118$ $E^*\approx 15$ MeV. It is clearly seen that the form of the TKE - M matrix between the elastic scattering peaks changes drastically as one goes from ^{256}No to the superheavy nuclei.

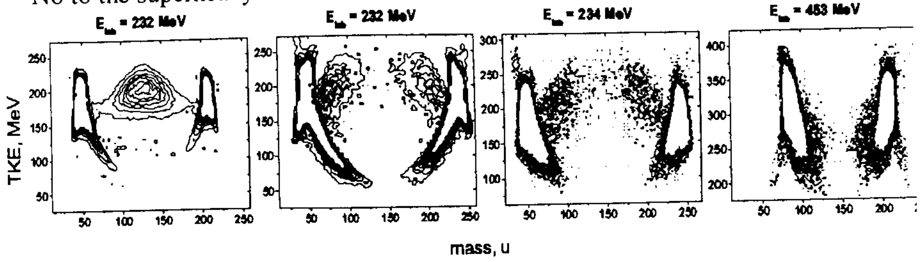

Fig. 6. Two-dimensional matrices TKE-Mass of the products of the indicated reactions.

For ^{256}No it is of a triangular form characteristic of compound nucleus fission; and only at its edges the contribution is seen of events that can be considered as quasi-fission. As one goes to the ^{286}112 nucleus, the quasi-fission process becomes distinctly dominant in the TKE-M matrix, the maximum yield of fragments lying around mass 208 and additional to it.

For the ^{292}114 nucleus the picture again changes, it is seen that the intensity of the quasi-fission peaks in relation to the yield of fragments in the symmetric mass region differs essentially from the similar ratio for the ^{286}112 nucleus. This tendency is more clearly seen from the lower part of Fig. 7, which shows the yields Y(M) for the two reactions ^{48}Ca+^{238}U and ^{48}Ca+^{244}Pu, which correspond to an approximately similar fluence of ^{48}Ca ions at the target.

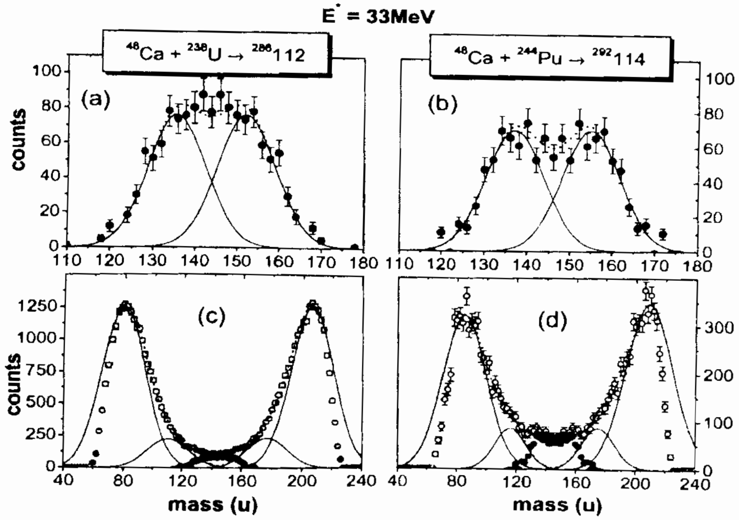

Fig. 7. At the bottom: mass distributions of the reaction products. Open points show the experimental data; solid points represent the extracted components, corresponding to the compound nucleus (CN) fission. At the top: the extracted components of CN fission and their description by a sum of two Gaussians.

The obtained ratio between the intensities of the quasi-fission peaks for these two reactions is ≈6÷8 in favour of ^{48}Ca+^{238}U. At the same time, as seen from the upper part of Fig. 7, the distributions Y(M) in the symmetric mass region (A/2±25), derived using the same technique and corresponding, in our opinion, to the fission of ^{286}112 and ^{292}114 compound nuclei, differ little from each other in shape, the intensity of the maximum and the area of the distributions.

Hence it follows that the fission cross section for compound nuclei of ^{286}112 and ^{292}114 (and consequently the cross section for the complete fusion and production of compound nuclei) are approximately equal, whereas the quasi-fission cross section differ by a factor of 6÷8.

Another important consequence of these data is that the asymmetric shape of the mass distribution has been observed. In this case, as opposed to the case of actinide nuclei, the stabilizing role appears to be played by the nearspherical shell of the light fragment of mass 130÷134, but not by the deformed shell of the heavy fragment of mass ≈140.

On the whole, the analysis performed of the mass and energy distributions of the fission fragments of nuclei in reactions with ^{48}Ca ions allowed reasonably reliable values to be found for the quasi-fission and fission cross sections of compound nuclei of ^{256}No, ^{286}112 and ^{292}114. Table 1 presents both the results obtained from the studied reactions with ^{48}Ca ions and our estimates for the quasi-fission and fission of the compound nuclei for the reaction ^{86}Kr+^{208}Pb.

Table 1: Cross-sections and TKE.

Reactions	E_{lab}(MeV)	E^* (MeV)	σ_{fis}	$\sigma_{fis}/\sigma_{cap}$ %	‹TKE›(MeV)
^{48}Ca+^{208}Pb	230	33	350 mb	96	193
^{48}Ca+^{238}U	232	33	6 mb	3	215
^{48}Ca+^{244}Pu	233.5	33	4 mb	9	220
^{86}Kr+^{208}Pb	486	28	~6 μb	$\leq 10^{-3}$	260
^{86}Kr+^{208}Pb	453	15	≤500 nb	-	260

In the case of the reaction ^{86}Kr+^{208}Pb, in the symmetric fission region (A/2±30) the quasi-fission process dominates, by which this reaction differs sharply from the reaction ^{48}Ca+^{238}U and especially from ^{48}Ca+^{244}Pu, in which the contribution of the compound nucleus fission in the same region of fragment mass is dominant.

