Beryllium **C**lustering **Que**st in **Rel**ativistic Multifragmentation

BECQUEREL Project

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Abstract

The program of irradiation of emulsions in Nuclotron's beams named BECQUEREL Project is destined to continue irradiation in newly produced beams with the purpose of studying in detail processes of fragmentation of light radioactive nuclei, as well as obtaining basic information about the charge states of secondary particles in irradiating by moderate and heavy nuclei. The expected results would make it possible to answer some topical questions concerning the cluster structure of light radioactive nuclei and to clarify the role of the collective effects in a dense matter of colliding nuclei. Thanks to the best spatial resolution, the nuclear emulsions would enable one to obtain unique results along these lines.

Irradiations will be performed in the secondary beams of He, Be, B, C and N radioactive nuclei formed on the basis of Nuclotron's primary beams of stable nuclei. Then irradiations by Bi nuclei will be carried out.

This project combines efforts of a number of teams of possessing scanning and measuring devices (microscopes) and emulsion processing equipments. Of special interest is use by the emulsion collaboration of a completely automatic microscope complex of the P. N. Lebedev Physics Institute.

This collaboration owns unique information and experience in processing experimental information on the interactions of light nuclei obtained in Dubna and that for heavy nuclei at energies obtainable in BNL and CERN (former EMU Collaboration).

The results on the coherent dissociation of Li, C, O, Mg, and S nuclei obtained by this method are now of special interest since they open new possibilities in understanding the topical problems of the structure of nuclei. The advantages taken from the use of Nuclotron's beams consist in that a limiting fragmentation is set in, the reaction takes shortest time, fragmentation products are collimated in a narrow angle cone, and ionization losses of the reaction products are minimum.

The emulsions are especially helpful in the study with neutron deficit nuclei. It is especially interesting to search for proofs that there exists a proton halo for radioactive nuclei like ^{8}B. The latter is very important in astrophysical processes of nuclear synthesis. It is just this area of investigations seems to be most urgent in the coming years.

Motivations of the Research

One of the major goals of the modern physics of the atomic nucleus is a wide-range problem of becoming aware of the wealth of the table of isotopes as steps toward the creation of the surrounding world. This diversity makes it possible to realize, in rather various scenarios, the creation of a world of stable nuclei in Nature. Radioactive nuclei and the resonances of short-lived nuclei are not a simple tail of debris from stellar burning reactions, but rather necessary "waiting stations" on the way of the most effective generation of stable nuclei. Observing nuclear activity in cosmos, including radioactive nuclei, may hint at unexpected solutions in the domain of thermonuclear synthesis of energy.

These assertions have found support in the past years on ACE and SOHO satellites (Slide 1). Their spectrometers analyze the isotopic and ionic composition of galactic and solar projectiles. An isotopic analysis reveals radioactive isotopes of aluminum, chlorine, and manganese with half-lives of the order of few million years. This corresponds to a specific time of rotation of relativistic nuclei around the Milky Way. The ^{7}Be isotope with a half-life of 53 days has been discovered that is the latest evidence for nuclear transformations occurring in the Sun. Thus, Nature provides a kind of clock in the form of radioactive nuclei for the analysis of astrophysical events.

The microscopic structure of nuclei defines the arrangement of the world on a giant scale. This is seen from the fact that isotopes are widespread in cosmic rays, the matter of stars, planets and nebula. The study of the nuclear structure is certain to have a deep relation to the nuclear aspects of astrophysical phenomena.

The investigations of light nuclei situated around the boundary of neutron stability have recently developed a new direction of a quest – physics of nuclei with exotic structures (Slide 2). New phenomena have been established in the structure of light nuclei and in the course of nuclear reactions [1]. In this domain are observed anomalously large radii of nuclei, the production of separated in space nucleon clusters [2]. Low binding energy of nuclear clusters makes it possible to determine the structure of such nuclei as molecular-like one. For the most part, these are radioactive nuclei, and among stable nuclei their nearest neighbors are the deuteron, the ^{3}He and ^{6}Li isotopes (Slide 3).

