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HUNGARIAN SCIENCE

and the

JOINT INSTITUTE FOR NUCLEAR RESEARCH

A BRIEF HISTORY

Scientists of Hungary and the Joint Institute for Nuclear Research have been collaborating for many decades. Starting from the year of JINR establishment in 1956, Hungarian engineers and physicists, whose creative contribution to the implementation of scientific programmes has been considerable, joined the research at the Institute laboratories. Among the initiators of the cooperation were such outstanding Hungarian scientists as Lajos Jánossy, Lénárd Pál, Albert Kónya and many others.

The main traditional JINR partners in Hungary were two major scientific organizations of the Hungarian Academy of Sciences (HAS), viz. the Central Research Institute for Physics (KFKI) in Budapest and the Institute of Nuclear Research (ATOMKI)in Debrecen. Hungarian specialists took advantage of the unique opportunities at JINR in their research in elementary particle physics, nuclear physics, theoretical physics, physics and chemistry of condensed matter, computer technology, and in applications of nuclear physics methods in various fields of science and technology.

While some time ago the cooperation priorities for Hungary were studies in elementary particle physics and in low- and intermediate-energy nuclear physics, today they are primarily in condensed-matter physics and in heavy-ion physics.

Staff members of KFKI were among the first joining the work to produce various experimental facilities (a xenon bubble chamber, a one-meter propane chamber, a semiautomatic measuring device for chamber images), as well as being involved in the elaboration of new theoretical models.

The first experiments in high-energy physics with participation of Hungarian specialists were conducted with the use of nuclear photoemulsions at the synchrophasotron of the Laboratory of High Energies; later they were successfully continued in electron studies of JINR at the IHEP accelerator U-70 (Protvino). Collaboration in nuclear physics began with the studies of nuclear reactions on light nuclei and in experiments at the IBR reactor. Theoretical physicists took part in the studies of the interpretation of phenomena that occur in weak and strong interactions, to describe symmetry properties and elementary particle systematics.

The research trends at the Institute of Nuclear Research (ATOMKI) in Debrecen were focused around issues of nuclear reactions, nuclear spectroscopy and applied research. Specialists from Debrecen took part in joint JINR studies in nuclear spectroscopy at the synchrocyclotron of the Laboratory of Nuclear Problems. Hungarian scientists successfully worked at the Laboratory of Neutron Physics where they studied nuclear reactions on light nuclei with an electrostatic generator. Theorists studied mesoatom properties during their visits to the Laboratory of Theoretical Physics.

Scientists and specialists from Hungary were and are permanent participants of international scientific conferences, symposia and seminars held in JINR Member-States.

The important role of JINR in training young Hungarian physicists, chemists and engineers deserves special mentioning. Most of them occupied later leading positions in their career, both at JINR and in various Hungarian institutions. In the period from 1956 to 1992, about 200 Hungarian specialists worked at JINR; more than 20 theses were defended at the scientific councils of the Institute.

Hungarian scientists took part in the activities of the governing and advisory bodies of JINR. Academician Dezső Kiss was JINR Vice-Director (1976–1979) and JINR Director (1989–1992), Professor Ervin Fenyves was JINR Vice-Director (1964–1966). At different times Deputy Directors of JINR Laboratories were János Erő, György Szenes, Norbert Kroó, László Cser and Zoltán Zámori. Until 2002, Norbert Kroó was, presently, Dénes Lajos Nagy is Member of the JINR Scientific Council.

On 1 January 1993, Hungary terminated its membership to JINR. Since that time Hungary has changed its relation with JINR to the level of bilateral agreement with HAS, thereby regrettably reducing cooperation to a large extent. However, mutual interest to revive fruitful scientific ties has been growing lately. Nowadays a new generation of young sientists has developed successful cooperation of JINR with research institutes of HAS and with university groups in the field of experimental condensed-matter physics and materials sciences using neutron scattering and heavy-ion implantation as well as in theoretical physics.

Today, the round-table discussion on JINR–HAS cooperation will serve the mutual interests and, undoubtedly, will promote strengthening of scientific ties both in basic and applied research. Further important impact of the meeting is expected from mutual presentations of JINR and HAS spin-off enterprises.

A.N. Sissakian

JOINT INSTITUTE FOR NUCLEAR RESEARCH

Academician A.N. Sissakian (left) meets president of the Russian Federation D.A. Medvedev (right) during his visit in JINR.

The Joint Institute for Nuclear Research (JINR) is an international intergovernmental scientific research organisation established through the Convention signed on 26 March 1956 by eleven founding States and registered with the United Nations on 1 February 1957. It is situated in Dubna not far from Moscow in the Russian Federation.

The Institute was established with the aim of uniting the efforts, scientific and material potentials of its Member States for investigations of the fundamental properties of matter. At present, JINR has 18 Member States: Armenia, Azerbaijan, Belarus, Bulgaria, Cuba, the Czech Republic, Georgia, Kazakhstan, Democratic People's Republic of Korea, Moldova, Mongolia, Poland, Romania, the Russian Federation, the Slovak Republic, Ukraine, Uzbekistan and Vietnam. Agreements are signed with Germany, Hungary, Italy, Serbia and the Republic of South Africa.

The history of JINR is associated with outstanding scientists from JINR Member States, including those from Russia, such as A.M.Baldin, D.I.Blokhintsev, N.N.Bogoliubov, V.P.Dzhelepov, G.N.Flerov, I.M.Frank, N.N.Govorun, V.G.Kadyshevsky, I.V.Kurchatov, A.A.Logunov, V.A.Matveev, I.N.Meshkov, M.G.Meshcheryakov, Yu.Ts.Oganessian, B.M.Pontecorvo, F.L.Shapiro, D.V.Shirkov, A.N.Sissakian, A.N.Tavkhelidze, V.I.Veksler and many others.

The main fields of JINR activity are theoretical and experimental studies in elementary particle physics, nuclear physics, and condensed matter physics. The research policy of JINR is determined by the Scientific Council.

There are 7 Laboratories at JINR, by the scope of scientific activities each being compatible with a large research institution. JINR staff totals about 5500 people, including more than 1200 scientists, and about 2000 engineers and technicians. The JINR University Centre provides annual practice at the Institute facilities for university students from Russia and other countries.

Available at the Institute is a unique choice of experimental facilities: the first in Europe superconducting accelerator for heavy ions the Nuclotron, the U400 and U400M cyclotrons with record beam parameters used for experiments on the synthesis of heavy and exotic nuclei, the unique neutron pulsed reactor IBR-2 and the proton accelerator the Phasotron used for ray therapy. JINR possesses powerful and high-speed computing environment integrated into the world computer nets. Plans for basic facilities upgrading have been developed at the Institute, as well as the organization of new frame projects to increase the attractiveness of scientific, educational and innovative programmes at JINR.

An important aspect of JINR activity is its extensive international scientific and technical cooperation: it collaborates with nearly 700 research centres and universities in 60 countries of the world. Only in Russia – the largest JINR partner – the cooperation is conducted with 150 research centres, universities, industrial enterprises and firms from 40 Russian cities.

About 1500 research papers and reports representing approximately 3000 authors are submitted every year by JINR to editorial boards of journals in many countries and to organizing committees of conferences. JINR publications are sent to dozens of countries of the world.

JINR accounts for more than 40 discoveries in nuclear physics. The decision of the International Committee of Pure and Applied Chemistry to award the name "Dubnium" to element 105 of the D.Mendeleev Periodic Table can be regarded as a sign of recognition of the outstanding achievements of JINR staff of researchers in modern physics and chemistry.

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HISTORICAL REMARKS

REACTOR NEUTRONS IN APPLIED RESERACHES IN THE 80es WITH PARTICIPATION OF THE HUNGARIAN SCIENTISTS

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Since the 70es of the last century in the Laboratory of Neutron Physics a group of specialists from CIFI (Budapest) under leadership of Yu.S. Yazvitsky and V.M. Nazarov (LNP JINR) took part in employing neutrons in the investigation of semiconducting materials, very actual in that period of rapid development of electronics. This group comprised J. Bogancs, A. Nagy, A. Szabó, Z. Seres and others.

Experiments on determination of boron atoms in semiconductors based on silicon were carried out at the 16-meter time-of-flight base of one of the channels of the pulsed fast reactor IBR-30 of LNP JINR. To determine boron range distribution implanted in silicon $^{10}B(n,\alpha)^{7}Li$ reaction was used. The results obtained were published in the JINR Preprints and in the international journals [1–6]. These investigations were both of methodical and applied importance. Due to high efficiency of interaction of thermal neutrons with boron, it was possible to use the suggested methodology not only in the material science, but also in the medical and biological investigations on neutron-capture therapy [7]. Later A. Nady initiated implementation of boron characteristics in the investigations of boron glasses [8, 9].

In the end of the 80es, at thetime of burst of interest to high-temperature superconductivity, young Hungarian scientists B. Toth and B. Sily together with V.M. Nazarov suggested a simple noncontact method for determination of critical temperature of superconductors [10]. International collective of the sector of applied research of LNP was well known for its intense studies on neutron radiography to which in the 80–90es the Hungarian specialists contributed as well. Instruments for visualization and processing of imagines were developed using neutron radiography based on time-of-flight method [11].

Participation of the Hungarian specialists in neutron activation analysis at that time was limited by studying high-purity material such as liquids [12], as well as metals. The unique results on the distribution of impurities in high-purity aluminum produced in the process of zone melting were obtained using epithermal (resonance) neutrons [13].

Since the early 90es, in connection with the resign of Hungary from JINR, for a long period of time participation of the Hungarian specialists in the applied researches with neutrons was terminated.

In 2006, during the Summer School in Dubna for young Hungarian specialists, the leader of the delegation László Rosta (KFKI) expressed particular interest from the Hungarian side to revive joint applied investigations with the Sector of NAA of the Department of Nuclear Physics of FLNP. Then in January 2007 in Budapest a discussion of the program of joint investigations of Sector of NAA (head M.V. Frontasyeva) with the relevant unit of NAA at KFKI (head Rózsa Baranyai) was organized. Joint projects in Life Sciences to be realized at the KFKI reactor at present and at the reactor IBR-2M after its reconstruction in 2010 were outlined. The first experience of the revived collaboration in the field of neutron activation analysis on interlaboratory comparison of the results of NAA of the environmental samples is demonstrated in [14].

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DEZSŐ KISS, JINR DIRECTOR FROM 1989 TO 1992

Professor Dezső Kiss was born in Debrecen, in 1929. He got his master degree in Debrecen, in 1951. He began his research work in the group of academician Sándor Szalay. Later he joined the group of Lajos Jánossy at the Central Research Institute for Physics (KFKI) in Budapest. He made there his Candidate of Physical Science (PhD) thesis in 1955 about muon lifetime measurements in cosmic rays. His interest then turned to the low-energy nuclear physics and measured neutron spectroscopy data at the Budapest Research Reactor. Between 1960 and 1963, he studied nuclear reactions following neutron capture at the Joint Institute for the Nuclear Research, Dubna, as a head of a group at the Laboratory of Neutron Physics headed by I.M. Frank.

Since then, KFKI and Dubna were the dominant places in his life. In 1966 he finished his Academical Doctoral thesis about experimental nuclear physics. Between 1967 and 1969, he worked at the Niels Bohr Institute in Copenhagen. In 1970, he turned back to particle Physics. He participated in Dubna-organized experiments at the Institute of High Energy Physics (Serpukhov) studying the formation and decay of kaons and pions in high-energy reactions. For these experiments with two coworkers he won the prize of the Hungarian Academy of Sciences. From 1975 he collaborated in CERN experiments studying neutrinos. In 1976, he returned to Dubna and until 1979 he was a vice director of JINR. During that time, he participated in designing a new, electronic neutrino detector.

Between 1979 and 1989, he was the vice director of KFKI. In 1976, he was elected to be a corresponding member, and in 1985 an ordinary member of the Hungarian Academy of Sciences. He wrote several textbooks on atomic and nuclear physics and gave regular undergraduate and graduate courses at Roland Eötvös University in Budapest. In 1984, he joined the neutrino experiments at the Lake Baikal with a Hungarian group. Between 1989 and 1992, he was the director of JINR as the one and only non-Soviet/Russian director of the Institute. He participated in the neutrino research projects at the Lake Baikal and in the Borexino experiment at the Italian Gran Sasso National Laboratory until the end of his life. Dezső Kiss passed away in 2001.

CsOK (ЧОК), spectrometer – first time-of-flight small angle scattering machine in the world

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Small angle neutron scattering is the powerful method to study different types of objects with typical sizes of nanometers in biology, polymers, colloidal and material science field. Nowadays it is well established method with the big numbers of installations all over the world [1], including machine "Yellow Submarine" at Budapest Neutron Centre [2].

First SANS machine on steady-state reactor was constructed in ILL. First machine on "white" neutron beam was constructed in JINR at reactor IBR-30 on beam N5. Neutron wavelength on such reactors is determined using time-of-flight (TOF) of neutron from reactor to the detector system. The idea of spectrometer belongs to Yuri M. Ostanevich and László Cser. They suggested that TOF spectrometer must have a lot of advantages in comparison with constant- wavelength machines. In particular, using white neutron beams with high wavelength resolution allows reduce uncertainty of neutron momentum transfer at scattering processe only to geometrical parameters of the spectrometer. The spectrometer got name "CsOK", after names of its principal creators – Cser Laszlo, Ostanevich Yuriy and Kozlov G.A. Word "CsOK", by the way, is conformable with Hungarian "csók", which means "kiss".

Detector system of the CsOK spectrometer. On the photo – Yu. Ostanevich and L. Cser.

The spectrometer had been build from "zero" level in short period of pair months. CsOK consisted of detector system, built from 8 boron counters (NMI-52 type), situated on the left and right from the direct beam (see photo). Such geometry of SANS installation is called "rectangular". The central part of the detection plane with central beam passing through it, remains free from counters and any construction materials. By this type of construction, an effective reduction of the direct beam background in the detector space can be obtained. It was the idea, which could be used for ring-wire detectors for spectrometer MURN at IBR-2. In addition to this detectors used the moved counter for measurements of the direct beam and symmetry center of the detectors (prototype of direct beam detector at MURN spectrometer). The amplifiers and discriminators (KFKI-NK-213) were manufactured in Hungary. Simultaneously in the experiment were used 8 detector and 256 memory channels to one detector. It was divided into four groups with 64 channels each one and width of channel was increasing for each groups twice. This idea is very powerful and used up to present moment.

The first experiments on the CsOK was done with biological objects, namely, hemoglobin solution, 50 S ribosome and collagen taken from a rat's tale with moistened with light water and heavy water. For hemoglobin and 50 S ribosome was obtained average value for the radius of gyration. For collagen with 400 fibers was obtained the value 65,4 nm for wet samples and 64 nm for dry one. The first experiments with proteins in solutions confirming the method as well as the basic characteristics of the spectrometer were briefly described in the publication. It is interesting to note that a new type of detector of thermal neutrons for the SANS instrument – circular multi-wires He^3 detector with a central hole were presented before this publication. Namely such a detector was the main part of data acquisition system of SANS instrument at IBR-2 during more than 20 years. Later this type of the detectors allowed us to propose and experimentally realize in 2000 a new approach to the collection of time-of-flight SANS data by using two detector systems at the YuMO [3] (named in honour of Yu M. Ostanevich). The SANS group tried to preserve this good tradition doing modernization of the instrument, installation of a two detector system as well as a new type two dimensional position sensitive detector at the YuMO.

At the present moment the scientific activities at the YuMO: *Biophysics*: research on model and biological lipid membranes, their structure, properties and interactions; interactions of membranes with biologically active molecules; structure of membranes and biomolecules under high pressure; membrane proteins: their structure, interactions with detergents, structural changes, behaviour of lipidic systems in couse of membrane protein crystallization. *Physical chemistry of surfactants and colloids:* investigations of behaviour of micellar solutions under normal conditions as well as under high pressure in a wide temperature range, in particular, kinetics of phase transitions of micellar solutions to crystals under high pressure. *Polymer physics*: studies of structure, properties and self-assembly of modified polymer gels; structure of polymer gels with covalent and non-covalent bound hydrophobic chains to understand a regulation of responsive properties of the gels; association behaviour of PEO/PPO star copolymer with hydrophobic terminal blocks in aqueous solution and micelle solutions of three-layer nanoparticles prepared by polymerization of methyl methacrylate in polystyrene-*block*-polymethacrylic acid and polymethyl methacrylate-*block*-polymethacrylic acid; structure of polycarbosilane dendrimers with different molecular architecture (shapes and sizes to be determined to clarify controversial literature data on properties of dendrimers). *Nanoparticle and material science:* investigations of structure of technical and biocompatible ferrofluids (effect of magnetic particle concentration and temperature variation on the structure of mono and double layer stabilization of ferrofluids); properties of FeCu alloys; structure of nanoparticles of C_{60} under different conditions as well as different kind of artificial membrane. *Mathematical methods:* development of new methods of treatment of SANS data in case of small statistics; creation of a new program to treat SANS data obtained from PSD detector.

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NEW TRENDS OF JINR

IBR-2 REACTOR AS THE MAIN BASIC FACILITY OF JINR FOR CONDENSED MATTER RESEARCH

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IBR-2 reactor is the main basic facility at JINR dedicated to condensed matter research. Other facilities are used for different activities from time to time. The IBR-2 operates as a fast pulsed reactor. Its main distinctive property, which makes it differ from other nuclear reactors, is the mechanical modulation of the reactivity by means of a movable reflector. IBR-2 is the most intense pulsed neutron source in the world (IAEA-TECDOC-1439, February 2005). Producing a record neutron flux of 10^{16} n/cm^2 /s in the pulse, the IBR-2 reactor is also an economical and relatively inexpensive facility. Activation of the equipment and the burn up of the active core are slow due to the low mean power. The IBR-2 reactor is mainly used for investigations in the fields of condensed matter physics (solids and liquids), biology, chemistry, earth and materials science. Operating experience has shown that it is a very effective neutron source; in most areas of application it compares well with the best neutron sources based on proton accelerators. At present, this experience is of special importance in connection with the increasing interest in long-pulsed neutron sources.

The IBR-2 has some specific features which make this facility very efficient for experiments which require:

- Broad momentum transfer range
- Broad energy transfer range
- Fixed scattering geometry
- Simultaneous measurements of elastic and inelastic scattering
- Tight collimation of the neutron beam

Different experimental techniques, many of them unique, have been developed at the IBR-2 reactor to study the properties of condensed matter. In recent years, IBR-2 spectrometers have provided important results in determinations of the precise structure of high-temperature superconductors and colossal magneto-resistance compounds, and in studies of the peculiarities of elementary excitation spectra in superfluid helium. Work to investigate the spatial structure of ribosomes and biological membranes and to model biologically related objects has been performed. Very efficient and productive research activities have been realized in the field of nanoscale heterostructures characterization using the neutron reflectometry technique. At the present time, applied investigations are being actively developed. Analytical work aimed at solving problems in the field of environmental protection (bio-monitoring of industrial regions, multi-element analysis of atmospheric aerosols) is being carried out using neutron activation analysis. At the FSD spectrometer, investigations of internal stresses in metals by neutron diffraction have been started. The high penetrating power of neutrons makes it possible to find internal defects and to determine stresses in components that cannot be studied using traditional non-destructive testing methods.

The user policy at the IBR-2 allows specialists from different organizations to gain access to the experimental facilities. The parameters and potentialities of the spectrometers are detailed in the “User Guide”, and the results of the research activities are regularly published in the Annual Reports of the Laboratory.

The long-standing experience of using pulsed nuclear reactors in Dubna shows that these facilities are effective and economical, and that they offer unique possibilities for neutron investigations in many fields of modern science. These reactors play an important part in forming ideas and providing technical solutions when creating new neutron sources all over the world. The successful operation of the IBR-2 reactor for more than twenty years provided the basis for the development of a new trend – the creation of long-pulse neutron sources. This provides reason enough to further upgrade the IBR-2 pulsed nuclear reactor.

To summarize: the successful completion of the ongoing reactor modernization program by 2010 will provide a world class neutron source until the year 2035. IBR-2 modernization in accordance with the approved plan (2000-2010) is completely feasible within the framework of the allocated budget. Prolongation of the Agreement with Rosatom will accelerate the completion of some activities and will compensate for the budget deficit inherited from previous years. The available manpower in general satisfies the project needs.

RADIOBIOLOGY WITH ACCELERATED HEAVY IONS: A NEW RADIOBIOLOGY

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High-energy heavy charged particles are an *effective tool* of solving fundamental problems of radiobiology. Classics of quantitative radiobiology pointed out the necessity and fruitfulness of using different types of ionizing radiation with different physical characteristics for studying the mechanisms biological action of ionizing radiation. In recent decades, a number of important practical tasks have emerged, the answers to which require a detailed study of the mechanisms of biological action of accelerated heavy ions. These tasks are associated, first of all, with *space radiobiology* problems related to working out the measures of radiation protection of the crews on long missions beyond the Earth's magnetosphere; using accelerated heavy ions in the treatment of oncological diseases; and resolving the problems of *standardizing the radiation exposure* of the staff working in mixed fields of different kinds of radiation.