From this the conclusion could be drawn that more symmetric reactions similar to ^{86}Kr+^{208}Pb are far less promising for producing superheavy nuclei. Nevertheless the recent results of the synthesis of element 118 in the cold fusion reaction ^{86}Kr+^{208}Pb at Berkeley deny such an assumption, that is, if the value σ_{ev}=2 pb obtained from this experiment is correct, then the relationship between the fission width and neutron width at excitation energy of ≈15 MeV changes drastically in favour of the survival of the compound nucleus as compared with the case of "cold" fusion in the reaction ^{48}Ca+^{208}Pb at the same excitation energy and the case of "warm" fusion in the reactions ^{48}Ca+^{238}U and ^{48}Ca+^{244}Pu. Therefore further research in this direction is extremely interesting both to fission physics and to the problem of synthesising superheavy nuclei.

Measurements of subbarrier fusion-fission in the Pb,U,^{244}Pu,^{248}Cm + (^{48}Ca, ^{58}Fe, ^{64}Ni, ^{86}Kr) reactions and the analysis of low energy fission dynamic using a 4π-array neutron multidetector "Demon" and fission fragment trigger "Corset" will be continued. It is planned to continue the investigation of the influence of shell effects on the ^{252}Cf spontaneous fission dynamics. Experiments will be carried out in collaboration with: Vanderbilt University (Nashville, USA), INPN (Catania, Italy), ISN (Grenoble, France), University of Brussels (Belgium), University of Texas (USA), IP (Bratislava, Slovakia), INP (Alma-Ata, Kazakhstan).

Formation and Decay of Hot Nuclei

At the recoil separator VASSILISSA the de-excitation reaction of compound nuclei with the excitation energies of up to 300 MeV and evaporation of protons, α-particles and up to 20 neutrons will be studied in reactions of ^{40}Ar, ^{40,48}Ca with ^{144,154}Sm targets. It is planned to determine fusion and survival probabilities of the compound nuclei formed at the fusion reactions with double magic ^{48}Ca ions and to compare these results with our recent experiments leading to the same compound nuclei with the use of different bombarding ions. These experiments will allow to obtain data for the complete fusion reactions leading to the heavy compound nuclei with Z ≥86, to obtain new data for the fission barriers and fissility of the nuclei at the region Z≥90. Investigations of deep subbarrier fusion for the reactions ^{12}C + ^{204,208}Pb are planned. Experiments will be carried out in collaboration with GSI (Darmstadt, Germany), Comenius University (Bratislava, Slovakia), INPN (Catania, Italy), University of Messina (Italy), RIKEN (Japan).

Fragment-Separator COMBAS

During the year 1999 a number of experiments has been carried out devoted to the reaction mechanisms study in nucleus-nucleus collisions at intermediate energies and the determination of the intensity of secondary radioactive beams of halo-like nuclei: ^{11}Li, ^{12}Be and ^{14}Be.

The measurements have been performed by using the double achromatic separator of charged reaction products - COMBAS in the forward angle spectrometry. Inclusive yields of the isotopes with the atomic number $2 \leq Z \leq 11$ produced in reactions of ^{18}O (35 A· MeV) with ^{9}Be (light target) and ^{181}Ta (heavy target) have been measured.

The isotopes near the stability line or proton rich isotopes produced in more massive stripping nucleons are characterized by asymmetric shapes of the isotopic velocity distribution with the following behaviour:

- the maximum yields are concentrated near the beam velocity and a tendency of the broadening of width is observed as the number of the transferred nucleons increases,
- a gaussian-like fall down on the high-velocity side with a tendency of increasing the width as the number of the transferred nucleons increases,
- exponentially falling down tails of the low-velocity side with a tendency of exponential rising tails as the number of the transferred nucleons increases (becomes flattened).

The group of weakly-bound isotopes (^{8}He, ^{11}Li, ^{14}Be and ^{15}B) has a single component gaussian-like shape of velocity distributions with a maximum close to the beam velocity and with a tendency of increasing width as the number of the transferred nucleons increases.

The Q_{gg} - systematics serving as a criterion for the binary production of isotopes is displayed in Fig. 8. The exponential function drawn through the points corresponding to neutron-rich isotopes of ^{6}He and ^{8}He fits good the experimental data for isotopes of each element. For isotopes with $2 \leq Z \leq 10$ exponential approximation is made by shifting of the same exponent. The simple exponential approximation realized by the Q_{gg} - systematics discribes as the whole the yields of the isotopes produced in stripping nucleon reactions with large negative Q_{gg} values.

No evidence was found for any dramatic reaction mechanism change for peripheral reactions in comparison with the same in low energy range. In the beam direct selection of isotopes produced in far peripheral nucleus-nucleus collisions in the Fermi energy domain the dominant of stripping, pick-up and exchange nuclear reactions are observed. For isotopes around the stability line considerable contributions from dissipative processes (orbiting effects) are registrated. The production rates of exotic nuclei of ^{9}Li, ^{11}Li, ^{11}Be, ^{12}Be and ^{14}Be have been also determined, which can be used as secondary radioactive beams of halo-like nuclei (Table 2).

Table 2. The production rates of halo-like isotopes of Li and Be induced in the reaction of 35A MeV ^{18}O on the ^{9}Be target (200-mg/cm^{2}). The primary beam current on the target was 10 μAe.