Great progress has been made towards studying the structure of nuclei with excess and maximum number of neutrons. It is quite possible that neutron halos of light nuclei can play the role of catalyser in stellar thermonuclear processes. In this way, the problem of the Coulomb

repulsion in nuclear fusion is known to be less serious. Then this results in a simplification of the chain of generation of the C, N, O isotopes – the most important steps toward heavier elements. For instance, a fusion of two ^{6}He isotopes leads to the production of a ^{12}Be isotope that is quickly decayed into the known CNO cycle, avoiding the formation of an unstable ^{8}Be nucleus.

Practically research of the structure of proton-rich (or neutron deficient) nuclei is merely being planned. The major goal of the appropriate experiments is to define the properties of nuclei near the boundary of proton stability. To study the structure bonds of excess protons and the effect of the charge on the production of both cluster structures and proton halos, as well as to study unstable residual nuclei.

The structure of such nuclei can turn out to be another key to understanding the processes of synthesis of elements in stars, on the Sun and primordial processes of nuclear synthesis when Universe was arising. It is found to form the basis of the so-called fast proton capture processes. The presence of the proton halo (far removed from nucleus core) becomes "stringboard" for the isotope generation when advancing along the boundary of proton stability with a subsequent decay into the region of stable isotopes. It solves the problem of the Coulomb repulsion in nuclear synthesis. The chief merit of such a version over the neutron fast capture mechanism is the proton stability. This implies that a stellar thermonuclear process does not need to be of an explosive nature. A nuclear system in a state of the type of halo can "be waiting" till a β^{+} decay occurs, and then absorb the neutron.

One of the candidates to the system of the proton halo type is the ^{8}B nucleus. The transition of the latter to the solar CNO cycle, which is important for ^{4}He production, can occur through the addition of a proton to ^{7}Be and the consecutive addition of the ^{4}He nucleus. The produced ^{12}N is decaying into a stable ^{12}C isotope. As compared with the well-known Hoyle's version through ^{8}Be, the advantage of the above-mentioned case consists in that the life-time of ^{8}B is by 16 orders of magnitude larger than that of ^{8}Be.

Another example is the fusion of one more proton to the ^{8}B nucleus resulting in the production of a radioactive ^{9}C one. The fusion of ^{4}He to ^{9}C does lead to the formation of an isotope ^{13}N nucleus intermediating in the CNO cycle. Such examples of cluster nuclear systems may still be cited including some nuclei in excited states.

The proposed series of investigations is aimed at elucidating the applicability of the picture of clustering. Our approach to the study of clustering in nuclei is justified on the basis of the experience obtained when studying the ^{6}Li and ^{6}He fragmentation in emulsion at relativistic energies. A program of further research of the fragmentation of neutron-deficient Be, B, C, and N isotopes is suggested.

Project's participants have agreed to give it the name Becquerel but not only in honor of a great founder of the photographic method for observation of radioactivity. The English version of the title of our paper contains one of the first purposes of the project: Berylium Clustering Quest in Relativistic Multifragmentation.

Nuclear physics at relativistic energies

The experiments with nuclear beams at the energy of a few GeV are recognized to be one of the most promising ways for understanding the basic properties and the intrinsic structure of radioactive and unbound nuclei. Such beams can be employed to produce short-lived nuclear beams by means of breakup, charge exchange or fission (splitting) reactions. In the framework of such an approach, there is almost no restriction to the life time of a relativistic nuclide in question. A technical advantage in detecting proton-rich nuclei is a decrease of the effects of ionization losses in the relativistic domain.