At the Laboratory of Radiation Biology (LRB), versatile research into the regularities and mechanisms of the biological action of heavy charged particles of different energies is performed at heavy ion accelerators. The research is aimed at studying the specifics of the damaging action of the heavy charged particles on the cellular DNA in different organisms and studying the mechanisms of the lethal and mutagenic action of multi-charged ions. Using accelerated heavy ions, one of the *central problems* of radiobiology was solved – the problem of relative biological efficiency of different radiation types; the mutation mechanisms in pro- and eukaryotic cells were determined; and the cellular DNA damage character and reparation regularities were found. The specific features of the interaction between high-energy heavy ions and biological object allow charged particles to be considered a unique tool for resolving a number of fundamental and practical problems of modern biology.

For solving the problem of the biological effects of heavy charged particles, the data on the regularities and mechanisms of their genetic action on cells with different genome organization levels seem to be extremely important. The character of the DNA damage caused by heavy charged particles is substantially different from that caused by gamma-rays. Accelerated heavy ions, unlike gamma-rays, induce mainly the cluster-type damage in the DNA. These kinds of lesions are the combination of simultaneous disorders of a DNA part with the formation of single-strand breaks, modification of bases, and sugar modification. The events of this kind result from a local energy deposition which happens when a heavy charged particle travels through a DNA thread. The cluster-type damage determines the specifics of the lethal, mutagenic (induction of gene and structural mutations in prokaryotes and formation of chromosome aberrations in higher eukaryotic cells), and transforming action of radiation on cells with different genome organization levels. The LRB has acquired ample experimental material regarding the genetic action of heavy charged particles.

Among the topical but still poorly studied issues of the biological action of heavy charged particles is their cataractogenic effect. The available data on the cataract formation regularity in experimental animals irradiated by high-energy heavy ions (argon and iron) show that the doses as low as 0.01 cGy cause a cataract in the distant future. At the LRB, both in vivo and in vitro detailed studies of the cataract formation mechanism under the effect of high-energy heavy ions are underway.

The issues of the damaging action of heavy charged particles on the central nervous system are important and remain unresolved in many ways. Research in this field seem to be extremely topical for solving space radiobiology problems as there is evidence that behavioral functions of the experimental animals irradiated with heavy ions have been disordered. Low doses of accelerated iron ions cause an irreversible disorder of the cognitive and other functions in an irradiated organism. Research in this important field has also been started at the LRB.

Thus, versatile studies of the biological action of heavy charged particles of different energies are performed at JINR's accelerators. The main fields of research include the mechanisms of the genetic action of accelerated heavy ions; regularities and mechanisms of this type of radiation acting on the crystalline lens and retina; high-energy heavy ion action on the central nervous system; and mathematical modeling of radiation-induced effects of charged particles. The special features of the interaction between high-energy heavy ions and biological objects allow such ions to be considered a unique tool for resolving many fundamental issues. This all gives us a ground to regard high-energy heavy charged particle radiobiology as a new radiobiology different from the "classical" one.

FUNDAMENTAL AND APPLIED RESEARCH USING HEAVY ION BEAMS

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In the last few decades, heavy-ion physics has become the most intensively developing field of low- and intermediate-energy nuclear physics. The main directions of progress are: synthesis and investigation of nuclear, physical and chemical properties of transfermium (Z>100) and superheavy (SHE) elements, production and study of properties of exotic light nuclei, investigation of fission-fusion and quasi-fission processes in interactions of massive heavy ions, studies of reaction mechanisms with accelerated ions of stable and radioactive isotopes.

Basic studies

A fundamental outcome of the macro-microscopic theory is the prediction of an “island of stability” of superheavy elements. Theoretical predictions of the position of this “island” vary strongly depending on the model. The shell correction amplitude has a maximum for the superheavy nucleus $^{298}114$ in macro-microscopic models. After calculations performed using the Hartree-Fock method or using a self-consistent relativistic mean-field model, the proton shells are predicted at Z=120 or 126. Following the well-known neutron shell with N=126 (^{208}Pb), the next closed neutron shell is expected at N=184. For nuclei with Z > 120 the unusual bubble structure has been predicted.

Complete fusion reactions ^{238}U+^{48}Ca, ^{242,244}Pu+^{48}Ca, ^{243}Am+^{48}Ca, ^{245,248}Cm+^{48}Ca and ^{249}Cf+^{48}Ca were investigated in attempts to synthesize superheavy nuclei located in the immediate vicinity from the predicted proton and neutron magic numbers. The results obtained during 2000–2008 demonstrate that in ^{48}Ca-induced reactions one can produce and study new nuclei in a wide range of Z and N. Decays of the heaviest isotopes of Rf, Db, Bh, Hs, Mt, Ds, Rg and isotopes of the new elements 111-116 and 118 were observed.

First experiments on the chemical identification of element 112 produced via ^{48}Ca+^{238}U were carried out using the gas transportation method. The experimental data point to “Hg-like” behaviour of element 112 and rather “noble gas like” behaviour of element 114. This observation is the first indication of the influence of relativistic effects on the properties of superheavy atoms. This problem is fundamental for modern chemistry.

Another important result on the study of the physical and chemical properties of superheavy elements and the identification of their atomic number is the chemical identification of dubnium (Db) as a final product in the alpha-decay chain of element 115.

One of the most important tasks for the future will be the exact determination of Z and A of the isotopes synthesized in reactions with ^{48}Ca. The traditionally used α–α-correlation method is inapplicable in that case.

Long lifetimes of the isotopes produced in reactions with ^{48}Ca make it possible to change the approach to the synthesis of superheavy nuclei. The properties of superheavy elements are predicted to be similar to those of volatile elements Hg, Tl, Pb, Bi, Po, At or Rn. Now one can use an off-line separator. For precise measurements of masses and for investigations of chemical and physical properties of superheavy elements, the Mass Analyzer of Super Heavy Atoms “MASHA” was designed at FLNR. In experiments with an ECR-ion source, the mass resolution $\Delta m/m$ of $3 \cdot 10^{-4}$ was achieved for Kr, Xe and Hg isotopes. The MASHA set-up surpasses all known facilities in efficiency of the production of superheavy atoms and in extracting information on their masses and decay characteristics.

Experiments with radioactive beams produced in direct reactions were carried out at the ACCULINNA, COMBAS and MULTI set-ups.

Secondary beams of 25-35 MeV/amu ^{6,8}He, ^{9,11}Li, ^{12,14}Be, ^{8}B nuclei are produced using primary U400M cyclotron beams of ^{7}Li, ^{11}B, ^{13}C, ^{15}N and ^{18}O. Intensities of $1.5 \cdot 10^6$ and $7 \cdot 10^3$ pps, respectively, were obtained for 25 MeV/amu ^{6}He and ^{8}He nuclei.

Manifestations of the ^{6}He-nucleus structure in elastic scattering and transfer reactions of 150 MeV ^{6}He from hydrogen and helium nuclei have been studied. This study provided the first direct experimental verification for the theory predicting “di-neutron” configuration of the neutron halo in ^{6}He. The ground-state resonance of ^{5}H was obtained in the reaction

Applied research

In the field of applied research the most successful running project at FLNR is the design and semi industrial production of the so called nuclear filters. These filters are used for cleaning of gaseous and liquid media and for producing of nanostructures.

The abundant experience gained during several decades by the development and upgrade of the FLNR accelerators allowed to elaborate a series of cyclotrons: DC-60, DC-72, RC350, covering manifold needs both in applied and basic studies. The accelerators can be equipped with different types of ion sources: high frequency, “warm” 14 GHz and superconducting 18 GHz ECR also developed at FLNR.

Special attention is given to the development of methods of radioisotope production in (α, xn) reactions at the U200 cyclotron and in photonuclear reactions at the MT-25 microtron. The studies will be performed to improve the radiation control in the environment and the technological safety in nuclear plants, to develop novel technologies of the radioactive materials treatment, to apply nuclear methods in nuclear medicine (diagnostics and therapy) using the following isotopes: ^{67}Cu, ^{73}As, ^{88}Zr, ^{99}Mo(^{99}Tc), ^{97}Ru, ^{149}Tb, ^{178}W(^{178}Ta), ^{186}Re, ^{188}Re, ^{211}At, ^{225}Ac, ^{237}U, ^{236}Pu, ^{237}Pu.

The modernization of the U400–U400M accelerator complex and the full-scale realization of the DRIBs project will allow further investigations in heavy-ion physics, including experiments on the synthesis of heavy and exotic nuclei using ion beams of stable and radioactive isotopes and studies of nuclear reactions, heavy-ion interaction with matter, and applied research at the world level during the next 20 years.

NUCLOTRON-BASED ION COLLIDER FACILITY (NICA) AT JINR: NEW PROSPECT FOR HEAVY ION COLLISIONS AND SPIN PHYSICS

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The Joint Institute for Nuclear Research (JINR) in Dubna is an international research organization established in accordance with the intergovernmental agreement of 11 countries in 1956. At the present time, eighteen countries are the JINR Member States and five countries, having an Observer status. The JINR basic facility for high-energy physics research is represented by the 6 AGeV Nuclotron. It has replaced the old weak focusing 10 GeV proton accelerator Synchrophasotron, which delivered the first nuclear beams of the relativistic energy of 4.2 AGeV in 1971. Since that time the study of relativistic heavy ion physics became one of the main directions of the JINR research program. The new flagship of the JINR is the NICA/MPD project. The main goal of the project is to start in the coming years experimental study of hot and dense strongly interacting matter at the new JINR facility. This goal will be reached by: 1) development of the existing Nuclotron accelerator facility as a basis for generation of intense beams over atomic mass range from protons to uranium and light polarized ions; 2) design and construction of the heavy ion collider having maximum collision energy of $\sqrt{s_{NN}} = 9$ GeV and averaged luminosity of 1027 cm-2·s-1 and 3) design and construction of Multipurpose Particle Detector (MPD) at colliding beams. Realization of the project will provide unique conditions for the world community research activity. The NICA energy region is of major interest because the highest nuclear (baryonic) density under laboratory conditions can be reached there. Generation of intense polarized light nuclear beams aimed at investigation of polarization phenomena is foreseen as well.

NICA/MPD Goals and Physics Problems

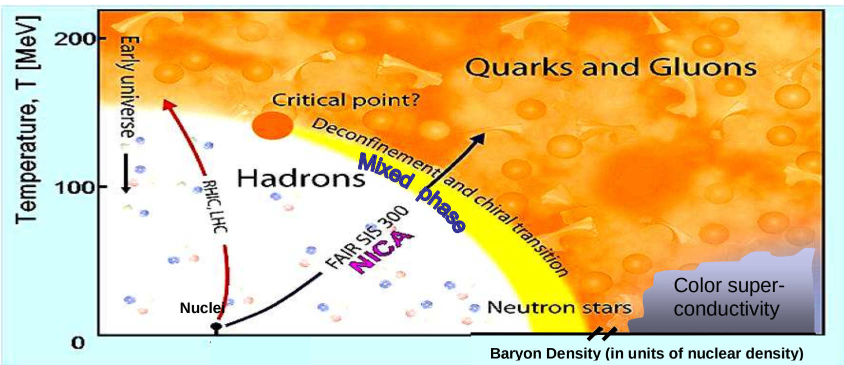

Fig. 1. Phase diagram of nuclear matter (artist's view)

The investigations are relevant to understanding of the evolution of the Early Universe after Big Bang, formation of neutron stars, and the physics of heavy ion collisions. The new JINR facility will make it possible to study in-medium properties of hadrons and nuclear matter equation of state, including a search for possible signatures of deconfinement and/or chiral symmetry restoration phase transitions and critical endpoint in the region of $\sqrt{S_{NN}}$ =3-9 GeV by means of careful scanning in beam energy and centrality of excitation functions The first stage measurements include: multiplicity and global characteristics of identified hadrons including multi-strange particles; fluctuations in multiplicity and transverse momenta; directed and elliptic flows for various hadrons; HBT and particle correlations. Electromagnetic probes (photons and dileptons) are supposed to be added at the second stage of the project.

The beam energy of the NICA is very much lower than the region of the RHIC (BNL) and the LHC (CERN) but it sits right on the top of the region where the baryon density is expected to be the highest. In this energy range the system occupies a maximal space-time volume in the mixed quark-hadron phase (the phase of coexistence of hadron and quark-qluon matter similar to the water-vapor coexistence-phase). The net baryon density at LHC energies is predicted to be lower. The energy region of NICA will allow analyzing the highest baryonic density under laboratory conditions.

The conditions similar to NICA are expected to be reproduced at FAIR facility (GSI) after put the synchrotron SIS300 into operation in 2016. Two different approaches — fixed target experiment CBM at FAIR and collider experiment MPD at NICA will allow a wide variety of methods to be used in these studies. Therefore both facilities, FAIR and NICA/MPD, can be considered as two complementary basic facilities aimed at the study of relevant physics of Hot and Dense Baryonic Matter. GSI and JINR have already a long-term experience of successful cooperation.

NICA General Layout

The NICA (Fig. 2) will consist of a cascade of accelerators. The multicharged ions will be generated in the unique ion source "KRION" developed at JINR, and accelerated in linear accelerator up to 6 MeV per nucleon. Then they are injected in the Booster-Synchrotron – a new machine to be built, accelerated in there, extracted and stripped on a carbon foil into "bare state". Transferred to the Nuclotron they are accelerated up to experiment energy. Before extraction the ion bunch is compressed and becomes of 30 cm length. Such ion bunches are injected, cycle by cycle, into collider rings and provide in collisions the required luminosity. Construction of the new facility is based on the existing buildings and infrastructure of the Synchrophasotron and Nuclotron of JINR.

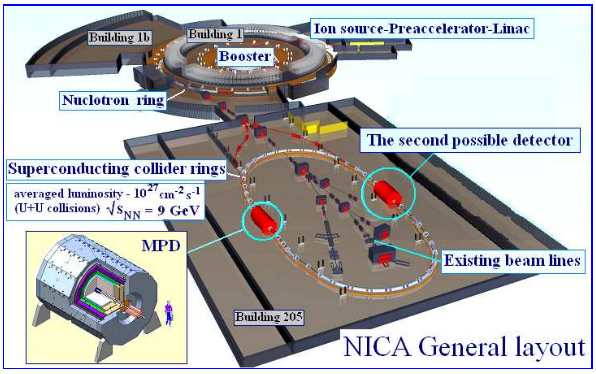

Fig. 2. NICA General Layout. The accelerator chain includes: heavy ion source – RFQ injector – linac – booster ring – Nuclotron – Superconducting collider rings.

The peak design kinetic energy of U92+ ions in the collider is 3.5 AGeV. Beam cooling and bunching systems are foreseen. The collider magnetic system is fitted to the existing building. The project design presumes realization some of fixed target experiments. Collider operation with polarized deuteron and light ion beams is foreseen as the second stage of the project development.

MPD for Mixed Phase experiments

The proposed MPD (Fig. 3) has to detect the high multiplicity events and perform particle identification. The tracking system includes Inner Tracker (IT) - silicon strip detector, Time Projection Chamber (TPC) – the main tracker, Outer Tracker (straw barrel detector) and End Cap Tracker (straw wheels). This system is immersed into homogeneous magnetic field of 0,5 T of superconducting solenoid with the axis parallel to the beam direction. The detector provides reconstruction and momentum measurement of charged particles in the region $|\eta| < 1$. In the extended region of $|\eta| > 1$ the accuracy of momenta measurement is lower. For the particles identification Time of Flight (TOF) System based on the RPC is proposed. This system allows pion, kaon and proton identification in the momentum range of 0.2 - 2 GeV/c. The TPC option of the tracker could provide also particle identification by measuring its ionization energy loss. For the electron/positron and gamma detection in the central region the crystal Electromagnetic Calorimeter (ECal) is considered. Two counter systems (Beam-Beam Counters) are located symmetrically at the edges of the detector along the beam axis to provide the trigger information and for precise definition of interaction point.Two Zero Degree Calorimeters (ZDC) provide the energy measurement of spectators and determination of “centrality” in the ion-ion collision.

Some basic parameters are: Interaction rate of U+U events at luminosity of 1027 cm-2·s-1 is of 10 kHz (interaction rate of central events is of ~ 500 Hz); the accuracy of vertex reconstruction by means of IT is better then 0.2 mm; the TPC produces ~ 50 hits on track and provides momentum measurement accuracy of ~ 1 % in the range of 0.2 – 2 GeV/c; TOFsystem has resolution of ~ 100 ps and provides pion and kaon separation with probability of 5% below 2 GeV/c.

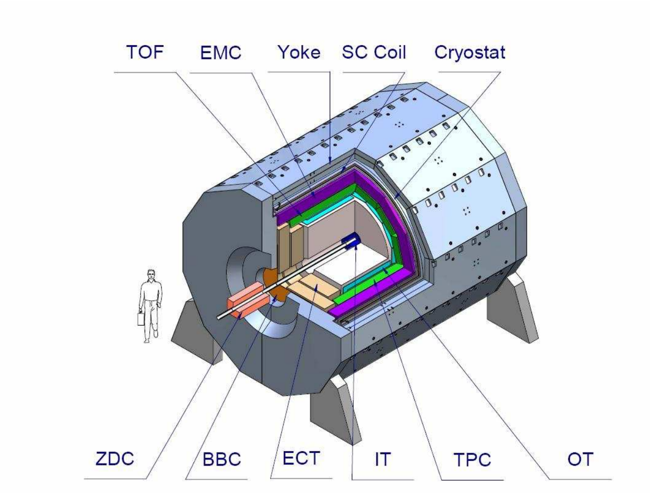

Fig. 3. The MPD schematics. IT – inner tracker (silicon strip detector), TPC –Time Projection Chamber (main tracker), OT (Outer Tracker, straw), ECT (End-Cap Tracker, straw), TOF (Time of Flight, RPC chambers), BBC – beam-beam counters, ZDC – Zero Degree Calorimeters, ECT - End Cap Tracker (straw chambers).

Summary and Outlook

The new facility at JINR in Dubna will allow to study very important unsolved problems of strongly interacting matter. The NICA/MPD commissioning is scheduled in 2014. The design and organization work has been started. The first issue of the NICA/MPD Conceptual Design Report is completed. We suppose a wide world cooperation with many Laboratories both at R&D and construction stages of work. Important innovation aspects of the activity are supposed.

UNIVERSITY CENTER AND EDUCATIONAL PROGRAM OF JINR

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University Center, JINR

The key element of JINR's policy as regards training research staff has always consisted in understanding that the graduate students should be trained in their specialty at the Laboratories under the supervision of the Institute's scientists. With this aim, in 1961 JINR's first Director, a Corresponding Member of the Academy of Sciences of the Soviet Union Prof. D.I. Blokhintsev and the Director of JINR's Laboratory of High Energies, a Member of the Academy of Sciences of the Soviet Union Prof. V.I. Veksler succeeded in opening in Dubna two Departments of Lomonosov Moscow State University (MSU): the Department of Theoretical Nuclear Physics and the Department of Elementary Particle Physics (headed first by Profs. D.I. Blokhintsev and V.I. Veksler, respectively). Up to now, these two departments have been successfully functioning as part of the Dubna branch of the MSU Institute of Nuclear Physics. Many of those who did very much as students' supervisors at JINR were outstanding people who shared their knowledge and experience of educating physicists – for example, Members of the Academy of Sciences of the Soviet Union Profs. S.N. Vernov and B.M. Pontecorvo.

Later it became clear that the branch alone cannot provide JINR with a wide range of specialists. Therefore in 1991 JINR, MSU, and Moscow Engineering Physics Institute (MEPI) jointly established the JINR University Centre (the UC). A great contribution to the establishment of the UC was made by the JINR director Prof. A.N. Sissakian, former director of JINR's Laboratory of Neutron Physics Prof. V.L. Aksenov, former director of the MSU Institute of Nuclear Physics Prof. I.B. Teplov, and many other scientists. In 1993 a JINR-based Department of Moscow Institute of Physics and Technology (MIPT) was opened, which also joined the UC. Also in 1993, the UC became a JINR's subdivision entrusted with the organization, running, and development of JINR's Education Programme. The first UC Director (1993 – 2005) Prof. S.P. Ivanova made a huge contribution to the creation and development of the UC. In 1995, JINR's own postgraduate studies were opened, whose functioning is also entrusted upon the UC.

In 1994, another important event took place: with the participation of JINR and the Russian Academy of Natural Sciences (RANS), Dubna International University for Nature, Society, and Man was established. In 2003, a new stage of Dubna University's education process began: graduate programs in physics were started at the University beginning with the first year of studies. To prepare this, the Department of Theoretical Physics (headed by the present Director of JINR, a RAS Member A.N. Sissakian) and the Department of Nuclear Physics (headed by a RAS Member Prof. Yu.Ts. Oganessian) were opened. Besides these, three JINR-based Departments are hosted also by the Dubna University. These are Department of Biophysics (head - Prof. E.A. Krasavin), the Department of Distributed Computing Systems (head - Prof. V.V. Korenkov) and recently organized Department of Nanotechnologies and New Materials (head - Prof. V.A. Osipov). At about the same time in 2003, the programs beginning with the first year of studies were started for physics students at the two JINR-based departments of the Dubna branch of Moscow Institute of Radio Engineering, Electronics, and Automatics: Electronics for Physics Facilities (head of the department - Prof. A.I. Malakhov) and Information Technologies for Computing Systems (head of the department - Prof. V.V. Ivanov).