Secondary beams (pps)				
^{9}Li	^{11}Li	^{11}Be	^{12}Be	^{14}Be
$5 \cdot 10^{5}$	$6 \cdot 10^{3}$	$3 \cdot 10^{5}$	$3 \cdot 10^{5}$	$5 \cdot 10^{2}$

In 2000-2002 using intermediate energy projectiles the yield and properties of heavy oxygen isotopes will be studied in reactions ^{36}S,^{40}Ar(20÷60 MeV· A)+^{9}Be,Ta. A track focal plane detector on the basis of a multilayer drift chamber will be constructed. Experiments will be carried out in collaboration with GSI (Darmstadt, Germany), Comenius University (Bratislava, Slovakia).

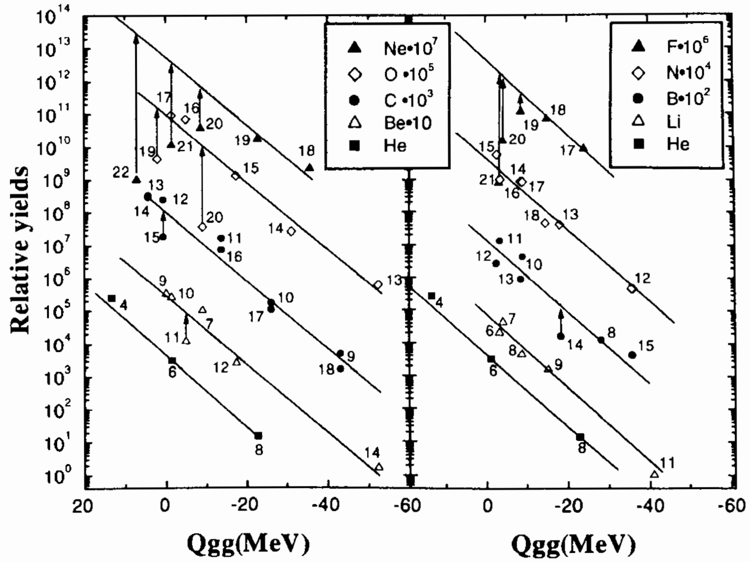

Fig. 8. Isotopic yields of elements with 2≤Z≤10 versus the Q_{gg} – values (the Q_{gg}-systematics). The value Q_{gg} is $(M_p+M_t) - (M_{det}+M_{undet})$, where M_p, M_t, M_{det} and M_{undet} are the ground state masses of the projectile, target, detected isotope and undetected isotope (the partner of detected isotope in the exit channel of the reaction) accordingly. Arrows for the isotopes O, F and Ne show a decrease in the yields of the isotopes as a possible consequence of the influence of the deexcitation effects. The numbers near isotopes (in frame) show the multiplied factors of the experimental yields.

High Resolution Beam Line ACCULINNA

The ACCULINNA separator was designed and built for the realisation of a physics program dedicated to the direct reaction study with radioactive ion beams. With primary beams of (32-34) A· MeV ^{7}Li and ^{11}B ions delivered by the U-400M cyclotron we obtained (20-30) A· MeV secondary beams of ^{6}He and ^{8}He nuclei focused on a physics target of 0.8 cm^2 in its area.

These secondary beams had intensities of 3×10^5 and 1×10^4 respectively, when the routinely produced primary beam intensity on the Be target made 4 pμA. A 36A· MeV beam of ^{6}He was obtained with a 42A· MeV primary beam of ^{13}C. The secondary beam energy spread was about 5 % (FWHM). Multi-wire proportional chambers installed on the beam path to the target provided a resolution of 1.5 mm and 0.15 degrees, respectively, in the hitting position and inclination angle for an individual projectile. The experimental installation used in our experiments is illustrated in Fig. 9.

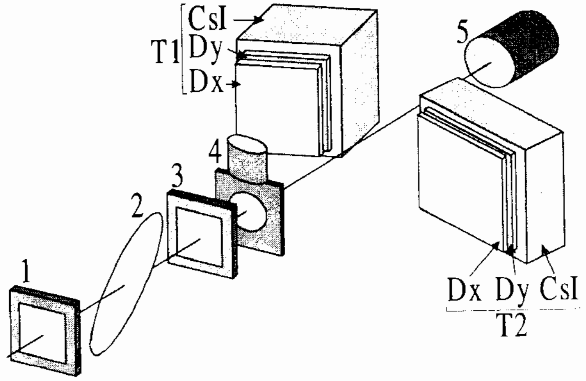

Fig. 9. Detector array. Particle telescopes T1 and T2 involve each two 400 Si strip detectors, Dx and Dy, and one thick CsI crystal. Installed on the beam axis are the target (4), two multi-wire proportional chambers (1 and 3) and plastic scintillation counters 2 and 5.

We concentrated our attention on the transfer reactions occurring between ^{6}He and ^{8}He projectiles and helium and hydrogen target nuclei. In the case of a ^{4}He target, these reactions could be the two- and four-neutron transfers, respectively, for ^{6}He and ^{8}He, i.e. an exchange effect, which could be observed in the center-of-mass frame as elastic scattering in the backward direction. Two-neutron transfer between ^{6}He and ^{1}H nuclei also could be a good test for the predictions made by the three-body model of ^{6}He.

In experiments involving the beam of ^{8}He nuclei the GANIL cryogenic gas target was used. In the study of the resonant states of ^{5}H and ^{7}He the RIKEN array of annular silicon detectors was used extensively together with the GANIL target.