The limiting fragmentation of nuclei serves as a basis for application of this approach to the study of the nuclear structure. This phenomenon was established in early researches as a relativistic nuclear physics performed at the Synchrophasotron. The fragmentation picture for one of the colliding nuclei was found to undergo a weaker dependence upon the properties of fragmentation of the other. The study of the fragmentation of relativistic nuclei may effectively supplement classic experiments on breakup of nuclei used as a target. In such an approach, the detection threshold is close to zero which makes it possible to study fragmentation processes at a rather weak nuclear excitations. The experimental approach based on the registration of the fragments of a projectile nucleus imposes a crucial requirement to the measuring technique, which provides the maximum angular resolution and the identification of fragments in a narrow forward cone. In addition, the fragmentation process leads to a noticeably smaller ionization, which is due to the reaction products, as compared with the primary nucleus signal. This fact imposes a special requirement on the width of the sensitivity range from primary nucleus down to particles with minimal ionization. Such are specific demands to an experiment when choosing a synchrotron as an instrument for studying the nuclear structure. The realization of measurements in a full solid angle is no longer of such an importance as the limiting angular resolution in a narrow cone of relativistic fragmentation.

Light relativistic nuclei in emulsion

The nuclear emulsion technique always provided overviews in the field of micro-world physics owing to high reliability of the events to be observed, excellent special resolution, and quite total observation of the charged particle tracks. In a number of important cases, it enables one to measure momenta, to identify particles. Therefore, it is just this technique that is an effective way for studying relativistic fragmentation thanks to a high emulsion resolution and the possibility of observing reactions in a full geometry. A special advantage is the observation in emulsions of neutron-deficit nuclei due to the most complete observation of the final states.

Relativistic nuclear physics is keeping it in its arsenal of experimental means. Over the past decade the international EMU collaboration joining physicists from five continents obtained an impressive review material on global collision features using CERN's relativistic lead nucleus beam. In the framework of the search for the effects of the quark-gluon plasma this information has made it possible to tune the theoretical models describing nuclear collisions. Not in the last place is the practical contribution of Dubna's participants that consisted not only in scanning of irradiated material, but also in its treating at the Laboratory of High Energies. One of the results is that the classic technique has kept its "shape" by the moment of obtaining an extracted beam on the Nuclotron. The use of this experimental standard is the basis for the suggested investigation already in the domain of classical physics of the atomic nucleus.

The emulsion technique may successfully be used to study proton-rich nuclei. In the latter the nucleons produce, with a large probability, charged clusters which, when decaying, are detected in emulsion. It should be stressed that emulsions are utilized to register multi-particle decays of nuclei or multifragmentation events. As an obvious case are the successful studies of the decay of ^{12}C nuclei on 3 α and ^{16}O on 4 α (Slides 4, 5, 6). Besides, the decays of proton-rich nuclei, can proceed with a large probability, with the formation of intermediate nuclear resonant states disintegrating into charged fragments. The emulsion may serve as a unique universal detector of the full fragmentation keeping information mostly in a single layer. This gradually reduces analysis work.

We consider prospects of the investigation of the fragmentation of relativistic radioactive ^{7}Be, ^{8}B, ^{9}C, and ^{10}C nuclei, having in their composition an excess of protons, and stable ^{6}Li and ^{7}Li nuclei. In emulsions exposed to relativistic nuclei one detects interactions of these nuclei with emulsion nuclei. For all the particles the charges are defined by the track ionization density. The angles of emission of all the charged particles with respect to the direction of the primary nucleus and the relative angles are measured with accuracy of the order of 10^{-4} radian. The magnitude of the average angles of the multiple Coulomb scattering of particles in an emulsion is taken to estimate the masses of all the charged relativistic fragments. The decay products are used to identify the multifragmentation channels and reconstruct the channels of nucleus decays to charged fragments. From the foregoing one obtains information about structural couplings of excess protons and the structure of the nucleus core as well as information about possible production of charged clusters in the nucleus and their momentum distributions. The relative momenta of decay products are measured. On the basis of these data, it is possible to get information about the excitation energy of a fragmenting nucleus.