The UC's activity is many-sided and includes the following fields: development of special module lecture courses for graduate students, support of the JINR postgraduate programs, and organization of JINR's major international actions, including the International Summer Student Practice.

The International Student Practices have been organized since 2004 on the initiative of the UC, Moscow Engineering Physics Institute, Moscow Institute of Physics and Technology, a number of Polish universities, and the Czech Technical University in Prague. During 2008 the UC has organized three International Student Practices

- *June 29-July 20:* Students from Bulgaria, Czech R., Romania, Slovak R., Ukraine (40 participants)
- *September 11-27:* Polish students (24 participant)
- *September 22-October 10:* South African students (21 participant)

The photo demonstrates the meeting of Polish and South African students in Dubna.

The UC is one of the organizers of the regular International Summer Schools „Nuclear Physics Methods and Accelerators in Biology and Medicine“. Students from Hungary participated in the previous School, which was held on July 8-19, 2007 in Prague. University Centre invites Hungarian students to participate in the 5th International Summer School to be held in Bratislava on July 6-15, 2009.

Traditional for the UC is its secondary-school oriented work, which includes: weekly classes for 2–3 groups of Dubna secondary school pupils at the UC School Practicum as part of an optional course of physics; annual (since 2003) visits to the UC by pupils from lyceums of Poland and Germany; open conferences of Moscow Region's secondary school pupils on modern issues of natural sciences (since 2005; 50–60 participants annually). The photo shows the meeting of academician Yu.Ts. Oganessian with participants of the Summer school "Modern physics - 2008".

The UC has good equipment, which is promptly developing. It includes lecture rooms with modern multimedia means for lectures and presentations, computer classrooms, and a school physics practicum. The UC is using specialized licensed software, which allows organization of the distance courses in different fields of physics. In 2006, a new structure was established at the UC: the student laboratories, which are developed jointly with the JINR-based departments of higher education institutions with the help of international funds and private grants.

On the basis of JINR, physicists are trained for many renowned Russian institutions of higher education in the following specialties: Nuclear Physics, Elementary Particle Physics, Condensed Matter Physics, Theoretical Physics, Technical Physics, and Radiobiology. The UC works out and coordinates a unified study process for the JINR-based departments with the aim of training highly skilled staff for JINR and its Member States. To provide this, the UC involves JINR's leading specialists as faculty members and helps to organize the research work of the graduates at the Institute's teams.

JOINT INSTITUTE FOR NUCLEAR RESEARCH AND THE SPECIAL ECONOMIC ZONE IN DUBNA

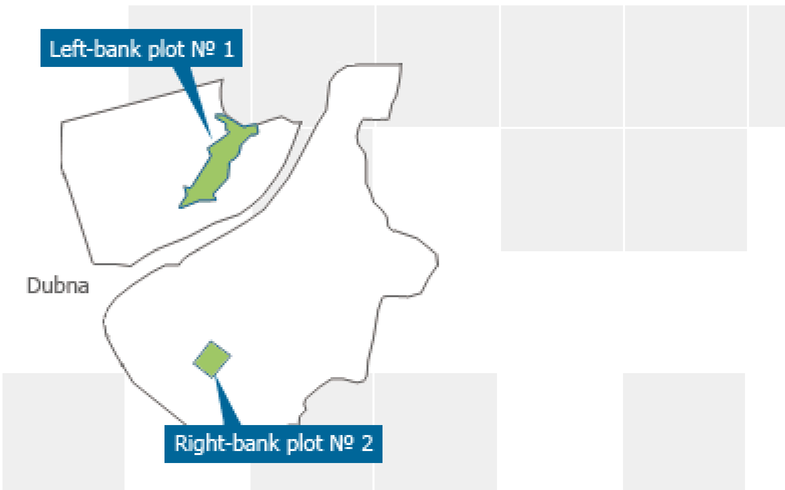
A.V. Ruzaev
Joint Institute for Nuclear Research

The Joint Institute for Nuclear Research (JINR) in Dubna is the international intergovernmental scientific organization, which has celebrated its 50th anniversary in March, 2006. Eighteen independent countries of Europe, Asia and Latin America are the members of JINR. In addition, agreements have been signed with Germany, Hungary, Serbia and the Republic of South Africa. Today our Institute cooperates with more than 700 organizations in 60 countries of the world and takes part in dozens of joint projects. JINR is the famous centre in the field of fundamental research in physics, and it is actively participating in education and innovation areas.

This triad "science-education-innovation" is the core of JINR development strategy. For the purpose of our meeting I have to stress specially the innovative part of the triad. For its realization JINR uses all basic so-called "state financial institutions for development" existing in Russian Federation – special economic zones (SEZ), venture and investment funds, federal scientific-and-technical programs – and also the programs of European Union and other international projects. As a result we shall be able to attract significant financial resources in the innovative projects of the Institute and of our region.

One of the most effective mechanisms of state support for innovations has been already proposed and launched in Russia (albeit with some delay) – setting up of special economic zones which activities are regulated by the Federal Law № 116 – FZ, dated July 22, 2005 "On special economic zones in Russian Federation". Currently, the four special economic zones of technological-innovative type have been founded: in Moscow (Zelenograd), Dubna, St. Petersburg, and Tomsk. There are more than 70 companies registered as SEZ residents and engaged in high-tech business in these zones, including 32 residents in Dubna SEZ.

The special economic zone of technological-innovative type was established in the territory of Dubna in December of 2005 under the Russian Governmental Order. This is the result based mainly on the development of JINR "innovation belt" in recent years, which has given start for a number of innovative companies grown out of the applied research of our scientists.



Map of special economic zone in Dubna

The distinctive features of JINR have reflected in the "soft" orientation of Dubna SEZ – it is mainly nuclear-physical, nano and information technologies. Dubna SEZ consists of two plots of territory on the left and right banks of Volga river (see fig).

The right-bank plot is located closely to the Joint

Institute and we are partially responsible for its business content and development. I shall name some of objects planning to be built: business-incubator, congress-centre, SEZ residents' and VIP offices, multi-access centre of equipment etc.

There are currently following SEZ types in Russia: a) Industrial-production zones, b) Technology-innovative zones, c) Tourist-recreational zones, d) Port zones. It must be emphasized that the essence of special economic zones is not to create "the hot-house conditions" for investors, but is in the development of standard management, in the elimination of excess barriers, in the introduction of the principle of "Single Window", in creation of the infrastructure required for.

Residents are guaranteed transparent and permanent **"rules of game"**. Such mechanism has successfully proved himself in many countries. **Tax benefit** for residents of technology-innovative special economic zone is the following:

- Exemption from Organizations Property Tax
- Exemption from Land Tax
- Reduced rate on the Unified Social Tax up to 14.0%
- Reduced rate on the Organizations Profit Tax by 4% for 5 years
- Exemption from the Transport Tax

Guarantees granted to SEZ residents: according to Chapter 38 of the Federal Law 116-FZ, the acts which threaten the position of the tax-payers – SEZ residents cannot be applied to them in the period of the action of the Agreement on conducting of technological-innovative activities. In the special economic zones the customs regulations of **free customs zone** are in force. It's a special issue to talk about but one can find the information easily. The **management** of the Special Economic Zones is entrusted to both the Federal Agency of the executive power which is authorized to perform the function of management of the SEZ and to its Regional Offices.

Also there is Supervisory Board consisted of VIPs of the Moscow region authorities, Federal agency, SEZ residents, scientific and educational organizations et al. JINR Director Alexei Sissakian is the member of Supervisory Board and the Chairman of the Scientific-technical Council on nuclear-physical and nanotechnologies.

An individual entrepreneur or a commercial company shall be recognized as a resident, except for unitary enterprise, if they are registered in accordance with the legislation of Russian Federation in the territory of the municipal entity, within the boundaries of which a special economic zone is located, and if they have concluded the agreement on technology-innovative activity with the management bodies of special economic zones. The special regime of business activity operates in the territory of special economic zones, and with the aim to develop hi-tech business the state creates the favorable conditions for commercial enterprises, being SEZ residents, at the expense of Grant of tax, customs and administrative preferences, favorable land use treatment, as well as guarantee against unfavorable change of Tax legislation of Russian Federation.

The specific character of JINR activities has been reflected in the directions of the Special Economic Zone: they are nuclear – physical, nanotechnologies and information technologies. In actual practice it means that the core of the left- and right-bank sites of SEZ will be those fields where JINR and other Dubna companies ("Dubna" University, CR "Raduga", DEP-Kamov, "Tenzor", "Atoll" and other enterprises) have already accumulated innovative results. JINR innovative projects are the examples of start-ups for SEZ in the following fields:

a) Nanotechnologies: materials and nanostructures on the basis of nuclear tracks for electronics and microelectronics; flexible printed circuits; silicon-on-insulator etc,

b) Safety and “antiterror” systems: detector systems for identification of dangerous substances in close-space object,
c) Biomedical technologies, radiation medicine: medical accelerator equipment, radiation medicine technologies, radiopharmaceuticals.

In its innovative activity JINR uses all forms and mechanisms of technology transfer and venture financing existing in Russia and Europe. For example, in 2005–2006 we have taken part as a winner in the EuropeAid project for establishing of Centers for science and technology commercialization. This experience we use to help our residents and our partners in order to get comfortable conditions for their business. Just now we have registered 5 companies connected with JINR through charter capital as the SEZ residents.

One has to know some information about Russian institutions in the sphere of venture financing. The main player in this market is state owned “Russian Venture Company” with the volume of investment resources about 15.0 billion rubles – it is “Fund of Funds”. In 2007 the first competitive selection of public-private venture funds was held, which resulted in founding the **te.** "VTB-Venture Fund“ – the main strategic partner of our Institute.

In addition to that, the Ministry of Economic Development, jointly with the subjects of Russian Federation, has spurred the emergence of regional venture funds for small technological firms. One of them in the Moscow region with our another good partner – asset management company “Troika-Dialog”.

At the meeting of the State Council Presidium of the Russian Federation in Dubna on April 18, 2008, President Dmitri Medvedev emphasized that „…we have a society with a brilliant innovation potential, creativity of our nation is talked about everywhere, in many different places, and we ourselves realize that we are capable of rapid and creative thinking" . President Medvedev stressed that our priorities are in the so-called concept of four "I‘s": institutions, infrastructure, investments, and innovations.

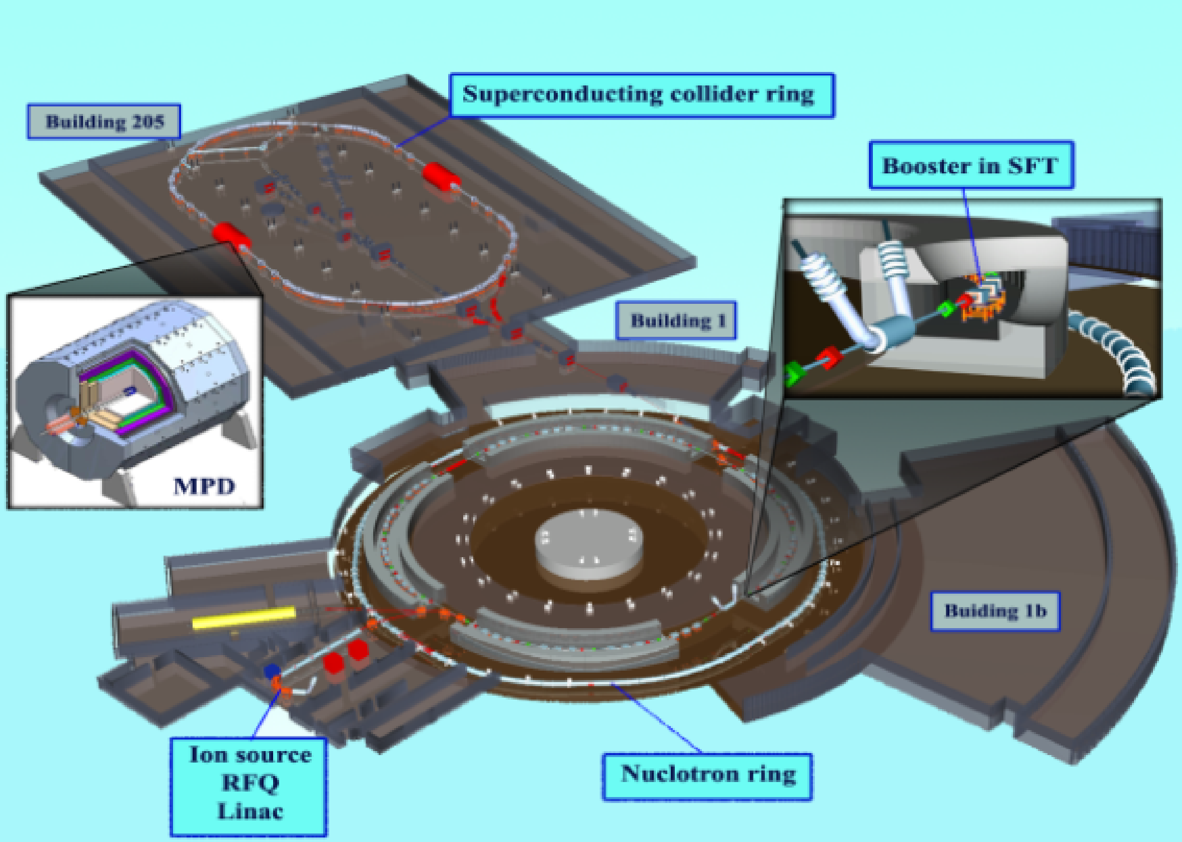
During the visit President Medvedev has supported some large-scale projects proposed by JINR and especially stressed Institute’s role as the centre for international cooperation. For example the International Innovative Nanotechnology Centre in Dubna is one of such projects and it was supported by JINR Committee of Plenipotentiaries. We are going to combine JINR possibilities and the conditions of SEZ in order to create modern and dynamic nanocentre for science, education and business. Our main partners in this project – “Kurchatov Institute” and the “Russian nanotechnology corporation" with its initial capitalization of 130.0 billion rubles from the federal budget.

On the whole the modern innovation infrastructure in Russia includes about 300 facilities with varying degrees of government support. By the beginning of 2008 Russia had 55 technological parks and 66 innovation technology centers, employing 1200 small enterprises with total staff of about 20,000 people and an output worth over 30 billion rubles a year; 80 business incubators and 86 technology transfer centers; 10 national information and analytical centers to monitor global and Russian scientific and technological potential. Joint Institute is one of the leaders in the innovation sphere.

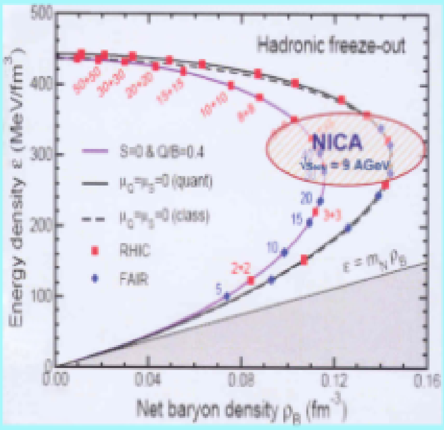
Finally, I would like to underline that we have in Dubna the good opportunity to create the special economic zone as a real international one – open and dynamic. JINR Member states to my mind have the keen interest in this issue and we already had a lot of negotiations concerning common actions with governments, scientists, businessmen. And we indeed try to strengthen and develop existing scientific and business contacts with Hungary.

THE BASIC FACILITIES OF JINR

Heavy Ion Collider NICA at JINR
(Nuclotron-based Ion Collider fAcility)



	Booster	Nuclotron	Collider
Circumference [m]	216	252	225
Final kinetic energy [GeV/n]	0,4	1 – 3,5	1 -3,5
Rigidity, [T·m]	2,4 - 25	8.2 - 36	14 - 36
B field, [T]	0.17–1.8	0.37 – 1.64	1.56 – 4
Beam emittance [π·mm·mrad]		0.26	
Bunch number per ring	4	1	15
Bunch length [m]	5	3	0,3
Pressure, [Torr]	10^{-11}	10^{-9}	10^{-10}
Beam intensity	$3,2{\cdot}10^{9}$	$1,1{\cdot}10^{9}$	$15x1{\cdot}10^{9}$
Average luminosity for UxU, 3.5 GeV/u, [cm-2·s-1]	-	-	$1.1{\cdot}10^{27}$



NICA is a new accelerator complex constructed on the JINR site. It is based on the experience and technological achievements at the Nuclotron facility and incorporates new technological concepts.

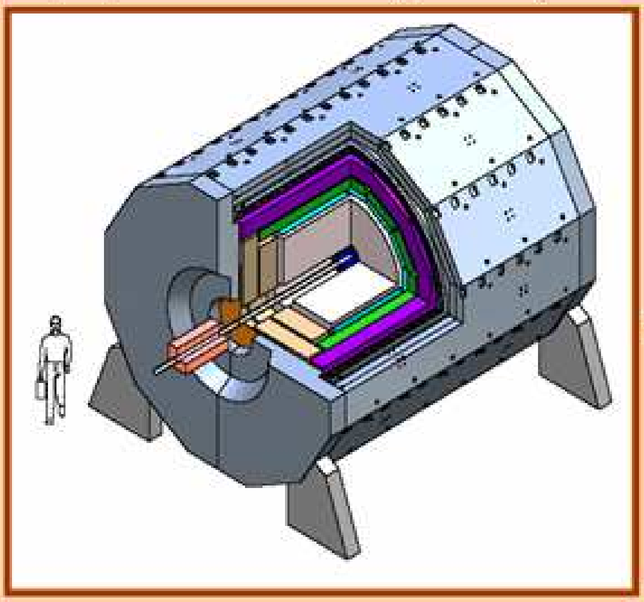
http://nica.jinr.ru

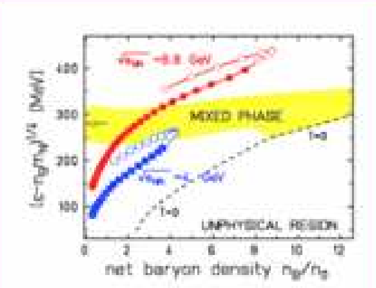
A.Butenko

The MultiPurpose Detector – MPD

to study heavy ion collisions at NICA

A MultiPurpose Detector is proposed to study the hot and dense matter in collisions of heavy ions over atomic mass range A=1-238 at a center-of-mass energy up to $\sqrt{s_{NN}}$ = 9 GeV. The MPD experiment is foreseen to be carried out at the future JINR accelerator complex of heavy ions – the Nuclotron Based Ion Collider fAcility (NICA) which is designed to reach required parameters with an average luminosity of $L=10^{27}$ $cm^{-2}s^{-1}$.





The phase diagram demonstrates, that domain of excited dense baryonic matter accessible in the planned MPD experiment is located roughly between the dynamical trajectories presented for two colliding ion energies. The hadronic phase at high net baryon densities and moderate temperatures as well as new states of the matter beyond the deconfinement, chiral transition and mixed phase may be reached in this sector of the phase diagram.