The angular dependence of the differential cross section for the elastic scattering of 151 MeV ^{6}He nuclei from ^{4}He is shown in Fig. 10. A one-step, two-neutron exchange mechanism could account for the obtained distinct rise in the cross section at the backward center-of-mass (CM) angles. This result can be interpreted as experimental evidence in support of the theoretical wave function. The calculations also showed that the "cigar"-like configuration alone could contribute only negligibly to the obtained two-neutron exchange, which is thus by about 100% due to the "di-neutron" configuration.

Thus, on the basis of the data on 2n-transfer reactions one draws a conclusion that the three-body α+n+n configuration seems to be prevailing in the Borromean ^{6}He nucleus, and its "di-neutron" component dominates in the 2n-transfer reactions induced by ^{6}He at energies close to 25 MeV/nucleon. The damping of the ^{6}He t+t clustering could be an indication of new structural properties of halo nuclei.

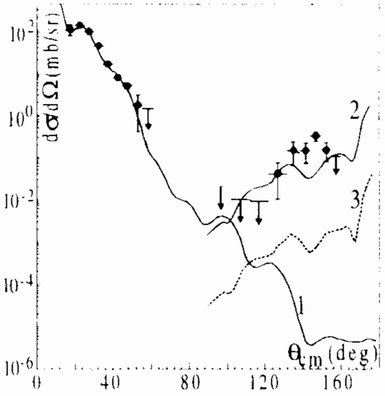

Fig. 10. Differential cross section for elastic scattering of 151 MeV ^{6}He ions from a helium target. Curves: 1 – OM fit to the data obtained in the forward hemisphere. 2 – DWBA calculations with an approximation to the full 3-body wave function, 3 – calculations taking only the "cigar"-like component of the wave function.

We carried out experiments aimed at the observation a 4n-exchange effect in the elastic scattering of 210 MeV nuclei of ^{8}He from helium target nuclei. The data shown in Fig. 11 indicate that, in spite of rather low cross section limits achieved for the CM angles lying between 140 and 165 degrees, the 4n-transfer effect is not seen.

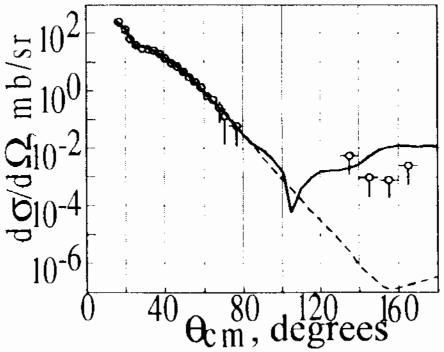

Fig. 11. Data on the elastic scattering of ^{8}He on ^{4}He (circles). Curves for calculations: OM (dashed) and 4n-transfer (solid) processes

The result of an OM calculation is shown in Fig. 11 with a dashed curve. To simulate the 4n-transfer process a one-step DWBA four-neutron exchange mechanism was exploited. The four neutrons in the ^{8}He nucleus were treated as a cluster, and the spectroscopic factor equal to one was assumed for this four-neutron cluster. Looking at the solid curve in Fig. 11, one sees that the simple, one-step, single particle, DWBA analysis of this process shows that the expected cross-section values for the 4n-transfer are close to and/or slightly exceed the achieved sensitivity limits in this angular range. Therefore, we come to a preliminary conclusion that the 4n-transfer from ^{8}He to ^{4}He can hardly occur with a large spectroscopic factor.

A series of experiments aimed at the observation of the ^{5}H ground-state resonance ended with an unambiguous result. As one can see from Fig. 12, the long-term puzzle of ^{5}He is resolved. The ground-state resonance of ^{5}H was obtained in the reaction ^{6}He+p$\rightarrow$^{5}H+2p. The binary kinematics condition for this reaction is provided due to the two-proton virtual-state interaction. The resonant state that is about 2 MeV above the t+n+n disintegration threshold could be revealed in the spectrum of the total energy of correlated protons emitted in the reaction exit channel. The width of this peak is mainly due to the apparatus resolution. The real width of the ^{5}H ground-state resonance is estimated to be by about one order of magnitude of the peak width seen in Fig. 12. The rest of the count distribution shown in this figure is well understood in terms of the space volume that is obtained with the real detector array that gives a limitation at the right side of the shown distribution.

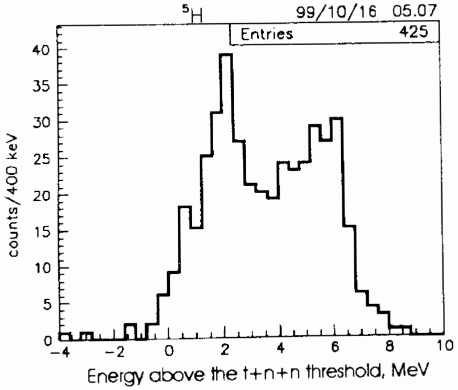

Fig. 12. The energy spectrum of space-correlated two-proton pairs detected in the reaction ^{6}He+p$\rightarrow$^{3}H+2p+n+n at a ^{6}He projectile energy of 36A MeV. Energy above the t+n+n threshold is presented in the abscissa axis

Recently we completed experiments where the population of different resonant states of ^{7}He occurring in the one-neutron transfer on ^{6}He from deuterium was investigated. The data are being analyzed at present to extract new information about the structure of the ^{7}He ground state p3/2 resonance and possible observation of another p1/2 resonant state in this nucleus.

Elastic scattering and 2n transfer reaction occurring as a result of ^{8}He+^{4}He collisions will be investigated with a 25A MeV beam of ^{8}He ions in a CM angular range of 25 – 165 degrees. The limiting cross-section sensitivity of these experiments will be extended down to 0.1 microbarns/steradian, what is by one order of magnitude better than the limits obtained in the 1999 experiments.

