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The Joint Institute for Nuclear Research — the first half-century

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Abstract. March 26, 2006 marked 50 years since the Joint Institute for Nuclear Research was founded. This review examines how the Institute became what it is, and discusses its achievements and prospects for future work.

The Joint Institute for Nuclear Research (JINR) is an international intergovernmental research establishment created in accordance with the Convention on Creation of JINR of March 26, 1956 and registered with the UN on February 1, 1957, and with UNESCO on September 24, 1957.

In reality, the Institute started its life considerably earlier. In 1947, an initiative by a group of scientists headed by Full Member of the USSR Academy of Sciences I V Kurchatov led to the construction about 120 km north of Moscow of the elementary particle accelerator (namely, a synchrocyclotron) which at the time was the largest in the world; the accelerator was commissioned and started successful operations in late 1949.

At the same time, an extensive program of fundamental studies on the properties of nuclear matter was launched, involving specialists from the USSR Academy of Sciences and from the atomic industry. Work was started on the territory of the future town of Dubna on designing the synchrophasotron — a novel accelerator with record technical parameters for the time. This accelerator — launched like the first artificial Earth satellite (Sputnik) in 1957 — became a symbol of the achievements of Soviet science.

The European Center for Nuclear Research (CERN) was created in Geneva in 1954 with the aim of consolidating the efforts of European countries in studying the fundamental properties of matter. This development speeded up the transformation of our Institute into an international scientific body capable of uniting the researchers of the socialist camp. Scientific ties between CERN and JINR soon emerged and have continued to grow ever since the creation of the Joint Institute. Cooperation between CERN and JINR is now important in the current work of building the Large Hadron Collider (LHC) and in preparing future experiments at this collider.

The agreement on the foundation of the JINR was signed in Moscow by representatives of eleven nations; at the present moment, the Institute has 18 member states.

The rise in the status of JINR is inseparable from the names of such outstanding scientists and Soviet science managers as D I Blokhintsev, N N Bogoliubov, I E Tamm, V I Veksler, G N Flerov, I M Frank, V P Dzhelepov, B M Pontecorvo, M G Meshcheryakov, I V Kurchatov, A M Petros'yants, E P Slavsky, and also from the names of eminent scientists from other member states: L Infeld and H Niewodniczanski (Poland), G Nadjakov (Bulgaria), Wang Ganchang (P.R. China), H Hulubey (Romania), L Janossy (Hungary), H Hertz and H Pose (GDR).

JINR — administration building

In the five decades of its activities, JINR has grown into one of the largest and most diversified scientific centers with first-class equipment for fundamental nuclear research; it unites the efforts of scientists in their drive to understand the structure and the laws governing the material world around us.

The staff of the Institute comprises about 6,000 people, among them a number of full members and corresponding members of the national Academies of Sciences, more than

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The first directorate of the JINR (left to right): I M Frank, M Danysz, V P Dzhelepov, V Votruba, D I Blokhintsev, V N Sergienko, V I Veksler, A M Ryzhov, N N Bogoliubov, and G N Flerov.

260 Doctors of Sciences and more than 650 Candidates of Sciences, and dozens of laureates of international and state awards. JINR is divided into eight scientific laboratories, each of which is on the scale of a large research institute.

Obviously, the most precious capital of the Institute is its staff — the people who worked or are now working at JINR, its top class professionals, the highest caliber experts in physics and related fields of science.

Academician Bogoliubov — one of the most important scientists of the 20th century, creator of scientific schools in mathematics, mechanics and physics — headed our Institute for very nearly 25 years. The JINR is legitimately proud of the scientific schools created by Blokhintsev, Veksler, Pontecorvo, M A Markov, Flerov, Frank, A M Baldin and many other physicists of the highest world-wide reputation.

JINR served as training ground for thousands of specialists with the highest-level skills, from every member state. Presidents of many national academies of sciences, heads of universities, and leaders of large scientific bodies are alumni of the JINR school. We find among them the former President of the Vietnamese Academy of Sciences and Technologies Dr. Nguyen Van Hieu, the Academician of the Russian (RAS) and Georgian Academies of Sciences A N Tavkhelidze, Academicians of the RAS A A Logunov, V A Matveev, D V Shirkov, and Yu Ts Oganessian, and many others. The Chinese Academy of Sciences was headed until recently by Academician Zhou Guanzhao, while Professor Ivan Wilhelm became Rector of the Karlov University in Prague in 1990. Both were Dubna's pupils.

A typical trait of the team of scientists of the Institute is its relentless initiative in launching original research projects, in pursuing novel research directions and frontline technologies of modern experimental physics, and the high reliability of the results reported. A number of ideas that have enriched our understanding of the physical world and served to make it more profound were generated at the Institute.