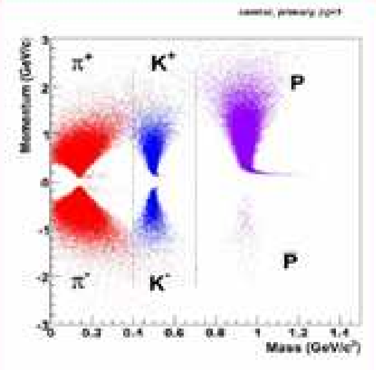
The detector should meet the following requirements:

- efficient reconstruction of events with high angular and momentum resolution for charged particles (from 100 MeV/c to 2000MeV/c)

-compatibility for the event rate up to 10 kHz with a multiplicity up to 1500 charged particles;

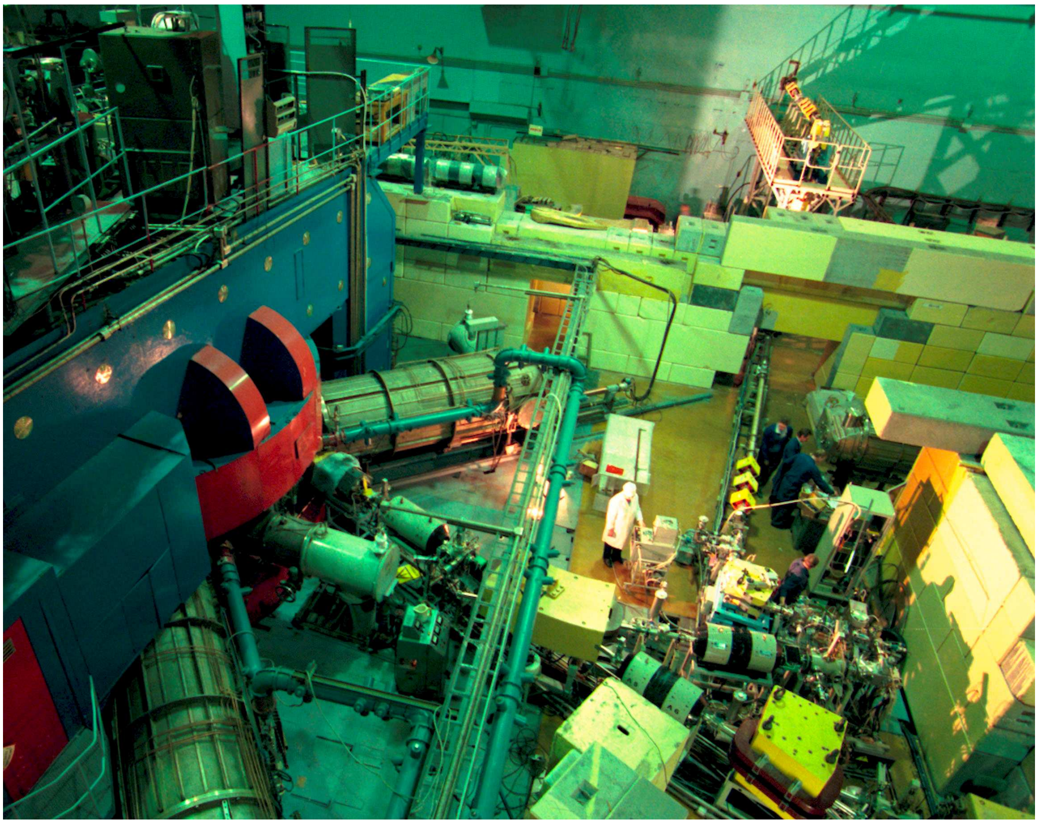
-reliable identification of charged particles and possibility to detect photons and π^0s;

- provide reliable information for "centrality" definition.



ACCELERATION COMPLEX FLEROV LABORATORY of NUCLEAR REACTIONS

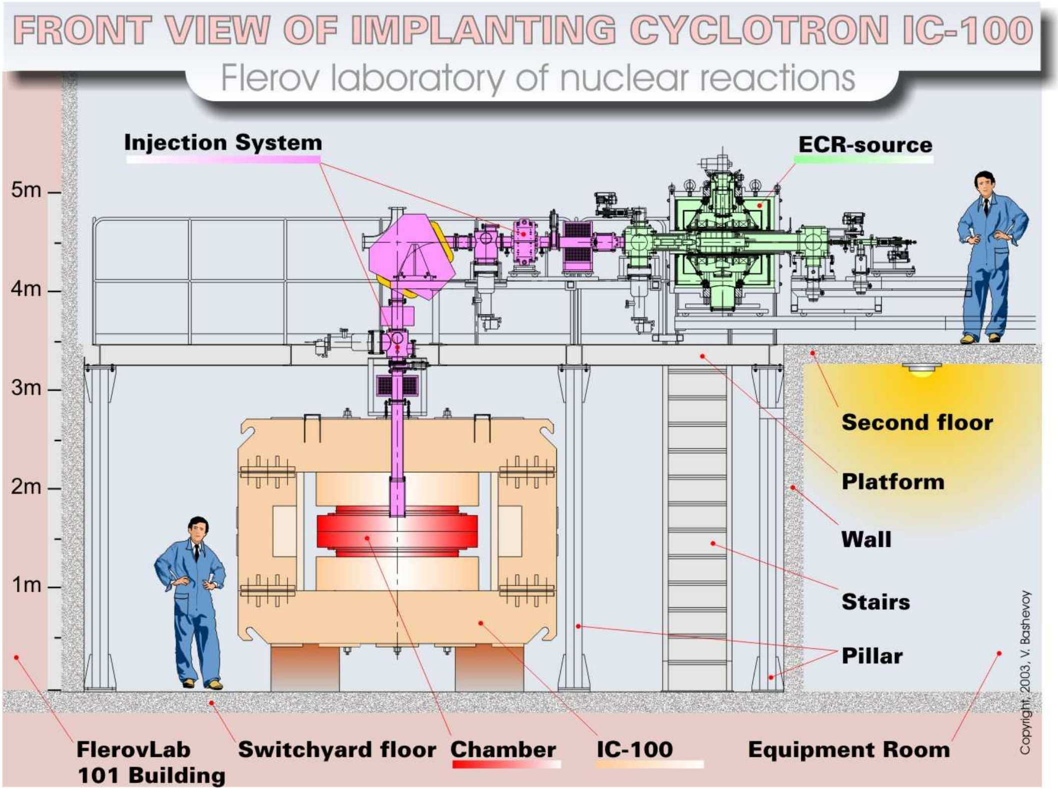
The complex includes four cyclotrons U400, U400MR, U200, IC100, the microtron MT25 and provides for intense accelerated beams of heavy ions are being used in FLNR for fundamental research and applied studies.



Technical parameters of the cyclotron U400MR

Parameters	U400MR	U400	IC100
Pole diameter, m	4	4	1
Magnetic field, T	2	2.1	2
Voltage at the dee,	150-200	80	50
kV	11.5-24	5.4-12.2	20-21
HV frequency, MHz			
Energy of			
accelerated ions,	20-120	4-20	1-1.25
MeV/nucleon			
A/Z	2-5	5-12	5.3-6

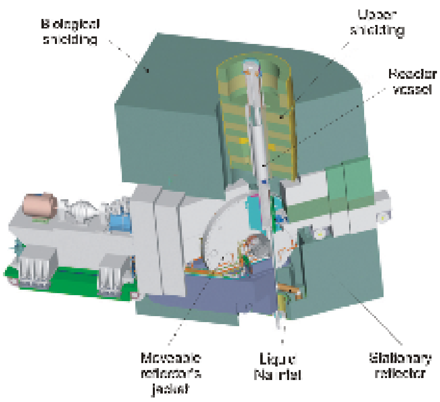
ACCELERATION COMPLEX FLEROV LABORATORY of NUCLEAR REACTIONS



Industrial production of nuclear filters has been implemented at the IC-100 cyclotron complex of the Laboratory of Nuclear Reactions at the Joint Institute for Nuclear Research. After the complete upgrade, the cyclotron was equipped with the superconducting ECR ion source and the system of external axial beam injection. The implantation complex was equipped with the special transportation channel with the beam scanning system and the setup for irradiation of polymer films. Intense beams of heavy ions Ne, Ar, Fe, Kr, Xe, I, and W with an energy of ~1 MeV/nucleon were obtained. the properties of irradiated crystals were studied, different polymer films were irradiated, and several thousands of square meters of track membranes with pore densities varying in a wide range were produced. Other scientific and applied problems can be solved at the cyclotron complex.

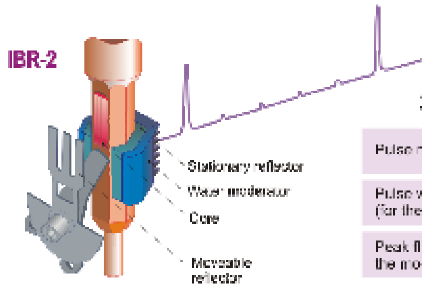
The IBR-2 Fast Pulsed Reactor

The IBR-2 is a fast pulsed reactor with mechanical modulation of reactivity by moveable reflector.



Reactor's history

1977	Reactor commissioning without liquid sodium coolant
1981	Reactor commissioning with liquid sodium coolant, first power
1982	Reactor start-up, first experiments
1984 - - 2006	Regular operation for physical experiments



Source parameters

Pulse repetition rate	5 Hz
Pulse width (for thermal neutrons)	320 μs
Peak flux density from the moderator surface	2.4×10^{16} n/(cm^{2}s)

Modernization Program

Comparison of reactor's design parameters before and after modernization

Parameter	IBR-2	IBR-2M
Mean power, MW	2	2
Fuel	PuO_2	PuO_2
Number of fuel elements	78	69
Maximal burn up, %	6.5	9
Repetition rate, Hz	5; 25	5; 10
Pulse width for fast neutrons, μs	215	~200
Rotation speed, rpm		
main reflector (MMR)	1500	600
auxiliary reflector (AMR)	300	300
MMR and AMR material	Steel	Nickel+steel
Moveable reflector service life, hours	20000	55000
Background, %	6	7
Number of satellites at 5 Hz	4	1

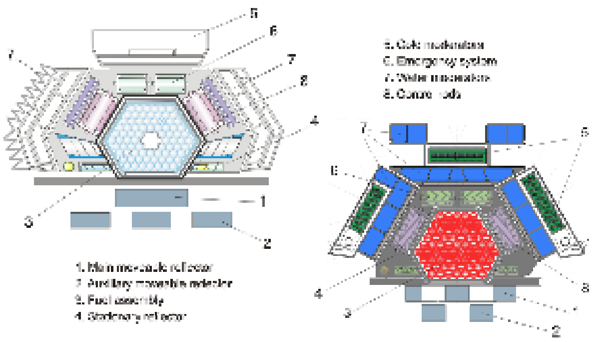
Modernization milestones in 2007-2010

№	Types of work	2007	2008	2009	2010
1.	Unloading of the active zone				
2.	Disassembly of worn-out equipment:				
	2.1. Reactor vessel				
	2.2. Moveable reflector (MR-3)				
	2.3. Control and protection system (CPS)				
3.	Assembly of new equipment:				
	3.1. Reactor vessel				
	3.2. MR-3				
	3.3. CPS				
4.	Physical start-up				
5.	First power				

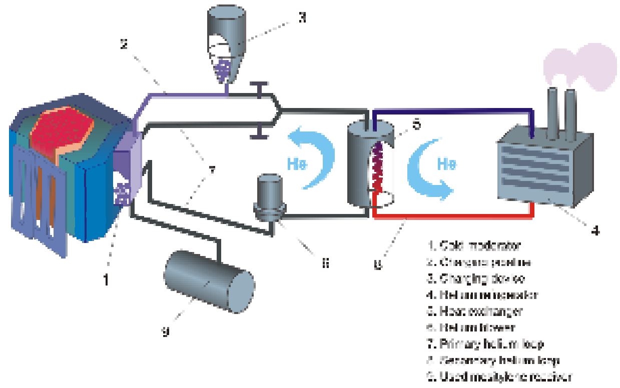
Main Goals

- Improvement of the reactor principal parameters;
- Increasing of operating reliability of the reactor;
- Modernization of the main equipment of the reactor.

Design scheme of the IBR-2 core (left) and the IBR-2M core (right)

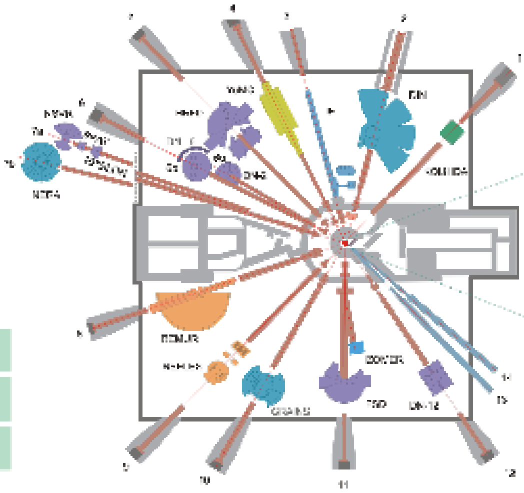


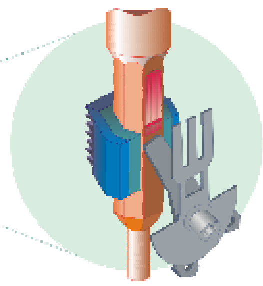
Principal scheme of the IBR-2M moderator's system



Neutron Instrumentation at IBR-2 Fast Pulsed Reactor

IBR-2 is a fast pulsed reactor with a mechanical modulation of reactivity by moveable reflectors.





Source Parameters

Pulse repetition rate	5 Hz
FWHM of thermal neutron pulse	320 μs
Flux density from the moderator surface	2.4 x 10[illegible] n/(cm²s)

Instruments

Diffractometers:

High Resolution Fourier Diffractometer HRFD
Max resolution: Δd/d = 0.0005 at d = 2 Å

General Purpose Diffractometer DN-2
Neutron flux at sample position: 10^7 n/(sm²s)

Texture & Stress Facility EPSILON, SKAT, NSVR
Max resolution: Δd/d = 0.004 at d = 2 Å

Micro Samples & High Pressure Specrtometer DN-12
Pressure on sample: 0 - 100 kbar;
Sample volume < 100 mm³

Fourier Stress Diffractometer FSD
Max resolution: Δd/d = 0.003 at d = 2 Å

Small Angle Spectrometer:

Small Angle Scattering Spectrometer YuMO
Momentum transfer: 0.007 - 0.7 Å^{-1}

Polarized Neutron Spectrometers:

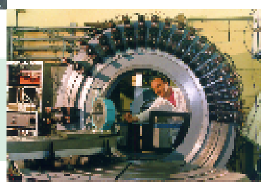
Spectrometer of Polarized Neutrons REMUR
λ-range: 0.7 - 10 Å;
Divergence in horizontal plane: 3 x 10^{-3} rad;
Divergence in vertical plane: 10^{-2} rad

Reflectometer of Polarized Neutrons REFLEX
λ-range: 0.7 - 10 Å; Q-range: 0.003 - 0.2 Å^{-1};
Average polarization: 98%

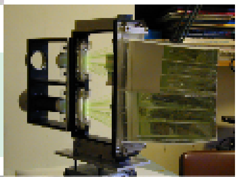
Inelastic Scattering Spectrometers:

Direct Geometry Spectrometer DIN
Energy resolution: 4% < ΔE/E < 10%;
Incident energy: 1 < E_i < 50 keV

Multi-Purpose Inverted Geometry Spectrometer NERA
Energy transfer (INS): 0 - 250 meV;
Momentum transfer (QNS): 0.1 - 3.0 Å^{-1};
Energy resolution: 2 - 5%



A general view of the SKAT-Texture diffractometer



A general view of the REMUR

Frank Laboratory of Neutron Physics
Joint Institute for Nuclear Research
Dubna, Russia

http://flnp.jinr.ru/34/

HUNGARIAN SCIENTISTS AT JINR FACILITIES

During the last decade, the JINR facilities have been mainly used in condensed-matter and heavy-ions physics. Majority of the experimental work in condensed matter physics was conducted at spectrometers of the pulsed reactor IBR-2. A series of experiments on magnetic layered nanostructures [1-4] has been performed on the polarized neutron spectrometers SPN-1 and its successor REMUR [5] by a group of scientists from the Nuclear Solid State Physics Section (head: L. Bottyán) of the Department of Nuclear Physics (head: D.L. Nagy) of the KFKI Research Institute for Particle and Nuclear Physics of the Hungarian Academy of Sciences (KFKI RMKI HAS) in collaboration with FLNP scientists (V.L. Aksenov, Yu.V. Nikitenko, V. Lauter-Pasyuk, Yu.N Khaidukov, A.V. Petrenko and others). The most extensive study in this field was done on the magnetic domain structure of antiferromagnetically coupled Fe/Cr multilayers. Formation and transformations of the domain structure as a function of the magnetic field history as well as the influence of ultrasound excitation on the distribution of the domains have been established.

Three-dimensional nanoparticles of different composition, introduced in solid or liquid matrix solution, have been studied on the small-angle neutron scattering spectrometer YuMO [6]. Further systems investigated by the group of neutron spectroscopy (head: L. Rosta) of the Research Institute for Solid State Physics and Optics of HAS (SZFKI HAS) in collaboration with FLNP groups of A.I. Kuklin and M. V. Avdeev included magnetic ferrofluids [7], different gels [8] and mixtures [9]. During the modernization period of the reactor IBR-2 until 2010, these investigations are being continued in other neutron centers including the Budapest Neutron Center (BNC).

Hundreds MeV heavy ions produced at the U-400 and IC-100 FLNR cyclotrons are another kind of particles extensively used by Hungarian scientists. An example of effective utilization of swift ion beams is experiments aimed at studies of nanoscale surface structures produced by single high energy ions and finding the correlation between surface and material bulk radiation damage. An example of effective utilization of swift ion beams is experiments aimed at studies of nanoscale surface structures produced by single high energy ions and finding the correlation between surface and material bulk radiation damage. Collaborative work of groups of K. Havancsák, Z. Homonnay and E. Kuzmann from Eötvös Loránd University, Budapest, the group of Zs Kajcsos (KFKI RMKI HAS) and group of V.A. Skuratov addressed the elucidation of dense ionization effects in radiation-resistant insulators, like MgO and Al_3O_3 [10], amorphous alloys and metals [12].

Common work of groups of K. Havancsák, Z. Homonnay and E. Kuzmann from Eötvös Loránd University, Budapest, the group of Zs Kajcsos (KFKI RMKI HAS) and group of V.A. Skuratov addressed the study of the properties of crystalline oxide of Al and Mg [10], different states of iron [11] etc, after bombarding by heavy ions. By changing the conditions of such bombardment like intensity, the energy of ions, temperature of the target, etc. one can tune the properties of modified systems.

Another use of heavy ions is studying different phenomena in nuclear physics. One of the examples is the clustering in nuclear fission reactions caused by ion bombardment, a phenomenon, which is the subject of a common project between the group of A. Krasznahorkay of the Institute of Nuclear Research of HAS, Debrecen (ATOMKI HAS) and the FLNR group headed by D.V. Kamanin in collaboration with the Moscow Engineering Physics Institute (Yu.V. Pyatkov). The first paper of this new project on the study of tripartition fission in the reaction $^{238}U+^{4}He$ has been recently published [12].

There is an increasing interest from Hungarian side in potentially using JINR facilities producing neutron and ion beams for life sciences [13], medicine [14] and industrial applications. Nevertheless, after its re-opening in 2010, most probably the modernized reactor IBR-2M will be the key facility initiating new fruitful collaborations between Hungarian and JINR scientists.

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14. · See abstract of E. Krasavin, this booklet

HUNGARY – JINR COLLABORATION IN 2004 – 2008

1) THEORETICAL PHYSICS

INCOMPLETE NONEXTENSIVE AND RÉNYI STATISTICS

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The statistical mechanics based on the nonextensive Tsallis entropy [1] finds support in recent studies due to non-Gibbs phase distribution functions which appear to be successful in analyzing certain experimental data [2]. In these investigations the statistical Boltzmann-Gibbs entropy is modified by the additional parameter q , appearing both in the distribution function and in the equation of state of the system. The incomplete nonextensive thermostatics or the Wang's formalism of the generalized statistical mechanics is based on Tsallis' definition of the statistical entropy [1], and on the incomplete normalization condition for the phase distribution function [3],

$$S=-k\int d\Gamma\frac{\rho-\rho^{q}}{1-q},\qquad \int d\Gamma\rho^{q}=1. \tag{1}$$

This is conform with a modified expectation value of a dynamical variable A

$$\langle A\rangle=\int d\Gamma A\rho^{q}, \tag{2}$$

where ρ^{q} is the phase distribution function, $d\Gamma$ is an infinitesimal element of phase space, k is the Boltzmann constant and $q\in\mathbf{R}$ is a real parameter, $q\in[0,\infty]$.

In this respect for the Tsallis statistics two problems occur: the problem of the physical interpretation of the parameter q and the problem of connecting such statistical treatments to equilibrium thermodynamics [4]. The latter gives rise to theoretical discussions in the literature due to the difficulties in the proof of the zeroth law of thermodynamics which is closely connected to the principle of additivity. In the Tsallis statistics the principle of additivity is violated as the initial statistical entropy is nonextensive due to its definition. In the case when the parameter q is a universal constant all attempts to proof the zeroth law of thermodynamics for finite systems failed and the thermodynamical limit is incompatible with the Gibbs limit, $q\to 1$. However, an unambiguous connection between statistical mechanics and equilibrium thermodynamics can be provided only in the special thermodynamic limit [5] when the parameter $1/(q-1)$ is an extensive variable of state [6,7]. In this case the final Tsallis entropy becomes extensive, the zeroth law of thermodynamics and the principle of additivity are restored, all functions of state are either extensive or intensive in conformity with the requirements of equilibrium thermodynamics.