Upgrade of ACCULINNA involving the extension of the ACCULINNA beam line with its exit from the cyclotron hall, installation of a liquid-tritium target, installation of neutron detectors and starting experiment involving the liquid-tritium target are planed.

Mostly, experiments exploiting of the potential of the liquid-tritium target will be conducted in 2001 -2002. This potential allows obtaining new result about resonant states of all the light exotic nuclear systems lying on the right side of the neutron drip line.

The work at ACCULINNA was performed in collaboration with the groups of GANIL (Caen, France) and YerPhI (Yerevan, Armenia). The part of the work related to ^{5}H and ^{7}He was carried out in collaboration with the groups of RIKEN (Saitama, Japan) and Kurcharov Institute (Moscow, Russia), GSI (Darmstadt, Germany) and Comenius University (Bratislava, Slovakia).

Nuclear Reactions at Intermediate Energies - the 4π - detector FOBOS

For 2000 the modernization of beam guide line 7 of U-400M (the FOBOS transport line) for producing secondary beams of proton-rich nuclei ^{8}B, ^{17}Ne, ^{20}Na with an intensity of ~$10^4 s^{-1}$ and energy resolution of $2 \cdot 10^{-3}$, experiments for the study of quasi-elastic scattering of ^{8}B at a hydrogen target and investigation of many-body correlations in the ^{8}B break-up are planed.

In 2000-2001 the results obtained at the ACCULINNA- and at the MULTI- beam-lines are to be applied in production of RIB - ^{6,8}He, ^{8}B in the main beam line of U-400M with the purpose of performing experiments at the FOBOS set-up. Experiments for investigating the interaction between ^{6}He and ^{8}He nuclei with heavy element targets (Pb, U, Cm) and registration of reaction products using a 4π spectrometer FOBOS and study of the interaction between the proton-rich ^{17}Ne and ^{20}Na nuclei with targets will be performed.

Setup MULTI

In 1999 the creation has been completed of the MULTI multimodule spectrometer designed for measuring the characteristics of nuclear reactions with stable and radioactive beams. The spectrometer includes multilayer scintillation and semiconductor (including epitaxial) detectors, position-sensitive proportional chambers, BGO-scintillation hodoscopes. Its time and position resolution (~1 ns and no worse than 1 mm respectively) and capability to simultaneously register several particles providing measurement of their energies at the same time (energy resolution no worse than 1%) allow complicated correlation experiments to be carried out on researching the breakup of the exotic proton-rich nuclei of ^{8}B, ^{10}Ne, ^{20}Na etc.

Using this spectrometer, experiments have been started at the U-400M cyclotron that are aimed at investigating the interaction of nuclei having an assumed proton halo with the target nuclei. The cross sections have been measured for the interaction of ^{8}B with silicon and hydrogen targets.

Within the framework of the DRIBs project, experiments have been started on laser spectroscopy of the fission fragments produced in irradiation of a uranium target on the microtron. The yields of fragments have been measured for the photofission of uranium over a wide range of mass numbers. For one of the fragments, ^{155}Eu, which is produced in the strongly asymmetric fission of ^{238}U, measurement has been carried out using a laser spectrometer in the off-line mode. The values for the charge radii, magnetic dipole and electric quadrupole moments have been determined.

The collaborative FLNR-GANIL experiments aimed at investigating the detecting properties of the MULTI setup have been continued. Using ^{36}S and ^{48}Ca beams, the masses and deformations have been measured for about 20 nuclides lying between the neutron shells N=20 and N=28. The deformation was measured with the use of the "clover"- detectors of the Eurogamma γ-spectrometer. In the γ-spectra of ^{30,32}Mg, $^{26-28}$Ne, ^{22}O, ^{12}C, the lower states have been investigated, and the probability ratios have been determined for the E2$^+$/E4$^+$ transitions. The measurement showed that the magic nucleus of ^{32}Mg is strongly deformed (β=0.3) (see Fig. 12), and that the same is true for the other nuclei near the neutron shells N=20 and N=28.

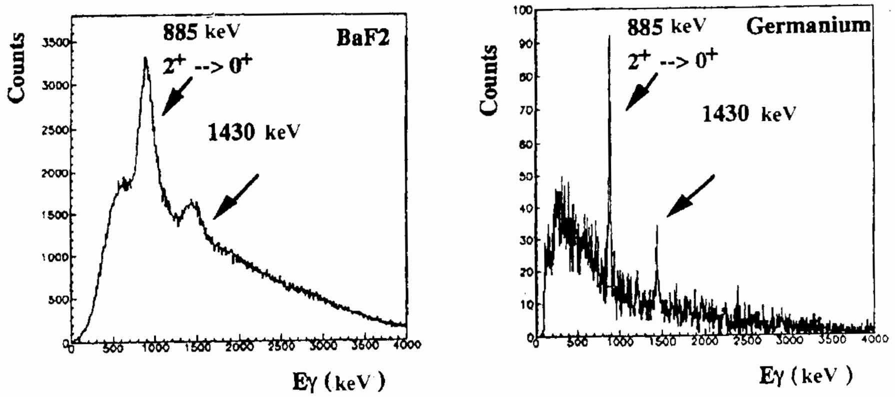

Fig. 12. Gamma-spectra of ^{32}Mg and BaF$_2$ (at the left), and germanium detector (at the right). Level 885 keV corresponds to the $2^+ \rightarrow 0^+$ transition. Level 1.4 MeV corresponds to $4^+ \rightarrow 2^+$ transition.