Among the research fields that are actively progressing today at JINR we find those that were born there: relativistic nuclear physics, the physics of heavy ions, and ultracold neutrons. The results obtained there are known the world over, established record achievements in the respective fields for many years, and helped to uphold the high reputation of our Institute and of science as a whole.

In 1957, a beam of protons accelerated to a target energy of 10 billion electron-volts was produced for the first time in the synchrophasotron of the Laboratory of High Energies (LHE) of JINR, led by the outstanding Soviet physicist Academician Vladimir Iosifovich Veksler. The successful launch of the synchrophasotron allowed the scientists of the twelve member states of JINR to join in a program of searching for new elementary particles and discovering yet unknown laws of the mysterious world of microscopic phenomena in the energy range that was previously unattainable by any laboratory in the world.

Even before the launching of the synchrophasotron, the LHE team had already been developing for this very purpose various particle detectors and designing experimental facilities of various types. Thus, the equipment for the irradiation of nuclear photoemulsions in an internal proton beam had nearly been ready by the time the synchrophasotron started operations, and the installation of bubble chambers was at the completion stage in the extracted beam of negative pions: Wilson chamber, the 24-litre propane bubble chamber, and the half-meter xenon-filled cloud chamber. Subsequently, the bubble chamber techniques that register almost every secondary charged and neutral particle became the principal method for studying processes of the multiple production of particles in the synchrophasotron. Electronic methods of experimentation were rapidly developed and improved. Extracted beams of the synchrophasotron were equipped with modern spectrometers that incorporated spark chambers and Cherenkov counters.

The first people who were ready to work with the proton beam accelerated to record energies were those in the nuclear photoemulsions group. When scientists from one such group handed Veksler a still wet photographic print with the first 'star' pattern that represented a collision of protons accelerated to 10 GeV with nuclei in the photoemulsion, a happy smile broke out on the face of the founder and first Director of the Laboratory of High Energies!

Left to right: V G Kadyshevsky (Science Supervisor of the Institute, JINR Director from 1992 to 2005), S N Mazurenko (Head of the Federal Agency on Science and Innovations of the Russian Federation), and A N Sissakian (current JINR Director).

An event of the generation and decay of the antisigma-minus hyperon was discovered after scanning 40 thousand stereophotographs that recorded tens of thousands of other interactions of negative pions with hydrogen atoms and carbon atoms of propane. The Dubna scientists presented to the Rochester Conference of 1960 in Berkeley (USA) the data that characterized for the first time and with unprecedented completeness the general picture of the processes of production of strange particles (Λ^0, K^0, $\Sigma^{\pm}$, and Ξ^-) in pion–nucleon interactions at the highest (at the time) beam energies. They reported, among other things, the discovery of the antisigma-minus hyperon, the first observation of the multiple production (more than two) of strange particles, and the discovery of the steep rise with energy of the cascade xi-minus hyperon production cross section. They also announced the verification of the nowadays universally known law of conservation of the baryon charge, formulated earlier by JINR scientists.

The history of the first Dubna particle accelerator — the synchrocyclotron of the Laboratory of Nuclear Problems (LNP) — is equally impressive and full of great events. Guided by the illustrious scientists Dzhelepov and Bruno Pontecorvo, the JINR synchrocyclotron team made 13 scientific discoveries. Pontecorvo's famous idea of neutrino oscillations was recently verified by experiment.

After the magnet pole diameter of synchrocyclotron was increased in 1953 to 6 m and its high-frequency system was substantially redesigned, the 680-MeV proton version of the accelerator was commissioned, with a proton beam intensity of 0.25–0.3 μA; the LNP synchrocyclotron remained for a number of years the highest-power proton accelerator in the world.

Together with the reconstruction of the magnet and of the HF systems of the synchrocyclotron, a novel (regenerative) method of extracting particles from the accelerator was applied. This allowed an increase in the intensity of the extracted beam by a factor of several dozen. A beam-bending magnet and collimators extracted 14 beams of protons, pions, and neutrons of various energies to the experimental pavilion separated from the accelerator by a 4-meter-thick heavy concrete wall and covered by a 1.5-m-thick concrete ceiling; this arrangement offered exceptional opportunities for research not only to LNP physicists but also for visiting research workers from Moscow, Leningrad, Khar'kov, and other cities. Increasing the internal proton beam intensity to 2.3 μA and raising its extraction efficiency, the implementation of the slow extraction of protons and the production of a few new beams substantially improved the feasibility of principally novel experiments and the conditions for running physics- and applications-oriented research at the synchrocyclotron.

Extensive studies of neutron-deficient isotopes were conducted at LNP from 1959 to 1979; this led to the discovery of more than 100 new radioactive isotopes.