The Rényi thermostatics is based on Rényi's definition of statistical entropy with a usual norm equation for the phase distribution function

$$S = k\frac{\ln\left(\int \rho^q \, d\Gamma\right)}{1-q}, \qquad \int \rho d\Gamma = 1. \tag{3}$$

The expectation value of a dynamical variable A is given as

$$\langle A\rangle = \int A\rho \, d\Gamma.$$

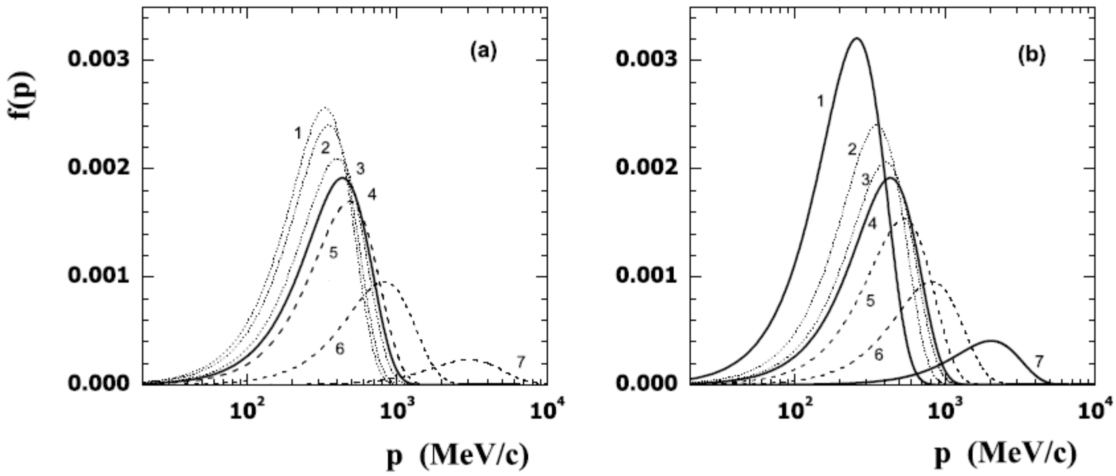

Fig. 1. The single-particle distribution function for classical non-relativistic ideal gas of nucleons in Wang's formalism of Tsallis statistics at the temperature T=100 MeV and the specific volume $\nu=3/\rho_0$ for two treatments of a parameter z': (a) a universal constant [8] for N=10 and different values of z' =20, 30, 100, ±∞, -100, -30 and -20 (the curves 1,2,3,4,5,6 and 7, respectively), (b) an extensive variable of state [7] in thermodynamic limit for different values of the specific z' =3, ±∞, -3 (solid lines 1,4,7, respectively). The dotted and dashed lines (b) correspond to the calculations considering z' as an universal constant [8] for z' = 3 and number of particles N=10,50 (lines 2,3) and z' =-3 and N=50,10 (lines 5,6). The line 4 on both panels corresponds to the conventional Boltzmann-Gibbs statistics.

In our paper [8] the microcanonical and canonical ensembles of the Wang's formalism for the Tsallis statistics and the corresponding ensembles for the Rényi statistics were compared. It was shown that in Wang's formalism for the Tsallis statistics both in the microcanonical and the canonical ensembles the zero-th law of thermodynamics and the principle of additivity are violated, as long as the parameter q is a universal constant. This conclusion is also valid for the Rényi statistics in the canonical ensemble. On the other hand the microcanonical ensemble of the Rényi statistics coincides with the Gibbs one, hence, all laws of the equilibrium thermodynamics are satisfied in the thermodynamic limit.

In the paper [9] Wang's formalism of the Tsallis statistics was compared to the Rényi one in the thermodynamical limit [6,7]. An unambiguous connection between both statistical mechanicses and the equilibrium thermodynamicses are revealed. For this purpose expressions obtained in Wang's formalism of Tsallis statistics and the Rényi one were rewritten in terms of a new extensive variable of state z, related to the entropic parameter q. For the incomplete nonextensive statistics the thermodynamical variable of state z is expressed through the parameter q as $z = q/(1-q)$ and for the Rényi statistics as

$z = 1/(q-1)$. The functions of state were regularized by applying the limiting procedure of the thermodynamical limit. We obtained that in this limit Wang's formalism of the Tsallis statistics in the terms of the extensive variable of state z completely coincide with the original Tsallis thermostatics in both the microcanonical and the canonical ensembles. However, the Rényi statistics resembles the usual Boltzmann-Gibbs thermodynamics. In the microcanonical ensemble we proved for both the Rényi and Wang's statistics that in the thermodynamical limit all laws of thermodynamics, in particular the zeroth law, the principle of additivity, the Euler theorem, the fundamental equation of thermodynamics and the Gibbs-Duhem relation are valid. To put it simply both the Tsallis and the Rényi entropies are extensive in the thermodynamical limit, provided one composes subsystems with the proper, and hence different, q-values.

In the canonical ensemble, however, only the fundamental equation of thermodynamics, the first and the second laws were derived in general terms. For demonstrating further principles of equilibrium thermodynamics in the framework of the canonical ensemble, both for the Rényi statistics and for Wang's formalism of Tsallis statistics, exact analytical results were utilized for the ideal gas of identical particles. It was shown for this particular example that in the thermodynamical limit for both thermostatics the main thermodynamical equations, the zeroth law and the principle of additivity are satisfied. All functions of state are either extensive or intensive. Moreover, in the canonical ensemble in the thermodynamical limit both the Tsallis and the Rényi entropies are extensive. For the ideal gas of identical particles in both thermostatics the equivalence of the canonical and the microcanonical ensembles in the thermodynamical limit was demonstrated. This is a very important property to be verified for the self-consistent definition of any statistical mechanics. Fig. 1 shows the dependence of the single particle-distribution function on the momentum p for the ideal nucleon gas in the incomplete nonextensive statistics.

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TRANSVERSE AND LONGITUDINAL MOMENTUM SPECTRA OF FERMIONS PRODUCED IN STRONG SU(2) FIELDS

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During last years large amount of data on particle spectra have been collected in relativistic heavy ion collisions at the Super-Proton Synchrotron (SPS, CERN) and at the Relativistic Heavy Ion Collider (RHIC, BNL) at c.m. energy of $\sqrt{s} = 10 - 200$ GeV in a wide transverse momentum range, $0 \le p_T \le 20$ GeV. Since the microscopic mechanisms of hadron production in hadron-hadron and heavy ion collisions are not fully understood, it is very important to improve our theoretical understanding on this field. The forthcoming hadron and heavy ion experiments at the Large Hadron Collider (LHC, CERN) at $\sqrt{s} = 5500$ GeV will increase the transverse momentum window to $0 \le p_T \le 50$ GeV. Thus LHC experiments will become a decisive test between different perturbative and non-perturbative models of hadron formation, especially in the high- p_T region.

Theoretical descriptions of particle production in high energy pp collisions are based on the introduction of chromoelectric flux tube ('string') models, where these tubes are connecting the quark and diquark constituents of the colliding protons. String picture is a good example of how to convert the kinetic energy of a collision into field energy. New hadrons will be produced via quark-antiquark and diquark-antidiquark pair production from the field energy, namely from the unstable flux tubes. These models can describe experimental data very successfully at small p_T, especially at $p_T < 2-3$ GeV. At higher p_T one can apply perturbative QCD-based models, which can provide the necessary precision to analyse nuclear effects in the nuclear collisions.

However, at RHIC and LHC energies the string density is expected to be so large that a strong collective gluon field will be formed in the whole available transverse volume. The properties of such non-Abelian classical fields and details of gluon production were studied very intensively during the last years, especially asymptotic solutions.

The main subject of this paper [1] is the transverse momentum distribution of produced fermions as well as the longitudinal momentum in a wide rapidity range. In our previous paper on this topic (see Ref. [1]) we investigated the Abelian case, namely particle pair-production in a strong external electric field. We have demonstrated a scaling behaviour in time and transverse momenta, namely $t \cdot E_0^{1/2}$ and $k_T / E_0^{1/2}$. The kinetic equation and the numerical calculation yielded a fermion dominance in the mid-rapidity region. In case of realistic Bjorken type time evolution our numerical result on fermion spectra has overlapped the boson spectra obtained in 1+2 dimensional lattice calculations both in magnitude and shape.

In recent paper [2] we solve the kinetic model in the presence of an SU(2) non-Abelian color field. We focus on the determination of the appropriate kinetic equation system and its numerical solution in case of different initial conditions.

The fermion production in a strong external space homogeneous field can be characterized by a Wigner function, $W(\mathbf{k};t)$. The evolution of this Wigner function is investigated by the kinetic equation in the frame of the covariant single-time formalism, where a time-dependent Abelian (A^{μ}) [3-5] or non-Abelian (A^{a}_{μ}) external field is included. Here we choose a longitudinally dominant color vector field in Hamilton gauge described by the 4-potential

$$A^{a}_{\mu} = (0, -\mathbf{A}^{a}) = (0, 0, 0, A^{a}_{3}) . \qquad (1)$$

Starting from the QCD Lagrangian we obtained the kinetic equation for $W(\mathbf{k};t)$

$$\begin{aligned} &\partial_t W + \frac{g}{8}\frac{\partial}{\partial k_i}\left(4\{W, F_{0i}\} + 2\left\{F_{i\nu}, [W, \gamma^0\gamma^\nu]\right\} - \left[F_{i\nu}, \{W, \gamma^0\gamma^\nu\}\right]\right) = \\ &= ik_i\{\gamma^0\gamma^i, W\} - im[\gamma^0, W] + ig\left[A_i, [\gamma^0\gamma^i, W]\right] \end{aligned} \qquad (2)$$

Here m is the current fermion mass and g is the coupling constant.
The color decomposition with $SU(N_c)$ generators in fundamental representation (t^a) is given by

$$W = W^s + W^a t^a , \qquad a = 1, 2, ..., N_c^2 - 1 , \qquad (3)$$

where W^s is the color singlet and W^a is the color multiplet component (triplet in $SU(2)$ with $N_c = 2$).
The spinor decomposition is the following:

$$W^{s|a} = a^{s|a} + b^{s|a}_{\mu}\gamma^{\mu} + c^{s|a}_{\mu\nu}\sigma^{\mu\nu} + d^{s|a}_{\mu}\gamma^{\mu}\gamma^{5} + ie^{s|a}\gamma^{5}. \qquad (4)$$

Solving the kinetic equation for the Wigner function we can define bulk properties of the quark plasma. However the physical interest is also concentrated on the distribution function of produced quarks. In the Wigner function formalism there is no straightforward way to define the distribution function. We suggest phenomenological guess of the distribution function definition.

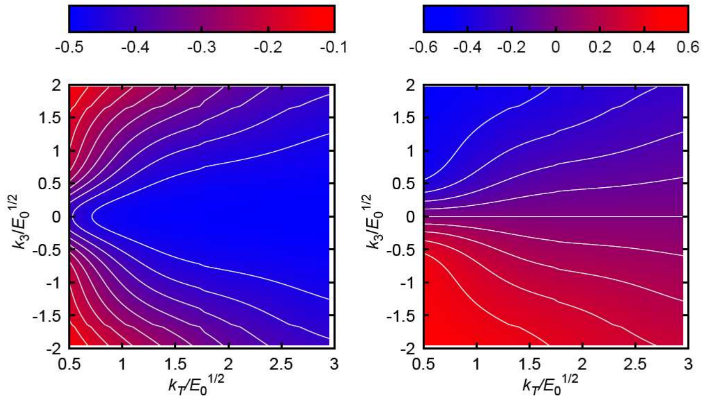

FIG. 1: The momentum dependences of the color singlet components $b_\perp^s(k_\perp,k_3)$ (left panel) and $b_3^\Diamond(k_\perp,k_3)$ (right panel) at $t=2/E_0^{1/2}$ for the Bjorken expanding scenario.

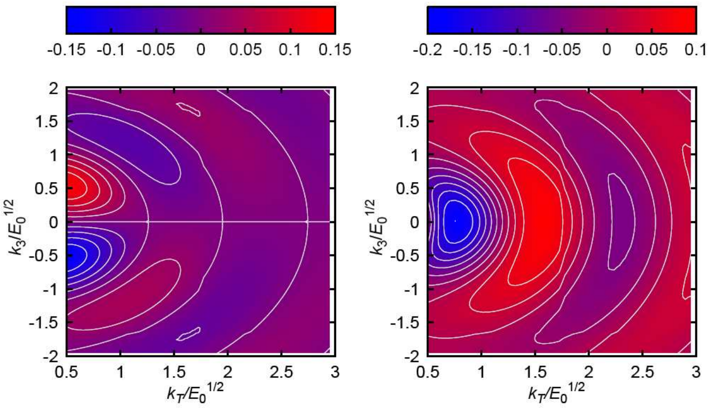

FIG. 2: The momentum dependences of the color singlet components $b_\perp^\Diamond(k_\perp,k_3)$ (left panel) and $b_3^\Diamond(k_\perp,k_3)$ (right panel) at $t=2/E_0^{1/2}$ for the Bjorken expanding scenario.

Comparing the energy density of produced quarks in Wigner formalism with the expression for usual energy density we obtain that

$$f_f(\mathbf{k},t)=\frac{ma^s(\mathbf{k},t)+\mathbf{k}\,\mathbf{b}^s(\mathbf{k},t)}{\omega(\mathbf{k})}+\frac{1}{2}, \qquad (5)$$

where $\omega(\mathbf{k})$ is one particle energy $\omega(\mathbf{k})=\sqrt{\mathbf{k}2+m2}$. The distribution function (DF) is positively defined and equals zero in vacuum.

Since the mass of light quarks is small, we neglect the mass term in our SU(2) calculation. In this case the distribution function for massless fermions is only depend on $\mathbf{b}s$. The zero fermion mass leads to the simplification of the kinetic equation, which is splitted into two independent parts: one for $as|a,\mathbf{c}_1^{s|a},\mathbf{c}_2^{s|a},es|a$ and another one for $b_0^{s|a},\mathbf{b}s|a,d_0^{s|a},\mathbf{d}s|a$. For the sake of simplicity we assume color isotropy among different color components of the external field: $\mathbf{A}^a \equiv \mathbf{A}^?$ in general case, and $A_3^a \equiv A^\diamond$. Then the kinetic equation has the following particular solution $\mathbf{b}^a = \mathbf{b}^\diamond$, $\mathbf{d}^a = \mathbf{d}^\diamond$.

In heavy ion collisions, one can assume three different types of time dependence for the isotropic color field to be formed: a) pulse-like field develops with a fast increase, which is followed by a fast fall in the field strength; b) formation of a constant field (E_0) is maintained after the fast increase in the initial time period; c) scaled decrease of the field strength appears, which is caused by particle production and/or transverse expansion, and the decrease is elongated in time much further than the pulse-like assumption.

Three sets for the time dependence of the external field [1] are given by:

$$E^\diamond_{pulse}(t) = E_0 \cdot \left[1 - \tanh^2(t/\ \delta)\right] \qquad (6)$$

$$E^\diamond_{pulse}(t) = \begin{cases} E^\diamond_{pulse}(t)\, at\, t < 0 \\ E_0 \quad at\, t \geq 0 \end{cases} \qquad (7)$$

$$E^\diamond_{scaled}(t) = \begin{cases} E^\diamond_{pulse}(t)\, at\, t < 0 \\ \frac{E_0}{(1+t/t_0)^k} \quad at\, t \geq 0 \end{cases} \qquad (8)$$

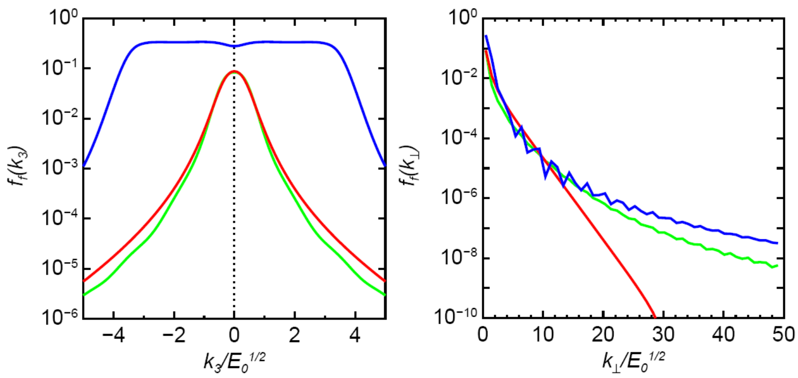

FIG. 3: Left panel: the longitudinal (k_3) spectra for fermions at $k_\perp/E_0^{1/2} = 0.5$ and $t = 2/E_0^{1/2}$ in the three physical scenarios: pulse (*red line*); constant field E_0 (*blue line*); scaled decrease (*green line*). Right panel: three transverse momentum spectra for fermions at $k_3 = 0$ and $t = 2/E_0^{1/2}$.

In eq. (6) we choose $\delta = 0.1/\ E_0^{1/2}$, which corresponds to RHIC energies. In eq. (Es) the value $\kappa = 2/3$ indicates a longitudinally scaled Bjorken expansion with $t_0 = 0.01/\ E_0^{1/2}$.

As it was outlined above the distribution function $f_f(k_\perp, k_3)$ of massless quarks depends only on $b_\perp^S(k_\perp, k_3)$ and $b_3^S(k_\perp, k_3)$. Figure 1 display the magnitudes of these quantities in 2-dimensional plots. The k_3 -symmetry of $b_\perp^S(k_\perp, k_3)$ can be seen clearly, as well as the asymmetric behaviour of $b_3^S(k_\perp, k_3)$.

The distribution function $f_f(k_\perp, k_3)$ is color neutral, thus the color quantities $b_\perp^\Diamond(k_\perp, k_3)$ and $b_3^\Diamond(k_\perp, k_3)$ do not contribute directly. However, they play important role in the kinetic equation. Their oscillating behaviour can be seen on Figure 2.

The left panel of Figure 3 indicates the behavior of the longitudinal momentum spectra at small transverse momentum value, where we choose $k_\perp / E_0^{1/2} = 0.5$. Pulse-type time dependence leads to a narrow k_3 -distribution (*red line*), which mimics a Landau-type hydrodynamical initial condition. The longitudinal spectra from constant field scenario (*blue line*) leads to a flat distribution function in k_3. This result agrees well with a 1-dimensional, longitudinally invariant hydrodynamical initial condition, as we expect. For the scaled field scenario (*green line*) time dependence is very similar to the pulse-type case, thus the similarity in the longitudinal spectra is evident.

The right panel of Figure 3 displays the transverse momentum spectra for the three different physical scenario at momentum $k_3 = 0$ and time $t = 2 / E_0^{1/2}$. Pulse-type time dependence leads to exponential spectra (*red line*), $f_f \propto \exp(k_T / T)$ with slope value $T = 1.54 \cdot E_0^{1/2}$. In the other two cases, we obtain non-exponential spectra generated by the long-lived field. Here the spectra from constant (*blue lines*) and scaled (*green lines*) fields are close, because the production and annihilation rates balance each other. Slight differences appear because of the fast fall of the scaled field immediately after $t = 0$.

Further analysis of the kinetic equation at high transverse momentum reveals the scaling between U(1) result obtained in [1] and [2] $f_{SU(2)} / f_{U(1)} = 3/4$. It is also was shown that assuming specific condition for singlet and multiplet components, namely $W? = \eta b s$, one can derive analogy of U(1) Abelian kinetic equation.

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DISTORTED INCIDENT WAVE APPROXIMATION OF DIFFUSE POLARIZED NEUTRON AND SYNCHROTRON MÖSSBAUER REFLECTOMETRY

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The off-specular neutron, x-ray and Mössbauer reflectometry spectra can be described similarly in terms of the Distorted Wave Born Approximation (DWBA). Here we report on a new theoretical approximation of off-specular Synchrotron Mössbauer Reflectometry (SMR) resulting in time-effective algorithm, which finally can be used in iteration procedure of data analysis programs.

Indeed, the strong energy dependence of the scattering amplitude of nuclear resonance scattering requires performing the calculations with proper resolution for the energy range of the hyperfine interactions. Unlike in case of neutron reflectometry, where, in the range of interest, the energy dependence of the scattering amplitude is negligible, the SMR calculation is to be performed for more thousands of energy channels and, therefore, the standard DWBA approach of diffuse SMR results in a slow algorithm for statistical fitting of reflectograms.