This result testifies that the stability of the nuclei close to the neutron drip-line is strongly influenced by their deformation. In the collaborative FLNR-GANIL experiments, the properties (masses, deformations) have been studied of about 20 nuclides lying between the neutron shells N=20 and N=28.

In the collaborative FLNR-Jyväskylä Accelerator Laboratory (Finland) experiments, carried out with the use of the detector modules of the FOBOS setup, the decay has been investigated of nuclear systems produced in the reaction ^{238}U+^{40}Ar. For the first time, fine structure has been revealed in the mass distribution of fission fragments of the system ^{278}110 with initial excitation energy of 60 MeV. This structure manifests itself as separate peaks situated in the vicinity of the mass numbers A~70, 100, 130 characteristic of the magic nuclei (clusters) of Ni, Zn, Sn, Sr.

A set of experiments on production and investigation of the properties of very neutron-rich isotopes in collaborations with GANIL (Caen, France) and RIKEN (Saitama, Japan) will be performed.

Investigation of the Nuclei Structure by Laser Spectroscopy

In 2000-2002 it is planned to perform the measurements of the charge radii, magnetic dipole and electric guadrupole moments for the nuclei situated at the boundary of nucleon stability (close to the proton line).

Isomeric Target - ^{178}Hf^{m2}: will be available for special-purpose requests

Development of the FLNR Cyclotron Complex for Producing Intensive Beams of Accelerated Ions of Stable and Radioactive Isotopes

In 2000, the major emphasis will be put on the optimization of the U-400 + ECR-4M cyclotron aiming at the performing of the experiments on the superheavy elements synthesis. Formation of the magnetic field of accelerator's central region for the optimization of the acceleration regime has been performed at the U-400M cyclotron, which resulted in a considerable increase of the ion beam intensity.

The U400M + U400 + MT25 Complex for Producing RIB (DRIBs-project).

Any further development during 2000-2002 will be connected with the realization of the DRIBs-project (production of radioactive ion beams in Dubna). Professor Yu.Ts. Oganessian presented the status report concerning the start of realization of DRIBs project to the 11th session of the PAC for Nuclear Physics.

Detailing of the project, R&D, selection of the main equipment carried out during 1999 have not changed the concept of the DRIBs project. The U400M accelerator and the MT-25 Microtron will be used for the production of radioactive nuclides and the U400 cyclotron will act as an accelerator of low-energy beams to energies of 5-20 MeV/nucleon.

Production of Exotic Nuclear Beams (U400M – U400 mode)

The assessments were based on the yield of ^{6}He (0.8 s) and ^{8}He (0.12 s) nuclei which can be produced at the irradiation of different targets (^{9}Be, ^{12}C and ^{181}Ta) with ions of ^{7}Li and ^{11}B.

The intensity of ^{7}Li^{2+} and ^{11}B^{3+} ions from the DECRIS15-4 source in a long operation cycle is around 100 eμA. It can be increased to 200 eμA without changing the design of the source elements. The intensity of ^{11}B ion beams on the producing target was 5 pμA; in the long operation mode the average intensity was about 4 pμA. Limitation of the intensity was linked with the stability of the Be-target and with the maximum level of the neutron flux both in the experimental hall and outside.

The project envisages an increase in the ion beam intensity to 10 pμA (a beam power of up to 5 kW). This quantity is still within the acceptable range of the background radiation in the hall of the U400M accelerator but it will require to built additional local shielding around the producing target.

Modeling for the DRIBS ISOL target will be continued. Firstly the optimum conditions will be more thoroughly investigated for the neutron-rich ^{8}He and ^{6}He nuclei. Beam of ^{8}He ions from the ACCULINNA separator was thermalized in a graphite stopper that was heated to a temperature of 2300 °C. The flux of the ^{8}He nuclei entering the stopper was continuously monitored with a Si detector. About 100% of these were obtained in a chamber that modelled the plasma volume of an ECR ion source. The distance between this chamber and the stopper was about 50 cm. The data obtained through the observation of the ^{8}He – ^{8}Li beta-decay chain show a delivery time of no more than 20 ms for the He atoms thermalized in the hot graphite stopper. At the second stage, the production of lithium nuclei will be investigated. The aim of this stage will be the ions of ^{8}Li, ^{9}Li and ultimately, ^{11}Li.

Energies of $^{7}Li^{2+}$ and $^{11}B^{3}$ beams are 35 MeV/n and 32 MeV/n respectively. Depending on the parameters of the U400M beams presented in the project, intensities of radioactive beams of ^{6}He and ^{8}He at the exit from the U400M accelerator are around 10^{10}/s and $3{\cdot}10^{7}$/s respectively. Comparative parameters of He ion beams are presented in Table 3. It contains also the data on the ^{11}B beam ($T_{1/2} = 13.8$ s).