After 30 years of operation, the synchrocyclotron was redesigned into a phasotron with helicoidal magnetic field variation. It has successfully served particle physics and the physics of atomic nucleus since late 1984 and is also utilized for applications. The beam parameters and the reliability of the new accelerator are substantially better than those of the earlier synchrocyclotron. It is now possible to extract intense beams of slow pions and muons, including a separated beam of 'surface' muons. Wide and narrow proton beams with energies from 70 to 660 MeV, a high-intensity beam of negative π mesons with energies from 30 to 80 MeV, and a beam of ultrafast neutrons with 350-MeV mean energy were produced for medico-biological and clinical research. The phasotron is also the highest-intensity source of meson beams in operation in the JINR member states.

The team of JINR theoreticians — at the N N Bogoliubov Laboratory of Theoretical Physics — enjoys the highest scientific reputation. In 1960, Bogoliubov formulated the concept of quasi-averages that influenced the evolution of quantum field theory (QFT) in important ways. Five years later, Bogoliubov, B V Struminsky and Tavkhelidze solved the problem of quark statistics by introducing a new quantum number that was subsequently rechristened 'color'. Dubna physicists were actively developing the quark model of hadrons. The assumption was that quarks are heavy objects bound inside hadrons by very strong forces responsible for their high mass defect and their confinement. This gave rise to the 'Dubna quark bag' model (N N Bogoliubov, P N Bogoliubov, Nguyen Van Hieu, V A Matveev, et al.) which led to a number of important results, including the explanation of the anomalous magnetic moments of nucleons. At the end of the 1960s, Matveev, P M Muradyan and Tavkhelidze were able to demonstrate the fruitfulness of the self-similarity concept of the strong interactions and obtained the quark counting rules[1]. A large series of papers was published in the 1970–1980s on the applications of the self-similarity principle and generalization of the quark counting rules for multiple and inclusive processes using the 3D formulation of the QFT (S Mavrodiev, Muradyan, A N Sissakian, V I Savrin, N B Skachkov, and L A Slepchenko). These results were widely used later for data processing and for the planning of experiments at large particle accelerators.

V G Solov'ev formulated in the 1970s the main assumptions of the microscopic quasiparticle–phonon model of the nucleus (QPM) which describes nuclear spectra on the hypothesis for interacting Bogoliubov quasiparticles and phonons in the random phase approximation. Further

[1] These results were incorporated into the cycle of studies "New quantum number — the color, and the discovery of dynamic behavior in the quark structure of elementary particles and atomic nuclei" that won their authors (A M Baldin, P N Bogoliubov, V A Matveev, P M Muradyan, and A N Tavkhelidze) the Lenin Prize 1988.

progress in the microscopic theory of nucleus remains an important component in the work of Dubna theoreticians. They succeeded in understanding the complex interplay of the low-lying states in deformed atomic nuclei and made an important contribution to the theory of nuclear vibrations and rotations and to fission theory; they also built the foundation of the interacting bosons model (R V Dzholos). The interest of nuclear physics theoreticians has shifted in recent years to nuclear states with extremal values of the angular momentum, deformation, and excitation energy. The shift was dictated by the need to improve microscopic models of the nucleus and to create a unified picture of nuclear excitations.

A qualitatively new stage in the evolution of our Institute began in the 1990s. The demise of the socialist camp, the dismantling of the USSR, and the cruel economic crisis in many of the JINR member states affected the life of our Institute. However, the Joint Institute managed to survive the trials of the hard times — by virtue of the efforts of many well-known scientists and politicians who fought to preserve it. The most important part was played by the foresight and wisdom of the founding fathers of JINR, by upholding the traditions of its scientific schools, the highest level of theoretical and experimental research in its laboratories, a unique scientific foundation, as well as the self-refusal and utter devotion to science of the highly skilled team of collaborators of the Institute — its scientists, specialists and workers.

The enactment at the end of 1999 of the Federal Law "On the ratification of the agreement between the Government of the Russian Federation and the Joint Institute for Nuclear Research concerning the site of residence and conditions of operation of the Joint Institute for Nuclear Research in the Russian Federation" was an extremely important event in the life of the institute. This federal law was signed by the then acting President of Russia Vladimir Putin on January 2, 2000. In this way, the Institute received confirmation of its guaranteed legitimacy in accordance with generally accepted international standards.

It became clear at the new stage in the evolution of JINR that the cooperation of the member states in an international institute must change to a qualitatively new level: it had to be mutually advantageous and based on the realistic resources of the member states of JINR. Today's principles underlying the work of the Institute comply with this approach and dictate its strategy, as well as development planning and the priority of research directions.