Based on perturbation theory, a new theoretical description of off-specular SMR and polarized neutron reflectometry (PNR) was given [1] leading to an algorithm about 13 times faster then the standard DWBA. The new theory, Distorted Incidence Wave Approximation (DIWA), differs from the usual expression of diffuse intensity of DWBA in such a way that the "distortions" are only considered on the incident path while the exit path is left undistorted. Therefore a DIWA calculation is considerable faster but it is

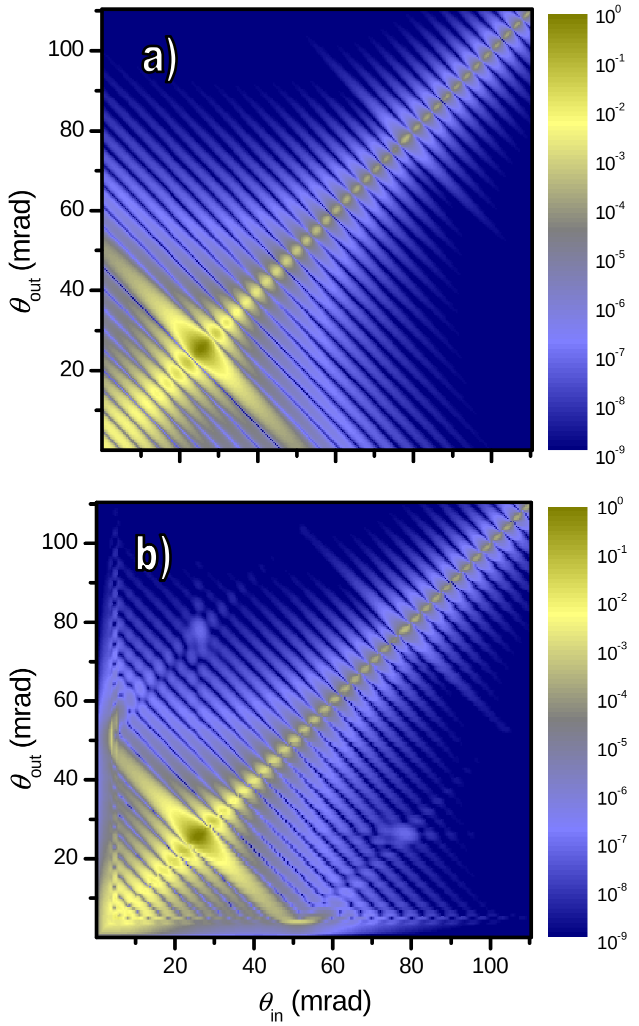

Fig. 1 Simulated 'θ_{in}-θ_{out}' PNR diffuse intensity maps for the MgO/[^{57}Fe(2.62nm)/Cr(1.28nm)]$_{20}$ antiferromagnetic multilayer structure (with 0.4 nm of wavelength). The intensities are normalized and shown on a logarithmic color scale. BA (a) and SDIWA (b) I^{++} intensities are shown. A unique domain bias parameter of η=0.1 was used.

not expected to be invariant with respect to exchanging the source and detector (a condition widely called "reciprocity"). The approximation is valid if the outgoing angle is significantly larger then the critical angle. The range of validity can be extended by mirroring the valid range as long as the conditions of the reciprocity theorem are fulfilled (always the case for neutron scattering).

After developing the corresponding software [2], simulations of diffuse scattering maps of an antiferromagnetically coupled MgO/[^{57}Fe(2.6nm)/Cr(1.3nm]$_{20}$ multilayer were made. The simulations show the different character of diffuse SMR and PNR in Figs. 1 and 2, respectively. The off-specular intensity depends on the material parameters (index of refraction, layer thicknesses) through its dependence on the specular intensity, but it is also dependent on the lateral structure through the correlation lengths characterizing the lateral inhomogeneities of the layers. This type of approach may model both natural (magnetic domains) and artificial lateral structures (magnetic lines, dot arrays, etc.), through a suitably chosen in-plane correlation function.

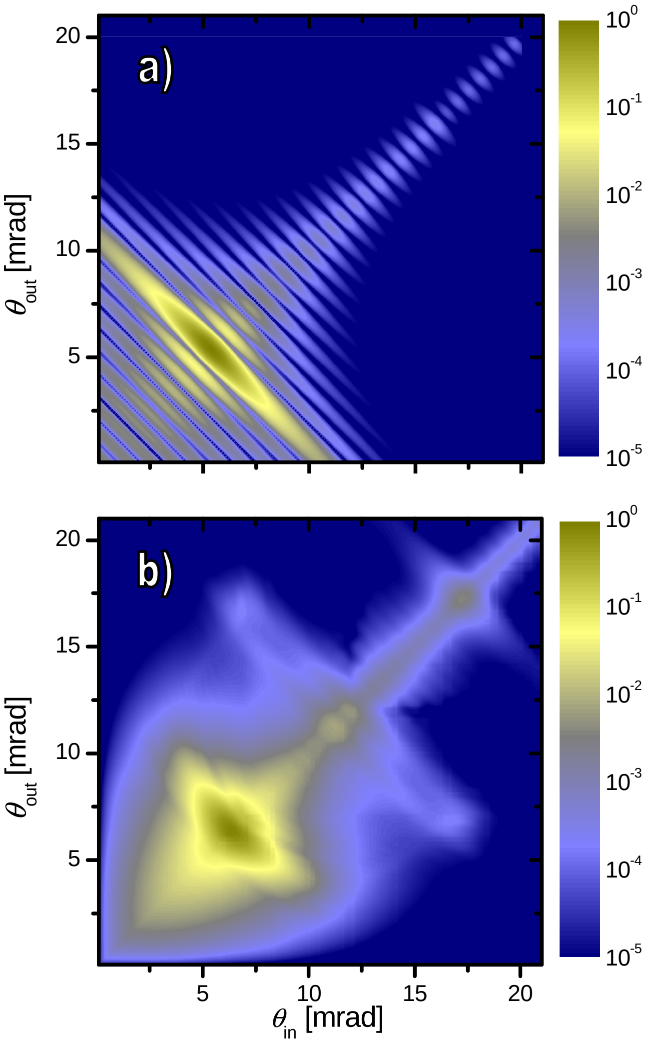

Fig 2 Simulated 'θ_{in}-θ_{out}' SMR diffuse intensity maps of MgO/[^{57}Fe(2.62nm)/Cr(1.28nm)]$_{20}$ antiferromagnetic multilayer structure around the 1/2-order antiferromagnetic Bragg peak using the BA (a) and the SDIWA (b). The intensities are shown on a logarithmic color scale and are normalized. A unique domain bias parameter of η=0.1 was used.

Figs. 1 and 2 display simulated PNR and SMR two-dimensional 'θ_{in}-θ_{out}' maps, respectively, for $\xi = 1$ μm correlation length with a unique domain bias parameter $\eta = 0.1$ in BA (1st Born Approximation) and DIWA approximation. The intensity is maximal along the diagonal specular line, and a broad diffuse intensity is observed around the half-order Bragg peaks. The $\theta_{in} < \theta_{out}$ semi-plane was mirrored onto the $\theta_{in} > \theta_{out}$ semi-plane. The Kiessig fringes are observed in both PNR and SMR diffuse scatter since the source for the diffuse intensity is the specular field. Due to the negligible absorption of the neutrons, the Kiessig contrast is stronger in PNR than in SMR. As expected, the diffuse intensity around the structural Bragg node at $\theta_{in} = \theta_{out} = 52$ mrad is missing since the diffuse scattering here is of purely magnetic origin and the magnetic contributions cancel each other at the momentum transfer corresponding to the first order Bragg peak. Moreover, because of the 2:1 layer thickness ratio of Fe/Cr, the 3/2-order Bragg reflection is forbidden.

The SMR map in Fig. 2b shows a number of features different from that of PNR in Fig. 1b. Due to the dominance of energy-dependent absorption for resonant x-rays, unlike in case of PNR in Fig. 1b, the SMR BA and SDIWA maps drastically differ from each other [1]. Since, independently, due to the stronger absorption, the Kiessig fringes are suppressed in the SMR map in Fig. 2b, the intensity does not oscillate near Yoneda wings. The total-reflection peak, being in the critical region, is somewhat difficult to distinguish from the 1/2-order AF Bragg node in Fig. 2 b.

Discussion of simulated SMR and PNR-scans and maps show that, except for exit angles below and around the critical angle of total reflection, the presented DIWA approach satisfactorily describes both the PNR and the SMR off-specular intensities. The new algorithm and the corresponding program cods are available from [2].

Effects in the specular reflectometry caused by the interface and surface roughness of the thin layers were also studied. Based on the method of characteristic matrices, a new formalism was worked out to separate the magnetic and structural roughness. [3].

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2) NUCLEAR PHYSICS

STUDY OF CLUSTERING PHENOMENA IN NUCLEAR FISSION

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Although the fission of actinide nuclei has been studied for a long time, there are many interesting phenomena still unexplored. For example, the predicted cold multi-fragmentation states, which are like sticking giant molecules and the predicted cold valleys of the collective potential energy surface, provide tests for our understanding of the physics of fission. The study of fission and mass distributions of the fission products from the 2nd and 3rd valley of fission potential can help us to understand the process much better. On the other hand exciting results were obtained in studies of the light nuclei along the N=Z line (α-clusters nuclei). Just to mention the exotic subjects being under study in this field such as α-chain molecules, α-ring molecules, hollow α-nuclei and so on. It is believed to be physical analogy of the exotic states mentioned in much heavier nuclear systems such as actinides where the role of strongly bounded clusters like α-particle are played by magic nuclei. Thus searching for manifestations of clustering of actinides seems to be of great interest and importance.

After discovering the hyperdeformed (3:1 axis ratio) states in uranium isotopes, we have been investigating superdeformed and hyperdeformed states in ATOMKI, Debrecen already for more than 10 yeas (see Ref. 1-4 as the most significant publications). Resonances were observed in the fission probability, the excitation energies and the angular distributions of fission fragments were measured using magnetic spectrometers. In this way, the energies and spins of these states were determined. The mass and total kinetic energy distributions (TKE) of the fission fragments are peculiar. These effects are most pronounced in cold fission, when the fragments are not excited or weakly excited. The mass distributions and TKE distributions have been deduced from the energy and time of flight of the fission fragments.

In a series of experiments using different time-of-flight spectrometers group from JINR (Dubna) [5-8] observed an unusual decay mode of ^{252}Cf (sf) which was treated as "collinear cluster tripartition". So far experimental manifestations of this decay channel were obtained in the frame of the "missing mass" method. It means that only two almost collinear fragments were detected in coincidence and they were much smaller in total mass than initial nucleus. It is reasonable to suppose that the "missing" mass corresponds to the mass of undetected fragment (or fragments) flying apart almost along a common fission axis. Shell effects in the resultant fragments seem to be decisive for the process of interest. One of the examples is shown in fig.1. A pronounced rectangular-like structure is observed in the fragments mass-mass distribution gated by neutrons. The rectangle is bounded by well known magic nuclei. Analysis of the neutron data from this experiment let one to conclude that the cluster mode observed manifests itself as a neutron source of high multiplicity (ν~6) to be almost in rest [9].

The first results of an experiment aimed at searching for collinear cluster tripartition channel in the reaction $^{238}U+^{4}He$ (40 MeV) have been published recently [8]. A two-arm TOF-E (time-of-flight vs. energy) spectrometer with micro- channel plate detectors and mosaics of PIN diodes was used. Among ternary events detected there are some presumably due to the decay of Pu shape-isomers built on the pairs of magic clusters. Fission of these states results in forming of long lived di-nuclear molecule like systems which can disintegrate via inelastic scattering on the materials on the flight path, as they reported.

We are planning a joint and complementary set of studies on the exotic fission processes of highly deformed (molecule-like) states in ATOMKI, Debrecen using special detectors built in Dubna and vice versa joint experiments in JINR (Dubna) using neutron multi-detector facility.

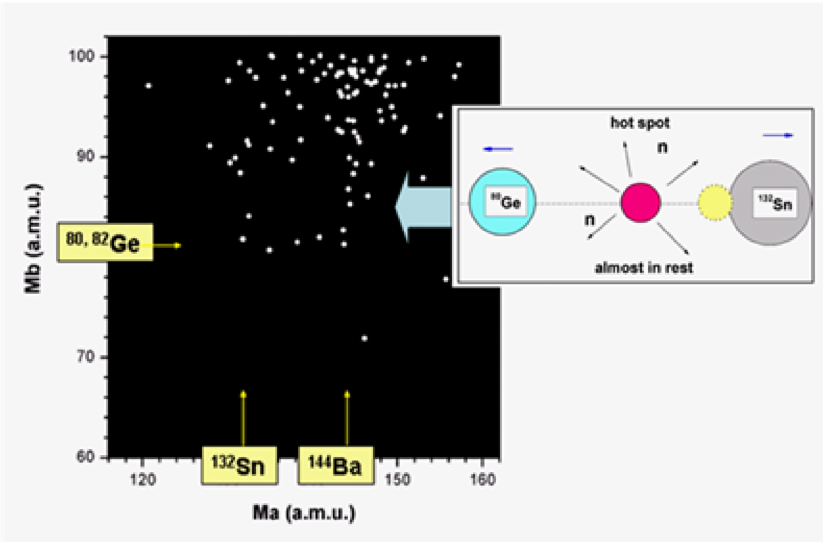

Fig.1. Fission fragments mass-mass distribution gated by neutrons from ^{252}Cf(sf). Rectangular-like structure bounded by magic clusters manifests itself as a neutron source of high multiplicity to be almost in rest.

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JINR-BNC DEVELOPING COLABORATION: NAA IN LIFE SCIENCES

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In the 70 and 80es of the 20 century the collaboration between FLNP JINR and Central Research Institute for Physical (KFKI), Budapest in the field of NAA was carried out following the world wide interest in semiconductors research.

Nowadays, the NAA proves its advantages in Life Science research, due to high accuracy, non-destructive approach, lack of biological matrix influence.

In this field of activity, the Neutron Activation Analysis Department of FLNP (JINR) and Neutron Activation Analysis Group of BNC (MTA KFKI) decided to join their efforts.

The first step in this collaboration was an interlaboratory comparison based on short lived isotopes. Samples of soil and vegetable selected from a series connected to a joint project between IFIN-HH in Magurele (Romania) and JINR were irradiated both at IBR-2 reactor in Dubna and BRR reactor in Budapest. The high values of the correlation coefficient for majority of determined elements and the results obtained on quality control process encourage the counterparts to extend their studies for a broader spectrum of elements.

This work was financially supported by the contract RII3-CT-2003-505925 (BRR_175) and JINR-Romanian Governmental Plenipotentiary Representative in JINR grant № 359/01.06.07 p.10.

3) CONDENSED MATTER PHYSICS

PARTICLE STRUCTURE AND INTERACTION EFFECTS IN FERROFLUIDS BY SMALL-ANGLE NEUTRON SCATTERING

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Dispersions of magnetic nanoparticles coated with surfactants (Fig.1) are known since 1960s as ferrofluids. The particle size ~10 nm corresponds to the single domain state in their magnetization.

Due to specific properties in a magnetic field ferrofluids are actively used in different industrial, technical, and biomedical applications. The knowledge about the microstructure of ferrofluids is very important to understand and control the mechanisms of their stabilization. Small-angle neutron scattering was actively used to reveal structure of different types of ferrolfuids at scale 1-100 nm. Among them are polar ferrofluids with double surfactant layers including alcohols (Fig.2) and water, as well as a new type of ferrofluids based on non-polar organic liquids (benzene, cyclohexane, decohydronaphthalene) where magnetite nanoparticles are coated with a single layer of short chain length mono-carboxylic acids (myristic and lauric acids).

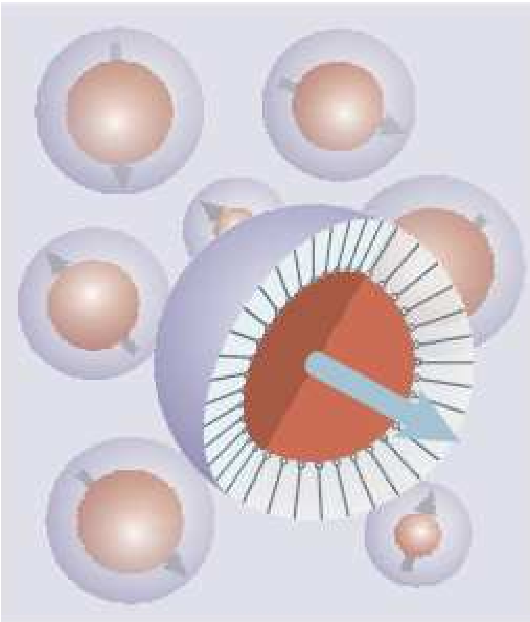

Fig.1. Schematic view of ferrofluids structure showing one-domain magnetic state of nanoparticles dispersed in liquid.

Highly stable new magnetic fluids in non-polar organic liquids obtained with short chain length mono-carboxylic acids, reveal a great difference in the particle size distribution function, particularly a decrease in the characteristic particle radius of magnetite when lauric and myristic acids are used instead of oleic acid.

The studied samples are synthesized at the Laboratory of Magnetic Fluids of the Center of Fundamental and Advanced Technical Research (LMF CFATR), Timisoara Branch of Romanian Academy of Sciences.

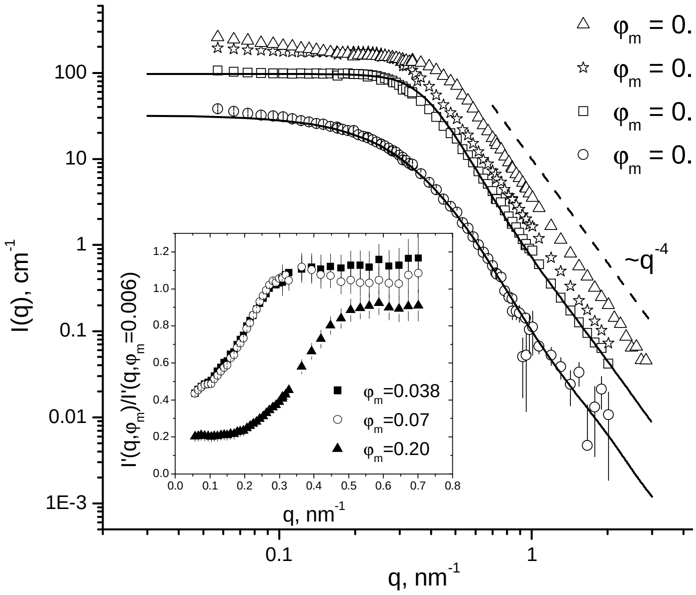

Fig. 2. Experimental SANS curves (points) for doubly stabilized ferrofluid magnetite/oleic acid/dodecylbenzenesulphonic acid/h-pentanol with various volume fraction of dispersed material φ_m. Lines are best fits for model of non-interacting spheres (φ_m = 0.006) and polydisperse hard spheres (φ_m = 0.038). Obtained thickness of 'hard' layer (surfactant shell), 2.3 nm, reveals significant interpenetration of surfactant sublayers. Inset shows effective structure-factors, where softening of interaction is seen for high concentrations. Dashed line corresponds to Porod law reflecting smooth surface of magnetite nanoparticles.

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APPLICATIONS OF SMALL-ANGLE NEUTRON SCATTERING IN STUDY OF NANOCARBON

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Small-angle neutron scattering (SANS) was applied for studying microstructural features in a number of nanocarbon systems. Particularly, they include shungites (Fig.1) - natural form of carbon- and nanodiamond powders. The complex pore size distribution function and fractal characteristics of the pore structures in these systems were analyzed. Absorption of D_2O was used to reveal difference in organization of open and closed pores. Also, the method was effectively used in the study of liquid dispersions of different forms of nanocarbon including colloidal fullerene water solutions (FWS), shungite aqueous dispersions, and dispersions of detonation ultrananocrystalline diamond in different liquids. The use of isotopic substitution hydrogen/deuterium in the liquid carrier made it possible to conclude about quantitative characteristics of the atomic distribution density inside the dispersed nanocarbon particles.

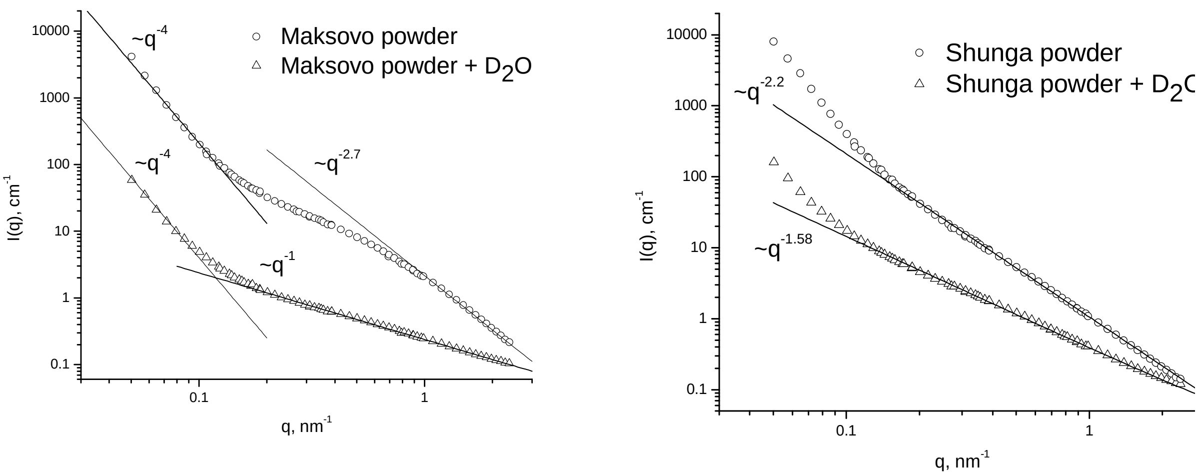

Fig 1. SANS analysis of the two-level structures in shungites from Maksovo (left) and Shunga (right) deposits. Changes are observed, when the powders absorb heavy water.

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STUDY OF PROXIMITY EFFECTS IN SUPERCONDUCTOR/FERROMAGNET INTERFACE USING WAVEGUIDE ENHANCEMENT OF NEUTRON STANDING WAVES

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Due to their incompatible nature, singlet superconductivity (S) and ferromagnetic (FM) order do not coexist. The exchange field, in a magnetically ordered state, tends to align spins of Cooper pairs in the same direction, thus preventing a pairing effect [1]. Conversely, ferromagnetic ordering is unlikely to appear in the superconducting phase. The energy for ferromagnetic ordering decreases and, instead of ferromagnetism, a non-uniform magnetic ordering ('cryptoferromagnetism') may appear in bulk materials [2]. However, due to the great progress of high-quality hybrid S/FM preparations, coexistence of S and FM can easily be realized in thin film heterostructures. On the one hand, Cooper pairs can penetrate the FM layer and in the interface region of a few nanometers may induce superconductivity even in the presence of a relatively large exchange field. On the other hand, magnetic order penetrates the SC layer and various novel FM and SC states may form with spatial oscillations and non-monotonic temperature variations with promising novel applications of structures like π-Josephson junctions, and S/FM spin-valves.