Table 3. RIB facilities ^{6}He, ^{8}He and ^{11}Be beam intensities

		on-line	**ISOL**
		ACCULINNA	**DRIBs**
^{6}He **808 ms**	**RIB**	**$1.5{\cdot}10^{6}$ pps** **25 MeV/n**	**$9{\cdot}10^{9}$ pps** **13+8 MeV/n**
	Primary beam	**^{7}Li; 5 pμA** **32 MeV/n**	**^{7}Li; 10 pμ** **32 MeV/n**
	Target	**Be**	**Be**
^{8}He **119 ms**	**RIB**	**$2{\cdot}10^{4}$ pps** **28 MeV/n**	**$3{\cdot}10^{7}$ pps** **6+8 MeV/n**
	Primary beam	**^{11}B; 5 pμA** **34 MeV/n**	**^{11}B; 10 pμA** **34 MeV/n**
	Target	**Be**	**Be**
^{11}Be **13.8 s**	**RIB**	**$9{\cdot}10^{4}$ pps** **36 MeV/n**	**$2{\cdot}10^{8}$ pps** **4+16 MeV/n**
	Primary beam	**^{13}C; 3 pμA** **42 MeV/n**	**^{13}C; 10 pμA** **42 MeV/n**
	Target	**Be**	**Be**

The transportation of an ion beam from the magnetic separator to the opening of the vertical channel of the U400 cyclotron via a transportation channel of 130 m length is performed by means of passive elements (electromagnetic lenses of turning magnets and correcting magnets) in the vacuum volume at a pressure of ~ $(1{-}2){\cdot}10^{-7}$ torr. The configuration of the transportation channel is presented schematically in Fig. 13.

Beams of Accelerated Fission Fragments (MT-25 – U400 mode)

The MT-25 electron Microtron accelerator generates electron beams with an energy of $E_{max} = 25$ MeV, an intensity of about 20 μA (full beam power: W = 0.5 kW). The limit intensity is determined by the power of a magnetron type tube of (1.6 kW) RF-generator operating with a duty factor of 10^{-3} (peak current in a pulse of 1 μs is 20 mA). In principle an increase in the ion beam intensity to a level of 100 μA can be achieved through designing a new RF-generator on a klystron type with a power of 13.5 kW. Such a SHF-generator has been created in the Institute of Physical Problems, Moscow, in 1992 and it still operates on the MT-30 facility. A generator of this type and all the accompanying upgrading of the RF-path could be introduced into the existing scheme of the MT-25 Microtron.

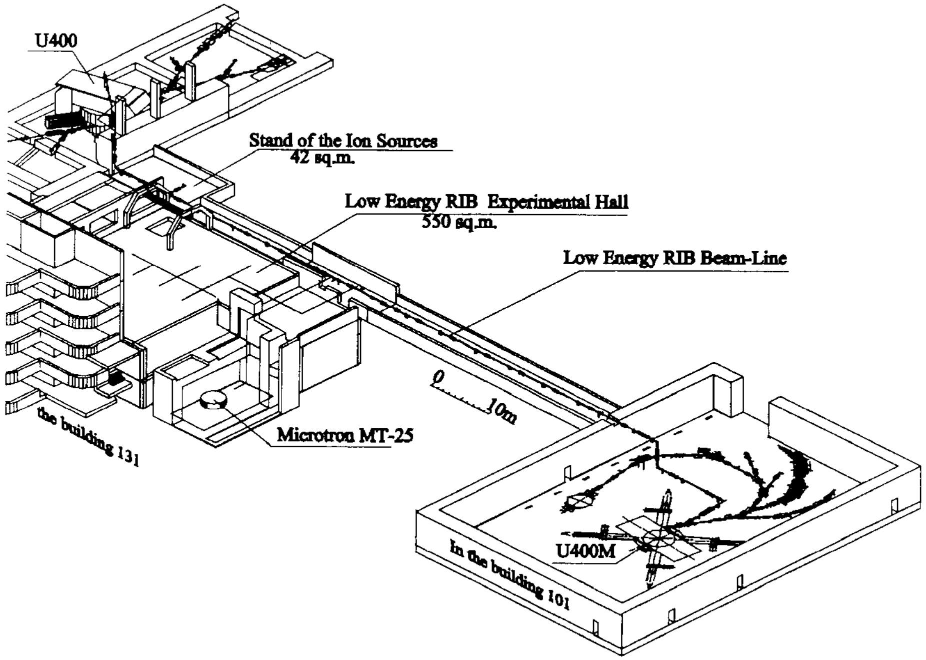

Fig. 13. A scheme of low energy beam transport channels of the DRIBs complex. The solid line - beams of radioactive ions generated at the U400M accelerator. The broken line - beams of fission fragments produced at the electron accelerator MT-25.

To choose optimum size of the ^{238}U target special experiments defining the yield of the fission fragments and their spatial distribution in the longitudinal and radial directions according the γ-ray beam have been carried out.

To produce relatively long-lived radioactive atoms, which include, for example, magic nuclides ^{132}Sn ($T_{1/2} = 40$ s); ^{133}Sb (2.5 min); ^{134}Te (42 min), the target can be manufactured of a more solid substance type of uranium carbide (density of about 12 g/cm^{3}). In this case the target volume can be decreased to 1.3 - 1.5 cm^{3}.

Atoms leaving a heated target are transported into an isobar separator directly linked with the working volume of the target. The separation is performed using the difference of the properties of elements at different temperature gradients of a moving collector. A system designed for isobars with A=132 (^{132}Sn, ^{132}Sb, ^{132}Tb, ^{132}I and ^{132}Xe) is described in a report by Dr. Robert Meunier (CSNSM-CNRS, Orsay, France) prepared in summer of 1999.

By the end of 1999 there will be carried out measurements on operating models and in the year 2000 a prototype of an isobar separator will be created. After the isobar separator atomic pairs reach an isotope separator source designed in analogy with well known sources operating in CSNSM (Orsay) and GSI (Darmstadt).

It is planned to create additional working space between the existing buildings 101 and 131 of FLNR for investigation of nuclear properties and decay characteristics of neutron-rich and proton-rich nuclei of light and medium masses, which are products of direct reactions, fragmentation reactions, as well as fission in the ground and isomeric states. A three-level design of this new hall, the three vertical sides of which are the existing walls of buildings 103 and 131, allows to install experimental equipment on the upper level using the first and second levels for installation of supply systems and loading-unloading works respectively.