Clustering in ^{6}Li nucleus

The important motivation for realizing the above mentioned feasible ways in the investigation of light nuclei became the results of the interactions of relativistic ^{6}Li nuclei with emulsion nuclei obtained by the teams from the Cairo University, the P. N. Lebedev Physics Institute of the Russian Acad. of Sci. (FIAN, Moscow), and Petersburg Nuclear Physics Institute of the Russian Acad. of Sci (Gatchina), (Slide 7). We describe the results of this investigation basing mostly on the work of M. I. Adamovich's group from FIAN in some detail [3]. They serve to be a prototype of practical tasks for radioactive nuclei suggested in this paper.

A stack formed by emulsion layers was exposed to a beam of ^{6}Li nuclei at the Synchrophasotron. During irradiation, the beam was directed in parallel to the emulsion plane. The first intriguing feature met by the three groups that the mean free path ^{6}Li nuclei was found to be strongly decreased as compared with the expected value (Slide 8). The obtained value would rather correspond to a nucleus with mass number A equal to 11. This points to an unusually large radius of the nucleon distribution in ^{6}Li nucleus. Using the geometric overlapping model, its value was estimated to be 2.7±0.1 fm, which is in a reasonable agreement with the known data on elastic scattering of protons on a ^{6}Li target.

Another distinctive feature of the ^{6}Li nucleus was got by means of a multiple track scattering analysis, which allowed one to establish the isotopic composition of relativistic fragments (Slide 9). An unusually enhanced yield of relativistic deuterons was established to be the same as proton one. A subsequent analysis dealt with ^{3}He and ^{4}He nuclei. The fragmentation of ^{6}Li in the form of clusters consisting of ^{3}He and tritium nuclei was shown to be by an order of magnitude weaker than structure produced by an α particle and deuteron. This explains an increased yield of deuterons as a reflection of the structure of weakly bound clusters of the α particle and deuteron (Slide 10).

The fragmentation channel ^{6}Li$\rightarrow\alpha$ points to a lower value of the mean transverse momentum of α particles, $\langle p^{\alpha}_T \rangle$=0.13±0.1 GeV/c when compared with the case ^{12}C$\rightarrow\alpha$ having $\langle p^{\alpha}_T \rangle$=0,24±0.01 GeV/c. In the spirit of an uncertainty relation, this fact is another indication to an increased size of a ^{6}Li nucleus.

Among the 1000 found ^{6}Li interactions it is possible to consider as "golden" 31 events of coherent ^{6}Li dissociation not accompanied by the target nucleus excitation (Slide11). Among them 23 events correspond to the dissociation channel α+d, four of them to ^{3}He+t, four to t+d+p and none of them to d+d+d. This topology shows the cluster structure of ^{6}Li nucleus in the most obvious manner. Thanks to the completely reconstructed coherent dissociation kinematics it became possible to reconstruct the ^{6}Li levels at 2.19 and 4.31 MeV with isotopic spin T=0. On the contrary, the 3.56 MeV level with isotopic spin T=1 is absent because of the α+d system isotopic spin T=0. This is the very clear illustration of an isotopic filtering in strong interactions.

The ^6Li study under discussion has indicated that the probability of the charge exchange process $^6Li \to ^6He$ on emulsion material nuclei is large enough. As was expected, it is accompanied by the production of a charged meson. This observation encouraged in 1999 an experiment on emulsion irradiation by a newly formed beam of tritons and ^6He nuclei on the JINR Synchrophasotron. Such a mixed beam (beam cocktail) is an unavoidable particular feature of the detection as far as both nuclei have the identical ratio Z/A and can not be separated in a magnetic analysis. The obtained fraction of ^6He was about 0.01. Particles with charge 2 are easily distinguishable by a visual analysis of an irradiated emulsion.