An S layer has been reported to affect the magnetic properties of the FM with scenarios – beside cryptoferromagnetism [2-4]– of magnetization leakage from FM into S layer [5,6], as well as a change of indirect exchange coupling of neighboring FM layers through S layer [7]. It is rather difficult to experimentally verify these theoretical predictions. This is why only a few experiments have been performed to study the influence of superconductivity on FM. In Refs. [3,4], for example, the observed reduction of magnetization below T_c in an S/FM bi-layer was interpreted as a cryptoferromagnetic effect, however, the experiment could also be interpreted as a consequence of magnetization leakage (an 'inverse proximity effect'), namely, by an induced negative magnetization in S layer and a suppression of the magnetization in the FM layer.

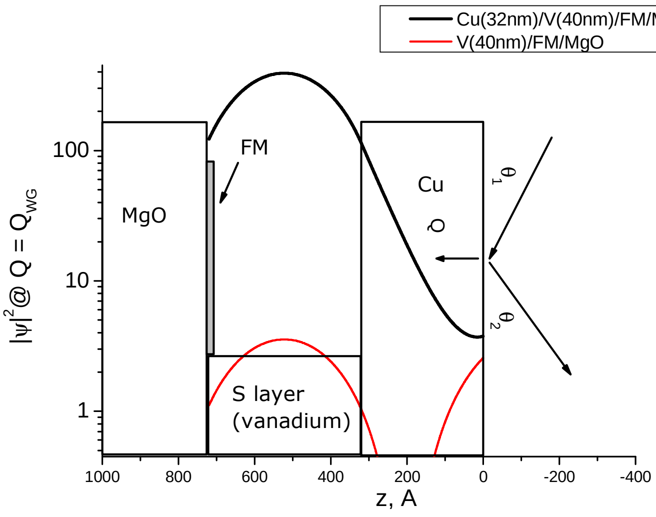

Fig. 1. Density of neutron flux inside a waveguide structure Cu(32 nm)/V(40 nm)/57Fe(0.5-1.5 nm)/MgO with and without Cu layer at Q = 0.009 Å-1 (solid black and dashed red lines, resp.). SLDs of materials are schematically shown by rectangular and incoming and reflected beams are shown by arrows.

In order to judge upon the interpretations one has to perform experiments with methods of depth resolution matching the layer thicknesses, like Polarized Neutron Reflectometry (PNR). PNR is sensitive to the magnetic depth profile $\vec{M}(\vec{r})$. In order to be able to observe such proximity effects, samples of layer systems with ultra-thin FM layer and possibly with reduced exchange coupling strength (as manifested by a decreased Curie temperature T_{Curie}) are necessary. Simulations reveal that a straighforward usage of conventional PNR, it is impossible to detect such weak magnetic signals. In order to increase the magnetic signal the enhanced neutron standing wave ('waveguide') regime is to be used. In order to enhance standing waves, we place the S/FM interface between two layers with high scattering potentials. Such optimization study has been performed for several candidate materials [8]. Accordingly, using the Cu(320 Å)/V(400 Å)/^{57}Fe(5-15 Å)/MgO structure, one can increase the neutron flux by two orders of magnitude (Fig.1) near the S/FM interface (at $Q = Q_{WG}$ (0.009 Å^{-1} in the present case). Such a flux increase leads then to an enhancement of quasi-secondary radiations (spin-flip scattering and diffuse scattering) at the same value of Q.

Several Cu/V/^{57}Fe/MgO(001) samples (size ~20×10×2 mm^3) with different thinkness of, and different exchange field in the FM layer (the latter achieved by co-evaporation of V with ^{57}Fe in different proportions) have been prepared in the KFKI Research Institute for Particle and Nuclear Physics, Budapest by molecular beam epitaxy (MBE) and, using magnetron-sputtering, further multilayers have been prepared in the Institute of Nuclear Research in Debrecen. To check structural, magnetic and superconducting properties of the samples, various experimental techniques were used, such as small- and wide-angle X-ray scattering, Rutherford backscattering (RBS) (of helium ions), Secondary Neutral Mass Spectrometry (SNMS) and SQUID magnetometry. X-ray Measurements have shown good quality of majority of the samples with layer structure close to nominal. For example, in Fig. 2*a* an x-ray reflectogram of the sample Cu(32 nm)/V(40 nm)/Fe(0.5 nm)/MgO is shown. The curve shows a total reflection region and clearly resolved Kiessig oscillations giving an evidence of a well layered structure with small interface roughness. RBS and SNMS of samples with all layers grown at 300 C by MBE reveal a considerable mixing of the Cu layer with the V underlayer. Samples therefore have been re-grown at 300 C (Fe and V layers) and cooled down before Cu layer growth, eliminating the mixing.

Magnetic and superconducting properties of the samples were analysed using a Quantum Design SQUID magnetometer at the Research Institute for Solid State Physics and Optics, Budapest. All measured samples showed a finite magnetization at 5 K (see for example Fig. 2b). Saturation magnetization and coercivity of the FM layer at $T \sim 10$ K were found to be M_{sat} = [0.2-1.4] kOe and H_c = [0.04-0.18] kOe, respectively.

The superconducting transition temperature T_C of the S layer was found by taking temperature scans of the magnetization in the range [1.8-10] K in a magnetic field of H = 10 Oe. A change of the magnetization at $T \approx 3$ K was observed for several samples. The absence of superconductivity for the rest can be explained by a substantial intermixing of Cu and V at the Cu/V interface or its suppression by large exchange coupling in the FM layer.

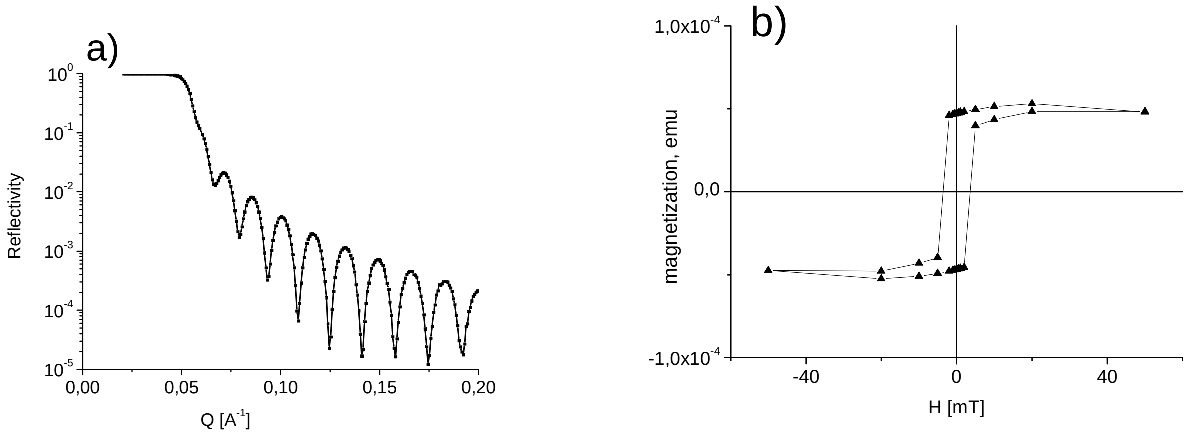

Fig. 2. Characterization curves for the sample Cu(32 nm)/V(40 nm)/Fe(1 nm)/MgO: a) X-ray reflectivity curve, using Cu K_α; b) Hysteresis loop measured by SQUID at T = 10 K.

In order to check the waveguide properties of the samples, room-temperature measurements were performed by polarized neutrons at the NREX+ reflectometer [9] of FRM-II, Munich, Germany. The presence of waveguide regime was searched for in the spin-flip channel. Spin-flip scattering originates from magnetization in FM layer non-collinear with the direction of the external magnetic field H. In order to induce such a magnetization in our samples, the samples were magnetized to saturation then rotated by 90^o for the reflectometric experiment in a magnetic field, H, with $0 < H < H_c$. In Fig. 3, polarized neutron reflectivities in the different spin states are shown in black (R^{++}) and red (R^{+-}).

The presence of the waveguide mode is proved by the dip in the R^{++} and the peak in the R^{+-} reflectivity curves at Q = 0.008 Å^{-1}, at a value closed to the expected one.The change in the relative intensity at the dip and the peak are 74%and 10%, respectively.By fitting the reflectivity curve using the FitSuite code [10], the absolute value of the magnetization and the angle between the external field and the magnetization of the FM layer were found to be M = 0.9 ± 0.2 kOe and 35^o ± 5^o, respectively.The intensity of the peak and the dip are very sensitive to the change of the magnetization vector. Our calculations show that using the present experimental setup (intensity of incoming beam, resolution) and the above described multilayer structure, it is possible to observe as low as 1% change in the FM layer magnetization. This is why such systems are especially suitable for studying the weak effects exerted by the superconducting film upon the FM layer in proximity to it below the temperature of superconducting transition.

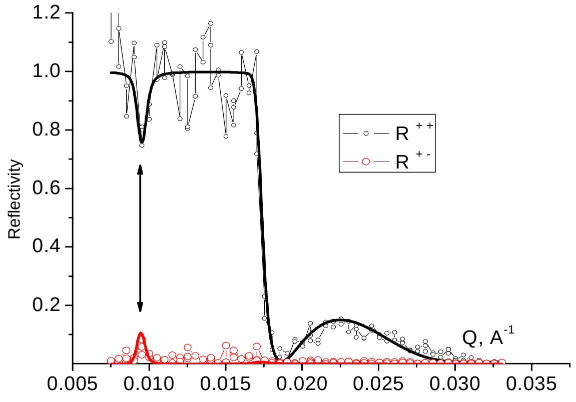

Fig. 3. Neutron reflectivities for different scattering channels from the sample Cu(32 nm)/V(40 nm)/Fe(1 nm)/MgO measured at RT in a magnetic field of 12 Oe. Arrow shows position of waveguide mode.

In conclusion, strong waveguide enhancement of neutron standing waves have been forseen by simulation and observed in various Cu/V/Fe/MO layer structures. The enhancement is large enough to detect weak magnetic signal of the thin (~ 1 to 4 nm) ferromagnetic Fe layer and changes in it by possible inverse proximity effects due to the superconducting transition of the V layer in proximity. Two series of samples were prepared by molecular beam epitaxy and by magnetron sputtering. The samples were well characterized by different techniques. Room-temperature PNR measurements proved that the well layered samples show waveguide properties, however, in case of layer mixing, the extended interface region decreases wave guide enhancement and the superconducting temperature of the sample simultaneously. The characterized samples with step-like depth profile are suitable for the scheduled PNR measurements at helium temperature [11].

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INVESTIGATION OF MAGNETIC NEUTRON WAVEGUIDES BY SPECULAR REFLECTION AND OFF-SPECULAR SCATTERING

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Recent advances in biochemistry and semiconductor nanotechnology demand new methods of characterization. A neutron beam with small cross section may be used as such method. In order to produce submicron neutron beams [1], we are developing neutron waveguides (NWG). The large magnetic neutron cross section allows to fabricate guides in which the optical index can be dynamically modulated [2]. We produced NWG with the following tri-layer structure: Py(20nm)/Ti(80nm)/Py(50nm)//*glass*. The samples are produced by RF sputtering. The top permalloy layer acts as the coupling layer with the incident beam, the Ti layer as the guiding layer and the bottom layer as the reflecting layer (see Fig. 1).

We have characterized our systems by polarized neutron reflectometry (specular and off-specular) on the reflectometer HADAS [3] at the FZ Jülich. The effect of the different imperfections (interface roughness, magnetic non-collinearity, dispersion of the layers thickness) on the reflectivity have been investigated. A polarized neutron beam (λ= 4.52 Å) is sent onto the sample with an incident glancing angle α_i (Fig. 1). A position sensitive detector is set after the sample and the scattered intensity is recorded as a function of α_f. The neutron wave function (WF) density for "+" spin state is shown in Fig. 2 as a function of the sample depth z and the incident angle α_i. In the Ti guiding layer there are 3 resonance states (order m = 1, 2, 3) in the total reflection region. The zero order resonance m = 0 is absent for this system. The WF density is enhanced at the interfaces in the Ti layer by a factor 10 to 30.

At the resonance conditions, one observes dips 10-15 % in the total reflection [4]. The reflectivities have been fitted with the program *SimulReflec* [5]. The resonances in guiding layer led to enhanced off-specular scattering at α_i = const and α_f = const (Fig. 3 a). Off-specular intensity consists of 1-2 % from total reflection and cannot explain the large dips in reflectivity. To fit the total reflectivity data we need to introduce artificially high absorption in the Ti guiding layer (60 times the tabulated value of 6.09 barn). However, we think that the neutrons are actually lost because they channel along the sample (over a distance up to 3mm), exit at the edge of the sample and are lost for the specular reflectivity.

Off-specular scattering has been modeled using the program *sdms* [6] based on the DWBA approximation [7]. It is possible to qualitatively account for the data by describing the system with magnetically collinear homogeneous layers (see Fig. 3 b). The shape and position of the diffuse scattering due to the guide effects (along the white lines) are easy to reproduce:

it is simply necessary to introduce an in-plane roughness correlation length ξ of the order of 100 µm. It is thus possible to reproduce the spots of enhanced intensity corresponding to the intersections of 2 resonant modes. However, the roughness parameter σ cannot be evaluated. The modeling does not account for the absolute value of the diffuse scattering and thus the absolute intensities cannot be adjusted to obtain a value for σ. For the following progress in off-specular scattering calculations we intend to compare it with *EFFI* program [8, 9] based on off-specular scattering formalism developed in [10].

In conclusion, with these measurements, we have shown: (i) neutron resonance states in magnetic neutron waveguides lead to enhanced off-specular scattering up to 10^{-2}; (ii) the amplitude of resonances on the reflectivitiy (10 %) mainly depends on wave guiding effect in Ti guiding layer and only a negligible part is connected to off-specular reflection.

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Also this investigation has been supported by French-Hungarian-Russian collaboration in the frame of ECO-NET project No. 16273ZA.

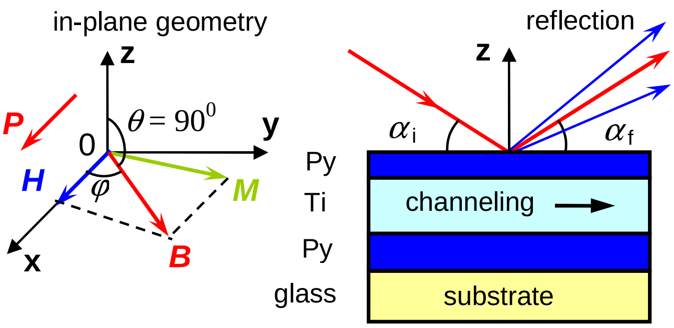

Fig. 1. Scheme of experiment.

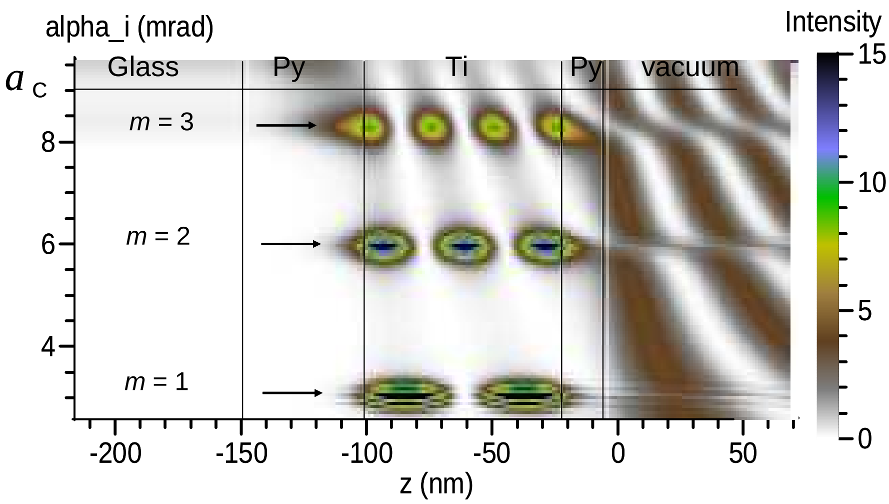

Fig. 2. Wave function density "+" inside the waveguide structure vs the incidence angle α_i and the sample depth *z* (calculated using SimulReflec [5]). The Ti guiding layer is 80 nm thick.

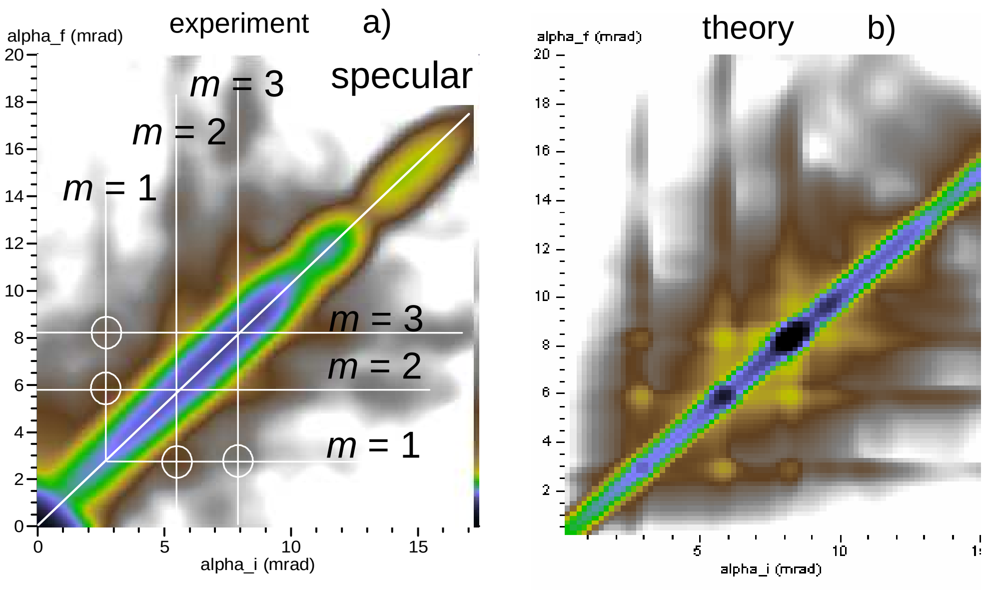

Fig. 3. Off-specular scattering (UP-UP) in the saturated state: (a) experiment; (b) simulation.

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DEPTH PROFILING OF MECHANICAL STRESS IN Al_2O_3:Cr INDUCED BY SWIFT HEAVY ION IRRADIATION

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Lattice damages produced by swift heavy ions are concentrated within small volume, surrounding ion trajectory, in so-called ion track region. This inevitably results in generation of local mechanical stress, which in own turn may affect final defect structure. The knowledge about of such a high energy heavy ion track-assisted stress is of considerable practical value in view of simulation of fission product impact in radiation resistant oxides and ceramics, as candidate materials for nuclear waste management (inert matrix fuel hosts) and prediction of their long-term radiation stability [1].

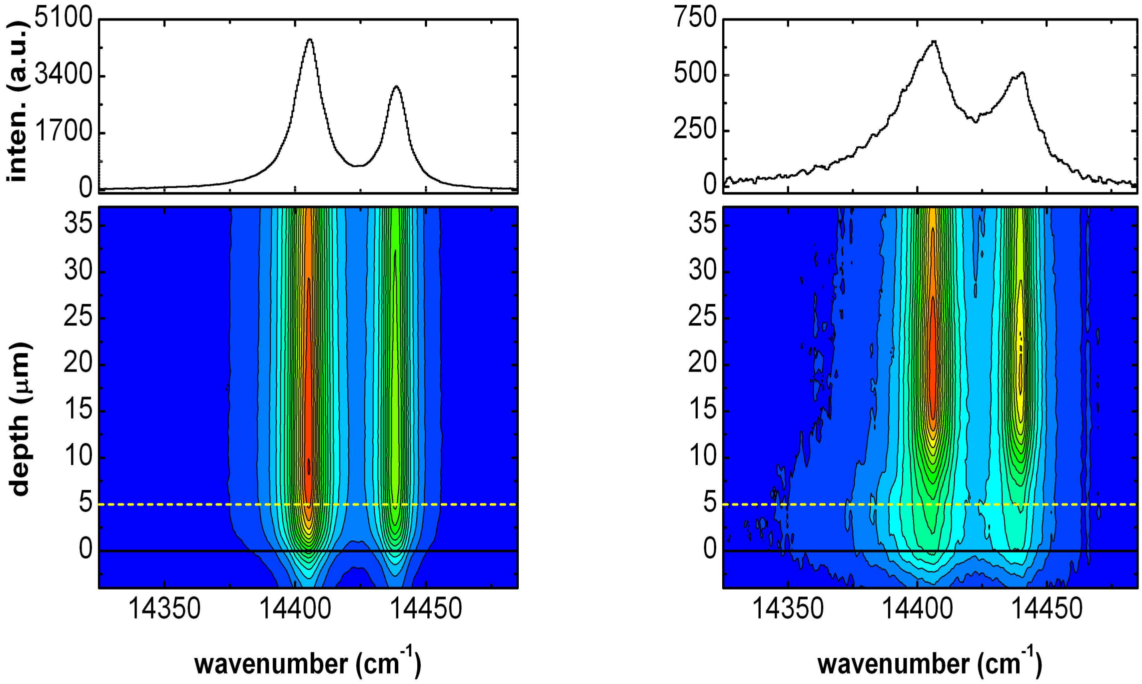

Figure 1: R-lines spectra as a function of depth. (a)- intact and (b) – Kr (245 MeV, 3×10^{13} cm^2) ion irradiated ruby specimens. Ion projected range is 18 μm. The residual stress level is defined through the shift of the R –lines positions. The spectra on top are measured at depth marked by dashed lines.