It is assumed that the total space of 550 m^2 will accommodate 6 beam channels for installation of experimental equipment (tentatively):

- a high-resolution γ-array,
- time-of-flight neutron array
- the chamber and detectors for collinear laser spectroscopy;
- a facility for investigation of oriented nuclei decay;
- a facility for precision measurements of nuclei masses (ion traps, mass spectrometers);
- Free channel.

The RFP for projecting was presented to the State Projecting Institute (SPI) in November 1999. The period for the development of the Technical Proposal June 1999. The period of construction - 20 months after preparation of the proposal.

Tentatively, all the work related with the creation of the main elements of the DRIBs accelerating complex could be divided into 4 stages:

1. R&D, creation of modules and prototypes.
2. Development of the technical project.
3. Equipment manufacturing
4. Mounting of the equipment, technical tests and start-up.

It is planned to carry out the work in 2 stages so that by the completion of the first stage there would be started experiments with beams of radioactive nuclei and continued in parallel the work on completing the construction of the whole complex.

I stage (years 2000-2001)

a) The production of radioactive nuclei of light elements on the U400M accelerator, separation and transportation of a low energy beam into the U400 hall, injection acceleration and extraction of the radioactive ion beams as well as channeling of the beam through the existing ion guides to physical facilities. The range of accelerated masses of ions is $5 \leq A_I \leq 46$. Beam energies from 2 to 20 MeV/n. Primary beams from ^{7}Li to ^{48}Ca generated on the U400M cyclotron will be used for the purposes. The start-up of the accelerating complex will begin with the production of radioactive beams of such ions as ^{6}He (13 MeV/n) and ^{8}He (8 MeV/n) with maximum intensity

b) Generation of a beam of ^{238}U low energy fission fragments in the MT-25 Microtron hall.
c) Completion of technical projecting of the building and of all the devices linked with the production of low energy beams of fission fragments and production of accelerated ions on the U400 cyclotron.

II stage (years 2001-2002)

a) Obtaining of low energy ion beams from the U400M accelerator and the MT-25 Microtron on the new laboratory space.
b) Beams production of medium energy ions (fission fragments) in ion guides of the U400 experimental hall.

It is made up in such a way that at the completion of the first stage (end of 2001) experimental program on beams of radioactive nuclei of light elements (^{6,8}He, ^{8}B, ^{11}Be etc.) would be started on the U400 accelerator in parallel with work on preparation of the second stage. The completion of the project - production of a beam of ions with medium masses (fission fragments) is planned for the end of the next year 2002.

The cost of the project does not exceed the budget financing for such items as materials and equipment, intended for the development of heavy ion physics, and determined by the Scientific Council and the Committee of Plenipotentiaries of the JINR.

The research program for the creation of the DRIBs project envisages a wide cooperation of Institutes and separate groups working with beams of radioactive nuclei in the field of physics and technology. It is planned to hold in the year 2000 a symposium on the problem of fusion and fission of nuclei using radioactive beams, as well as to discuss widely the physical topics of the International School-Seminar on Heavy Ion Physics (tentatively: September 2000).

Radiation effects and modification of materials, radioanalytical and radioisotopic investigations

Investigations on the physics of radiation effects in condensed matter

1. A phenomenon of the surface sputtering of monocrystalline tungsten, polycrystalline nickel and chromo-nickel alloys irradiated with high dosis of Kr, Xe and Bi ions has been studied.
2. In cooperation with the Laboratory of Oak-Ridge and the Institute of Transuranium Elements in Karlsruhe (Germany) influence of high ionization density on the microstructure of spinelle $MgAl_2O_4$ irradiated with high-energy Kr and Xe ions in the energy range from 70 to 600 MeV were performed.
3. A method of asymmetric track membranes producing has been developed. The membranes of this type look promising as permeable substrates for immobilization and study of metabolism of cells and other biological objects.
4. R&D of thermo-sensitive membranes based on a PETP matrix with grafted N-isopropylacrylamide (NIPAAM) and a mixture of NIPAAM and acrylamide is in progress. A response of membranes on the temperature variations and their electric surface properties has been investigated.

5. New methods have been developed for producing of high selective track membranes with profiled pore channels for filtering of disperse media of various nature. The results of these investigations have been prepared for patent pending in the USA.
6. Recrystallization of an amorphous Si(a-Si) layer prepared by irradiation with 17 KeV He ions was investigated after post-radiation burning in the temperature range of 500-1000°C.
7. The radiation damage of Si exposed to 245 MeV Kr was investigated. An extremely high temperature (up to 1000 degrees C) stability of collecting the radiation defects in struggling zone of the bombarding ions has been found.

Production of ultra-pure isotopes and radioanalytical methods for environmental studies.

1. A procedure for radio-chemical extraction of ^{149}Tb has been elaborated. A dependence of the ^{149}Tb yield on the ^{12}C-projectile energy has been studied.
2. Methods for producing of radio-isotopes ^{99}Tc(^{99}Mo) and ^{225}Ac via (γ,n) reactions at the microtron have been developed.
3. Radio-analytical study of ultra-pure isotopes (^{235}Np, ^{236}Np, ^{236}Pu) was conducted.
4. Distributions of relativistic particles and fast neutrons from massive targets Pb and U were measured with the help of track detectors withhin the project «Research in nuclear waste transmutation».

Received by Publishing Department
on December 14, 1999.