The very first result is that the $^6He \to \alpha$ fragmentation analysis shows that the transverse momentum distributions of α particles is rather narrow at a mean value $<p^{\alpha}_T> \approx 0.05$ GeV/c (Slide 12). Thus, it is even narrower than for the case of the ^6Li fragmentation. In addition, it is interesting to note that it was just in emulsion that the charge exchange $t \to ^3He$ were first observed (top of Slide 3).

Following this line it is interesting to investigate the cluster structure of the stable isotope ^{10}B comparing dissociation channels $^{10}B \to (^8Be)d \to \alpha\alpha d$, $^{10}B \to ^6Li\alpha$ etc. The analysis of such an irradiation is in progress now.

It is important to carry out irradiation with ^9Be nucleus beam (stable). Since beryllium is a source of a toxic aerosol a solution needs to be found for operation of a laser ion source like composition of beryllium with heavy elements.

Thus, it may be concluded that the emulsion technique may become an important source of rather complete information on the clustering problems and proton halos in nuclei. Relativistic fragmentation may deliver information on the properties of unbound nuclei like ^5He, ^5Li, ^8Be, and ^9B that are important “mediators” in stellar nucleosynthesis.

Emulsion irradiation in secondary beams of relativistic nuclei

Nowadays suggestions on the production of relativistic beams of the radioactive light isotopes are actively being discussed at the Laboratory of High Energies including accelerator experts. The approach based on the use of a charge exchange process toward higher charges instead of a break up one seems more fruitful at beam energy of a few GeV per nucleon. In this case, the mass number of an initial nucleus is conserved, beam losses in acceleration are lower, and a cluster nature of its intrinsic structure is partially set up.

The following processes can be utilized for obtaining unstable relativistic nuclei $^7Li \to ^7Be$, $^{10}B \to ^{10}C$, $^{12}C \to ^{12}N$ etc. A certain advantage in the production of secondary beams toward increasing charge is a relative background reduction of other fragments with Z/A closer to the stability region.

One of the possible applications of this method may virtually be the production of a beam at two successive charge exchanges at two targets, for instance, $^{10}B\to^{10}C\to^{9}C$, $^{11}B\to^{11}C\to{}^{11}N$ (crossing of the boundary of stability), $^{12}C\to^{12}B\to^{12}Be$, using the advantage of extended length beam transport channels (up to 100 m) and few separating magnets (up to 5). The latter chain could result in a coherent dissociation $^{12}Be\to^{6}He^{6}He$ to be observed which is important for the verification of the hypothesis about a nuclear molecular nature of this nuclide. Our results on identification of a ^{6}He nucleus in emulsion done in anticipation are most useful in this case.

Basing on the study of ^{6}Li and ^{6}He nuclei the emulsion technique is expected to enable us to reach deeper knowledge of the light nucleus structure along the line of proton stability. It is quit obvious that the investigations of the relativistic fragmentation of neutron deficient ^{7}Be, ^{8}B, $^{9,10,11}C$, and ^{12}N have to underlie future irradiations (Slide 13). The emulsion technique has a number of merits owing to the possibility of the vastest observing of the final states. In addition, the separation in the magnetic analysis and on-line diagnostics of newly produced neutron-deficient isotopes become simpler with increasing Z/A.

The search for the cluster structure of ^{7}Be may be thought of as a natural development of the ^{6}Li nucleus study. Such a structure can manifest itself in the fragmentation channels like $^{7}Be\to^{6}Li p$, $^{7}Be\to\alpha dp$ and others. The study of ^{7}Be nuclei is interesting from the point of view of its possible role of a core in a ^{8}B one. Besides, it is also interesting using the same technique to study the cluster structure of this nucleus and, at the same time, the structures of ^{6}Li and ^{7}Li nuclei having similar compositions and structures. In the planned experiment it is expected to define the relative probabilities of $^{3}He+^{4}He$ and $^{6}Li+p$ and obtain momentum distributions of the dissociation products and the distributions with the respect to the momentum of fragments produced in inelastic collisions. The data obtained in the mentioned experiments will make it possible to estimate the probability of the nucleon clustering in a nucleus.