To evaluate the stress level in some dielectric materials one can use the well-known piezospectroscopic method, utilizing the relationship between the stress and changes in optical spectra. Regarding ruby, the piezospectroscopic effect consists of in stress-induced shift of the Raman and *R*-lines luminescence positions. Recently, we have reported the first *in situ* piezospectroscopic estimates of the mean stress level in ruby crystals during (3÷7) MeV/amu Ar, Kr and Bi ion bombardment at relatively low ion fluences, $\sim10^{12}$ cm^{-2} [2]. In particular, there was shown, that mechanical stresses are registered for bismuth ions only, when the average electronic stopping power was about 30 keV/nm. Under *in situ* ionoluminescence measurements we registered integrated *R*-lines emission signal influenced by radiation defects and mechanical stresses in total probed volume. Evidently, non-uniform energy deposition along swift heavy ion path suggests the complicated dependence of luminescence efficiency on target thickness. To find the residual stress profiles trough the ion irradiated layer, laser confocal scanning microscopy (LCSM) technique has been applied. The depth-resolved photostimulated *R*-lines spectra from ruby specimens were acquired using SOLAR TII experimental set-up. Figure 1 shows the *R*-lines spectra as a function of depth, registered on Al_2O_3:Cr (0.023 wt. %) single crystal irradiated with 245 MeV Kr ions in comparison with data gathered from virgin part of the same sample. As can be seen, swift heavy ion irradiation results in broadening of the *R*-lines and appearance of shoulders extended towards lower wavenumbers, which are attributed to residual stress effect. As known, the frequency shift toward lower energies means that irradiated target layer is under compression [3]. The shape of the *R*-lines measured from irradiated part of the specimen clearly indicates that photoluminescence signals are formed by contribution of the characteristic emission of chromium atoms, which act as individual piezosensors, from differently stressed regions. Analysis of the stress field based on piezospectroscopic relations given in [3] shows that upper boundary of the stress level approaches the magnitude comparable with ultimate stress limit, ~2 GPa.

The residual stresses, as seen from Fig. 1 (b), are maximal in the near surface layer. Since electronic stopping power is also maximal in this region, one can state that lattice disorder induced by collective electronic excitations plays dominant role in generation of mechanical stress.

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ON THE DEFECT PATTERN EVOLUTION IN SAPPHIRE IRRADIATED BY SWIFT IONS IN A BROAD FLUENCE RANGE

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Positron annihilation spectroscopy (PAS) has been successfully used in studying irradiation-induced defects in different materials, including radiation-resistant insulators like Al_2O_3. The aim of this work is to get additional information on the defect production and evolution in alumina after the swift Kr ion irradiation utilizing the high sensitivity of the positron annihilation methods.

Al_2O_3 (0001) single crystal samples with a typical thickness of few hundred of micrometers were irradiated at room temperature with 245 MeV Krypton ions at the U-400 FLNR JINR cyclotron in Dubna. The fluence range was $5x10^9$ – $1.6x10^{14}$ ion/cm^2. In situ positron annihilation Doppler broadening measurements as a function of energy were carried out at room temperature with a magnetically guided slow positron beam in Coimbra [1], whereas the in situ positron lifetime measurements were performed at the pulsed positron beam facility in Munich [2] at 16 keV positron beam energy. These two set-ups were used to characterize the damaged region from the surface up to ~ 3 μm depth.

In Fig. 1, the Doppler *S* parameter values as a function of positron implantation energy E are shown for the reference sample and for some irradiated α-Al_2O_3 samples. The *S(E)* parameter values have all been normalized to the bulk value of the reference sapphire sample. As can be observed for all irradiated samples, the *S*(E) values above ~10 keV of incident positron energy are constant. This behaviour is in agreement with our expectation that near the surface, in the first few μm depth of the material, a homogeneous distribution of defects exists. Each *S*(E) curve was fitted using the VEPFIT [3] computer code to determine the normalized S_{sample} value in this region of the irradiated sample (free of surface contribution) and the positron diffusion length L_+. In Fig. 2, the normalized S_{sample} values as a function of the ion fluence in the range from 10^{11} up to 1.6×10^{14} ion/cm^2 are presented.

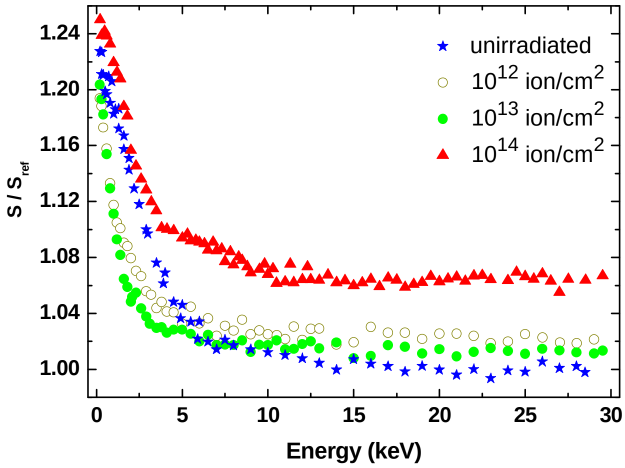

Figure 1. Doppler S parameter vs. incident positron energy E for the defect-free reference and for the Kr- irradiated sapphire samples.

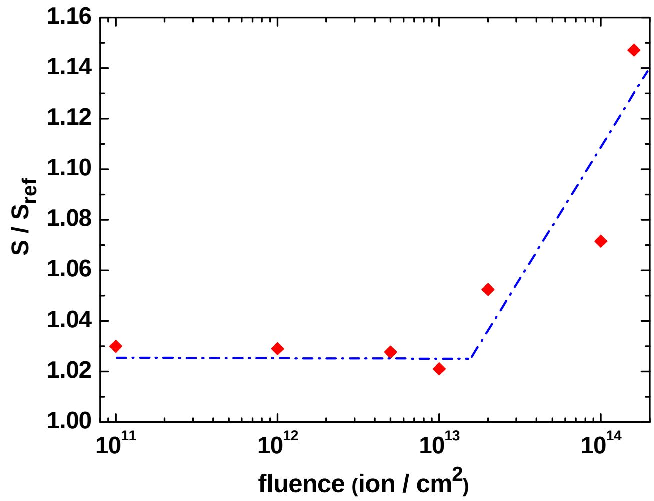

Figure 2. The S values of irradiated sapphire samples normalized to the defect-free reference sample in the fluence range of $10^{11} – 1.6\times10^{14}$ ion/cm^{-2}. The line is only to guide the eyes.

In the fluence range of 10^{11} – 10^{13} ion/cm^2, the normalized *S* values do not change indicating that there is a saturation trapping effect. The corresponding Doppler *S* value is approximately 2.5% higher than the defect-free bulk and this value can be related to the annihilation of positron in a monovacancy. For higher fluences, the *S* values increase drastically and a value of ~1.15 is achieved for a fluence of 1.6×10^{14} ion/cm^2. This high *S* value can only be explained due to the appearance of a new trapping site, i.e., large vacancy clusters or voids, where a longer-living trapped positron state can be formed. The increase observed in the positron diffusion length for fluences above 10^{13} ion/cm^2 (L_+= 15±1, 39±1 and 44±1 nm for 10^{13}, $5\text{x}10^{13}$ and 10^{14} ion/cm^2, respectively) combined with a reduction of the F^+ center ionoluminescence signal produced above the same fluence values [4], indeed strongly suggest the clustering of these first kind of traps, i.e., the clustering of monovacancies sets in.

In a previous work [5] the lifetimes related to these two kinds (with differing sizes) of trapping sites induced by the swift ions in sapphire were identified as 186 ps and 500 ps, respectively. The creation of the extended positron traps yielding in longer lifetimes was associated with the overlap of individual ion effects. An estimation of the effective region radius can be obtained through the mean distance between the near-neighbour regions. In the simplest description (Eq. 1.) the relation between the region radius r, the fluence F, and the mean distance d, can be written as:

$$d(nm) \approx 10^7 \big/ \sqrt{F} - 2r\,. \qquad (1)$$

From Fig. 2 it can be seen that the second trapping site appears for fluences above 10^{13} ion/cm^2 and assuming d = 0 at this fluence the use of eq. 1 provides an upper limit for the region radius r_{limit} ~1.6 nm.

In order to understand the nature of structural imperfections and their pattern induced by swift ions, a new set of Kr irradiated sapphire samples in the fluence range 5x10^9 – 5x10^{10} was used and analysed utilizing the pulsed positron beam at Munich. The sensitivity of Doppler broadening measurements for this fluence range is weak as compared to the lifetime measurement. For each irradiated sample the observed mean lifetime was below 186 ps, the value given above for saturation monovacancy trapping. The analysis of each spectrum indicates that the positron annihilates in two different places, a defect-free sapphire bulk state (τ_b = 145 ps) and in a trapped state related to the monovacancy defects (τ_d = 186 ps). For example the intensity I_2 takes values of 37±1%, 64±1% and 85±1% for fluences of 5×10^9, 2×10^{10} and 5×10^{10} ion/cm^2, respectively.

For the fluence range of this sample set, if it is assumed that the positron trapping sites (monovacancies) are inside a cylindrical volume around the ion path, the radius of the effective ion region can be estimated. In fact, in the vicinity of the surface, far from the projected range of the implanted ions, it is expected that each ion produce an independent cylindrical volume full of defects around the ion track [6,7]. Consequently, the positron implanted into the irradiated sapphire sample diffuses until the fully defected cylindrical volume around the ion path is reached and than occur the trapping and the annihilation. Assuming this picture, the trapping of positrons is limited by diffusion and the mean distance, d, between the border of these cylinders around the two near-neighbour paths, and those parameters should define the trapping rate k, of positrons through eq. 2 as [3]:

$$k = \frac{1}{\tau_b}\left[\left(\frac{L_+}{d/2}\right)^2 - 1\right] \qquad (2)$$

where $\tau_b = 145$ ps and L_+ represent the positron lifetime and the positron diffusion length, respectively, in the defect-free bulk sapphire sample. The positron diffusion length value, L_+ = 62 ± 1 nm was obtained by the VEPFIT [3] program applied to the S(E) curve of the unirradiated sample shown in Fig. 1.

Figure 3 shows the experimental values of trapping rate as a function of the ion fluence obtained from the mean lifetime values as [8]:

$$k = \frac{1}{\tau_b}\frac{\overline{\tau} - \tau_b}{\tau_d - \overline{\tau}}, \qquad (3)$$

where $\overline{\tau}$ is the mean lifetime of positron in the irradiated sample, $\tau_d = 186$ ps is the lifetime of positrons trapped in a monovacancy and $\tau_b = 145$ ps the positron lifetime in the substrate.

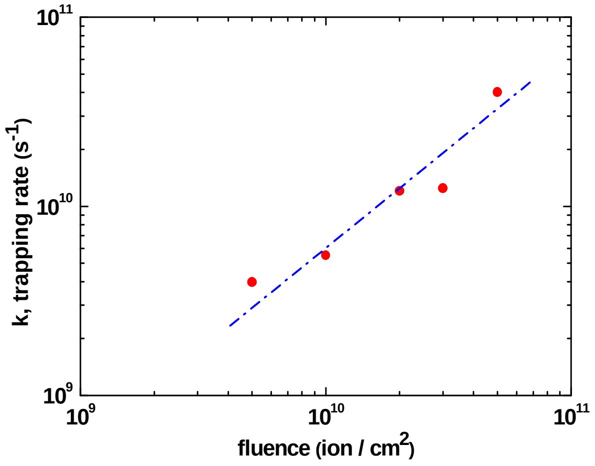

Figure 3. Overall positron trapping rates in monovacancies as a function of fluence inside the cylindrical volume around the ion track. Fluence range: $5x10^9$ – $5x10^{10}$ $ion.cm^{-2}$. The line serves only to guide the eyes.

Combining eqs. (1) and (2) and adjusting the values to the experimental data in Fig. 3, the effective radius of the cylindrical volume around the ion track can be estimated. The best agreement is obtained for an effective radius value of 1.5 nm. This value agrees well with the upper limit value of r_{limit}~1.6 nm obtained above when the overlap of tracks was taken into account to explain the creation of extended defects revealed by the second, longer lifetime component.

In summary, positron annihilation measurements on swift heavy ion irradiated samples have identified monovacancies as dominant defects inside the damaged cylindrical volume around the ion path. A value of ~1.5 nm was calculated for the effective cylinder radius, a value that is in good agreement with the estimation of tracks overlapping above 10^{13} ion/cm^2 fluence value. The overlap of cylinders/tracks seems to lead to the aggregation of monovacancies forming large vacancy clusters or voids, revealed by the setting in of a second, longer-living trapped positron state.

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AMORPHOUS IRON PHASE FORMATION IN SWIFT HEAVY ION IRRADIATED ELECTRODEPOSITED IRON THIN FILMS

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The aim of the present work was to determine whether electrochemically prepared crystalline Fe can be transformed into the amorphous state by swift heavy ion irradiation. On this basis ^{57}Fe conversion electron Mössbauer spectroscopy (CEM) was used to examine the deposits.

The Fe electrodeposits were prepared using a continuous flow plating system [1]. The irradiation of samples was carried out with 246 MeV energy $^{86}Kr^{8+}$ ions at room temperature at the U-400 FLNR JINR cyclotron, Dubna. The CEM spectra were recorded at room temperature by a conventional Mössbauer spectrometer (WISSEL) with a flowing gas (96% He, 4% CH_4) proportional counter and a ^{57}Co(Rh) source of 1.85 GBq activity. Isomer shifts are given relative to α-Fe. The evaluation of Mössbauer spectra was performed by least-square fitting of the lines using the MOSSWINN program [2].

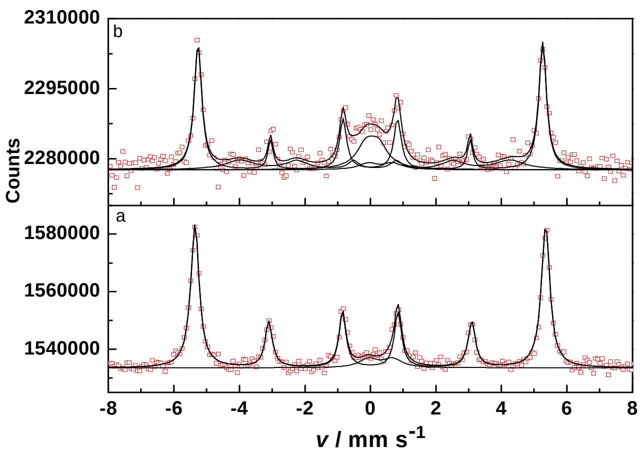

Fig. 1. ^{57}Fe Mössbauer spectra of the electrodeposited Fe foils before (a) and after (b) the irradiation with 246 MeV energy $^{86}Kr^{8+}$ ions.

Fig. 1 and Table 1 show the ^{57}Fe Mössbauer spectra and the Mössbauer parameters of the electrodeposited Fe foils before and after the irradiation with 246 MeV energy $^{86}Kr^{8+}$ ions.

The Mössbauer spectrum of the non-irradiated sample (Fig. 1a) was decomposed into a sextet (S1) and a doublet (D1). The sextet represents α-Fe. The doublet appears due to the oxidation of the surface, where the Mössbauer parameters are in the range characteristic of amorphous iron oxides and oxyhydroxides.

Table 1:

Mössbauer parameters of the electrodeposited Fe foil
before and after the irradiation with 246 MeV energy $^{86}Kr^{8+}$ ions

Sub-spectrum	Mössbauer parameters	non-irradiated sample	irradiated sample
	δ, mm s^{-1}	0.0	0.0
S1	*B*, T	32.8	32.6
	A, %	95.4	57.9
	δ, mm s^{-1}	0.32	0.31
D1	*Δ*, mm s^{-1}	0.75	0.75
	A, %	4.6	4.5
	δ, mm s^{-1}	-	0.14
S2	*B*, T	-	25.6
	A, %	-	21.5
	δ, mm s^{-1}	-	0.05
D2	*Δ*, mm s^{-1}	-	0.38
	A, %	-	16.1

δ, *Δ*, *B* and *A* denote isomer shift, quadrupole splitting, effective magnetic induction and spectral area, respectively

The ^{57}Fe Mössbauer spectrum of the sample irradiated with $^{86}Kr^{8+}$ ions with a fluence of 10^{13} ion·cm^{-2} (Fig. 1b) exhibit considerable changes compared to the non-irradiated one. The most striking change is the appearance of a new ferromagnetic component (sextet S2) with isomer shift around 0.14 mm·s^{-1} and effective magnetic induction around 26 T. This magnetically split pattern with six broad lines is considered as a superposition of a number of subspectra belonging to iron atoms being in slightly different microenvironments. In general, sextet S2 is typical for ferromagnetic materials being in amorphous state. The Mössbauer parameters of sextet S2 are similar to those found earlier for amorphous iron in samples prepared sonochemically from $Fe(CO)_5$ [3] and by vacuum deposition of 70 nm thick films of iron on Si wafers with subsequent heavy ion irradiation [4].

Based upon this comparison it can be assumed that the S2 sextet component assigned to ferromagnetic amorphous iron phase formed due to swift heavy ion irradiation in electrodeposited Fe foils is a reasonable assumption.

Beside sextet S2 a new doublet (D2) appears in the Mössbauer spectrum of the irradiated sample. The isomer shift of doublet D2 (Table 2) is characteristic of metallic iron. Consequently, this doublet D2 can be associated with metallic Fe atoms being in the paramagnetic state [1,5]. The wide linewidth may indicate the amorphous or highly disordered character of this paramagnetic phase, formed due to swift heavy ion irradiation, represented by doublet D2.

The appearance of both sextet S2 and doublet D2 in the spectrum of irradiated sample occurs on expense of the sextet S1 belonging to crystalline alpha iron. At the same time no change was observed in the relative area of doublet D1 (minor component) due to irradiation. This means that the surface oxide layer is not disturbed by the irradiation. However, a considerable transformation of crystalline iron takes place into amorphous and/or superparamagnetic Fe phases.

Another effect induced by the swift heavy ion irradiation is the change in the relative area of the 2nd and 5th lines compared to that of 1st and 6th lines of sextet S1, reflecting crystalline α-iron, in the Mössbauer spectrum. The intensity changes of 2nd and 5th lines are connected with the changes of the average direction of magnetic moment in the sample [6]. The relative intensity of the absorption lines before irradiation is $A_{2,5}/ A_{1,6} = 1/3$ while after the irradiation this ratio is $A_{2,5}/ A_{1,6} = ¼$. This indicates that the spins turn toward the direction perpendicular to the surface of the coating thus changing the magnetic anisotropy in the samples. This may be mainly associated with the change of the orientation of spins as an effect of the stresses formed around the defects produced by the swift heavy ion irradiation in the samples.

There are two main mechanisms of irradiation induced amorphization of crystalline solids: (1) continuous accumulation of defects which destabilize the crystal structure at some critical level, and (2) rapid quenching of irradiation induced liquid in the thermal spike regions [7]. For the irradiated iron deposits it can be assumed, that the thermal spike, i.e. the electronic excitation mechanism is the dominant one. This is supported by results of the calculations made using the SRIM 2003 code [8], which show that the electronic stopping power is much higher than the nuclear stopping power in Fe irradiated with 246 MeV energy $^{86}Kr^{8+}$ ions.

For the iron electrodeposits the condition of the irradiation, namely the electronic stopping power exceeds the reported values at which amorphization can be obtained in metallic systems [7]. Thus, the appearance of an amorphous phase due to heavy ion irradiation in the deposits can be expected. Under similar irradiation conditions to those used for the electrodeposits the occurrence of new amorphous phases was observed in electro- and/or vacuum deposited FeNiCr multilayers [1,5] as well as vacuum deposited Fe layers [9].

Further investigations to elucidate the effect of the irradiation conditions (fluence, energy and kind of ions) on the formation of amorphous Fe will be reported later.

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