The investigation of the ^{7}Li inelastic interactions will give the distribution of a single charge and two-charge fragments with respect to their masses and momenta. Basing on the nucleus dissociation probabilities in different channels it may be concluded that the production of a two-cluster structure $^{3}H+^{4}He$ of the ^{7}Li nucleus is likely (alternative – $^{4}He+p+2n$). This material is already exists.

An interesting ^{8}B nucleus beam can be produced in break up reactions of stable isotopes. Being intended for investigations with the aid of the emulsion technique such a beam could make the problem of the proton halo existence clearer. The particular feature of the ^{8}B nucleus is the lowest binding energy of one of the protons (135 KeV). Therefore, most probably the ^{8}B nucleus has a core in the form of the ^{7}Be nucleus and a proton weakly coupled with the core. Their space distribution defines to a large extent the value of the ^{8}B radius, the transverse momentum distributions for relativistic protons and ^{7}Be, and the distribution with respect to the relative transverse momentum of the dissociation products. The probabilities of individual channels of

dissociation are suggested to be measured for $^8B \to {^7Be}p$, $\alpha {^3He}p$, ^6Lipp, αdpp. The data obtained enable one to judge of the structure and proton shell of the ^8B nucleus.

After that, the production of the ^9C nucleus beam becomes a next logical step. Of all the nuclei, we have considered this one has the largest ratio of number of protons to that of neutrons. This nucleus has an additional proton as compared with ^8B nucleus. The binding energy of this additional proton is far larger than that of the external proton in the ^8B nucleus. Therefore, it appears that the ^9C has no external two-proton shell. This nucleus is particularly interesting since the substitution of one of the protons to a neutron leads to the unstable ^9B isotope in spite of the reduction of the Coulomb repulsion. One of possible explanations is a ^3He clustering with a neutron core. The probabilities of individual channels of dissociation are suggested to be measured for $^9C \to {^8B}p$, $^3He{^3He}{^3He}$ and others.

The ^{10}C nucleus is produced from the ^9C by adding one neutron. However, we are not led to the production in the ^{10}C nucleus of clusters in the form of a deuteron or a ^3He nucleus. Two-cluster structures in the form of ^7Be and ^3He nuclei or in the form of the ^8B and a deuteron are hardly probable because of a high binding energy of these nuclei in the ^{10}C nucleus. In the case of a single external proton, the nucleus core is presented by the unstable ^9B nucleus. In some other possible structure with two external protons the nuclear core is presented by another, also unstable ^8Be nucleus. It appears that such structures in their dynamics should be similar to the structures of neutron excess nuclei (proton skins -?). In the present case, one or two external protons keep nuclear resonant states from decaying.

The ^{10}C decay can proceed via cascade decays with production in the intermediate state of unstable intermediate ^9B, ^8Be, and ^6Be nuclei. In such a decay there are produced in the final state four charged fragments. We pay attention to the fact that when working with emulsion there is a possibility of obtaining experimental data on such multi-particle decays and studying the decays of ^9B, ^8Be, and ^6Be nuclei. The difficulties of the analysis of these data in the separation of different channels are explained by the fact that the distinctions in the relative momenta between final decay products in these channels may be insignificant.

Thus, the combination of new beams and the classic technique may result in new intriguing and conclusive finds.

Nuclear physics and image recognition

Sceptics adduce two main arguments against further use of nuclear emulsions: their costs and, above all, labor consuming processing. However, over the past years, most progress based on the use of advances of computer and informational technologies has been made to overcome these limitations.

Major advances in the use of emulsions fall on the fifties. Pioneer results in the field of elementary particle physics had been obtained. The problem of manufacturing thick emulsion

layers (600 microns), which made it possible to get volume images of events, had been solved. The used material was highly homogeneous which opened possibilities to make perfect track measurements and particle identification. So far, the reached level has essentially not been overcome. This is a grown up culture.

Nowadays, emulsions are manufactured by the Japanese company FUJI and the Moscow company FOMOS (former NIIKHIMFITOPROEKT). The company ILFORD, the classic in this domain, has lost its technology. When the needs of the investigations on nuclear physics will excite a growth of interest to emulsions, it will not be easy to satisfy it. A reasonable support of this technology in the framework of contemporary investigations would make it possible to conserve the photographic method of particle registration by the period of an automatic analysis of particle track pictures. Rapidly progressing application of automatic scanning microscopes and programming of image recognition enable one to expect the classical experimental technique to restore at a new level totally.

A completely automatic microscope complex PAVICOM for the study of the processes in high-energy particle physics (Slide 14) is presently being designed at FIAN (www.lebedev.ru/structure/pavicom). PAVICOM is created with the aim to increase the effectiveness of experimental studies in the area of nuclear physics, and in searching for neutrino oscillations performed by means of emulsions and other track detecting techniques. Optical pictures on setups are registered by means of CCD cameras, than digitized and recorded in a computer. Thus, scanning of nuclear emulsions is completely automated without using visual labor of a microscopist.

As compared to hitherto used “semiautomatic microscopes”, the main merit of PAVICOM is the possibility of measuring charged particle tracks in nuclear emulsions, high-energy nucleus tracks in films in a solid state transparent radiators with complete automation, not applying extremely hard labor of microscopists. In this case, processing of experimental material becomes about thousand times quicker. This turned out to be possible owing to the application of modern achievements of precision mechanics, means of computer techniques and software. During the recent years the automatic complexes of this type were or are being commissioned at CERN, Japan’s scientific centers, in Italy and some other countries.

In Russia PAVICOM is the only complex of this type. Its creation implies a revolutionary change in experiments exploiting emulsion technique in the detection of fast particles. Its potentialities are such that it completely satisfies the needs not only of FIAN’s investigations but also of other Russian laboratories and institutes. Thus, it actually plays the role of a center for collective use. In prospect, such a center may become a source of “information export” for “physics at a distance”.

Some groups of the Laboratory of High Energies have already get experience in using PAVICOM facilities when analyzing polymer film particle detectors exposed to an arrangement ENERGIYA for obtaining the spatial picture of a neutron flux in a massive target. The application

of the film track detectors is caused by a high level of electronic noise from Synchrophasotron operation, high effectiveness of detection of fission fragments, its low proper background, and a relatively simple processing technology.

PAVICOM group has developed and has widely used a technique of automatic image recognition and counting of tracks on pellicles of a large area. PAVICOM intended for processing track detector materials increases hundred and thousand times its velocity. Recognizing of the tracks, picking them out against the background of pellicle defects and their counting is not a difficult problem. The reached effectiveness of the program of counting the tracks from fission fragments is not less than 95%. This indicates that automatic recognition is applicable in principle. A considerable bulk of information was obtained in irradiating of the JINR ENERGIYA uranium-lead assembly. This material has presently being recognized by computers and its physical analysis is being carried out.

FIAN' group has also performed an experimental scanning of rare events of the coherent ^{6}Li dissociation in emulsion. When scanning the emulsion layers are divided into several areas of sharp images. The result is a shooting of a peculiar film consisting of dozen of frames, reflecting the movement of the microscope optics in three dimensions. Already now it may be concluded that the manifestation of such 3D images of rare events has become part of scientific arguments. It is possible to use them in electronic publications as hyperlinks.

The topical problem is the development of recognition procedures and precise coordinate measurements relevant to the goals of this proposal. To that end, it is necessary to draw on programming experts engaged in development of image recognition algorithms. The research tasks of relativistic nuclear physics may significantly stimulate future developments in this domain.

At the Laboratory of High Energies further transfer of the available microscopes to a computer control regime is suggested. Moderate expenses are needed for buying of personal computers and manufacturing for them interfaces.

Conclusions

In the performed investigations of the interactions of light radioactive nuclei with emulsion nuclei one and the sane method is used to study systematically the structure of several proton-rich nuclei. Attention is paid to the search for the manifestation of a structure like the proton halo, and structures with an unstable nucleus core. Consideration will be given to the determination of the total cross section for inelastic interactions of nuclei in emulsion, which will make it possible to estimate nucleus radii. In emulsions, the total charge of fragments is measured and the events with primary nucleus charge exchange are detected. The results of these studies will be summarized. They will be useful for understanding the particular features of the structure of nuclei in question.

The obtained data will be compared with the results of model calculations. The investigations performed will stimulate the development of emulsion technique in many laboratories, participating in this work. The results may be employed in planning further studies on

Nuclotron's beams, in particular for forming reaction triggers in the registration of particles by electronic methods.

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JINR Budget requests for the Becquerel Project

N N	*Item*	*Total for 2005-7*	*2003 г.*	*2004 г.*	*2005 г.*	*2006 г.*	*2007 г.*
1.	*Nuclotron beam time, hours*	**750**	**150**	**150**	**150**	**150**	**150**
2.	*Emulsion & Chemicals , $ (Cost of Emulsion 7000$ per liter)*	**50000**	**10000**	**10000**	**10000**	**10000**	**10000**
3.	*Computers, Electronics, $*	**25000**	**5000**	**5000**	**5000**	**5000**	**5000**
4.	*Contracts on R&D with External Institutions, $*	**18000**	**3000**	**3000**	**3000**	**3000**	**3000**
9.	*Travel Expenses on Collaborative Work, Conferences:*						
	Outside of JINR, $	**18000**	**3000**	**3000**	**3000**	**3000**	**3000**
	Inside of JINR, $	**10000**	**2000**	**2000**	**2000**	**2000**	**2000**
	Total direct expenses, $	**120000**	**24000**	**24000**	**24000**	**24000**	**24000**

Major Stages in the Bequerel Project

2002

Formation of a beam of ^{10}B nuclei with adequate divergence and uniformity. Irradiation of 0.5 liter emulsion. Scanning, analysis, and measurements.

Formation of a secondary beam of ^{7}Be nuclei with adequate divergence and uniformity using a charge exchange process $^{7}Li \to ^{7}Be$. Irradiation of 0.5 liter emulsion. Scanning, analysis, and measurements.

2003

Formation of a secondary beam of ^{10}C nuclei with adequate divergence and uniformity using a charge exchange process $^{10}B \to ^{10}C$, Irradiation of 0.5 liter emulsion. Scanning, analysis, and measurements.
Formation of a secondary beam of ^{12}N nuclei with adequate divergence and uniformity using a charge exchange process $^{12}C \to ^{12}N$. Irradiation of 0.5 liter emulsion. Scanning, analysis, and measurements.
Irradiation with heavy nuclei.

2004 г.

Formation of a secondary beam of ^{8}B nuclei with adequate divergence and uniformity using charge exchange and fragmentation processes $^{12}C \to ^{12}N \to ^{8}B$. Irradiation of 0.5 liter emulsion. Scanning, analysis, and measurements.

Formation of a secondary beam of ^{9}C nuclei with adequate divergence and uniformity using charge exchange and fragmentation processes $^{13}C \to ^{13}N \to ^{9}C$. Irradiation of 0.5 liter emulsion. Scanning, analysis, and measurements.

2005-7

Formation of secondary beams of neutron- rich isotopes of boron, beryllium with adequate divergence and uniformity using charge exchange processes like $^{12}C \to ^{12}B \to ^{12}Be$. Irradiation of 1 liter emulsion per year. Scanning, analysis, and measurements.