The International Scientific Council of JINR was formed in 1992 and included leading experts from the largest research centers in the world. International program and consultative committees were also organized. The representatives of the JINR member states answered for the first time the question of which research areas of the Institute hold maximum interest and promise for them. JINR works in a number of promising areas in collaboration with Russian institutes and other organizations, enjoying the effective support of the Russian Academy of Sciences, the Ministry of Education and Science, and the Federal Agency for Atomic Energy of the Russian Federation.

Three main research fields can be singled out among the broad spectrum of research at JINR. These comprise high-energy physics (also known as elementary particle physics), nuclear physics, and condensed matter physics.

An investigation into high-energy physics, related to particle production and interactions between particles, is the most straightforward path to learning about the structure of matter over ultrasmall spacetime scales. JINR scientists run experiments under this program not only 'at home' in Dubna but also at other research centers: at the Institute for High Energy Physics (Russia), CERN (Switzerland), the Enrico Fermi National Accelerator Laboratory (USA), the German Electron Synchrotron (FRG), etc. Dubna physicists have covered a broad range of issues concerning the study of fundamental properties of elementary particles and their interactions, and of rare processes that help in checking the predictions of the Standard Model and searching for new phenomena and types of behavior that fall beyond its limits. They also conduct measurements of the parameters of direct CP violation and all-round studies of the nature and properties of the neutrino. The new data on the properties of elementary particles in a wide range of energies will facilitate the formulation of the unified theory of fundamental interactions.

The Dubna experiments on relativistic nuclear physics — a new research field discovered and developed by Academician Aleksandr Mikhailovich Baldin — have attracted the intense interest of physicists in many research centers around the world. Thus, work is conducted on the interactions between relativistic nuclei in the energy range from hundreds of MeV to several TeV per nucleon; it aims at searching for manifestations of quark – gluon degrees of freedom in nuclei and asymptotic laws for nuclear matter, and also looks into the spin structure of the lightest nuclei. The search for and analysis of highly excited nuclear matter will make it possible to check the QCD theory and to come up with plausible answers to the following fundamental questions: what is confinement? what are the mechanisms of hadronization and of chiral symmetry breakdown? Experiments needed for this elucidation are conducted using the accelerator base at the Institute, as well as the accelerators at other scientific centers: CERN, BNL, GSI, RIKEN, and so forth.

Unique research and development work was carried out in 2002 at the Laboratory of High Energies (now bearing the names of Academicians Veksler and Baldin) on improving the system of slow extraction of a beam of charged particles from a nuclotron — the new accelerator of relativistic nuclei. We can now state that the nuclotron's technologically unique system of slow beam extraction successfully passed comprehensive testing and that the resulting beams comply with the prescribed parameters. Outgoing beams for a large number of ions were obtained in a broad energy range and possessed very good temporal structure and beam uniformity coefficient. The problem of slow resonance beam extraction from a superconducting accelerator was solved comprehensively for the first time world-wide. Another very important result was also achieved and opened new fields for research: a beam of polarized deuterons was accelerated and extracted from the nuclotron. The exploration into interactions of polarized deuterons is extremely important for understanding the nature of the spin.

On the whole, the design of the cryogenic support system of the nuclotron abounds in numerous novel technical ideas and solutions that have never been used before in acceleration practice. The nuclotron's cryogenic system utilizes rapidly cycling superconducting magnets, cryostatting by a two-phase vapor – liquid flux of helium with an extremely short cool-down time of the system, a parallel cryoagent-mediated

connection of hundreds of superconducting magnets, a vapor–liquid helium turbodetander, a helium screw compressor with a compression ratio above 25 in just two stages, jet-based liquid-helium circulation apparatuses, and much more. Each of the characteristics listed above was a new important step in the progress of helium cryogenic technology.

At the moment, the nuclotron is the only accelerator complex capable of providing within a year a wide variety of beams for experiments (from protons to iron nuclei) and meeting such conditions as precision energy variation, desired intensity level, extensive stretching and uniformity of the temporal structure of the extracted beams, and beam profiles required for experiments. Increased reliability and stability of operation of the accelerator complex, achieved through the effort of accelerator experts of the laboratory and their colleagues from the JINR member states, is the basis for boosting the work load of the nuclotron and for meeting target figures for further advance toward achieving maximum possible parameters of the accelerator.

The nuclotron has been used as a base for a User's Center for research in relativistic nuclear physics and for solving applications-dictated problems utilizing relativistic ions at energies in the range of several gigaelectron-volts per nucleon. Technologies required to create prototypes of rapidly cycling superconducting magnets will be further developed.

The second stream of our work involves nuclear physics research. A specific feature of the interaction between two complex nuclei is a profound restructuring of the interacting partners, which results in an exceptional variety of reaction products. An extensive program is being implemented in Dubna on studying the properties of nuclei, nuclear reactions, and new chemical elements, including transuranium and superheavy elements. JINR is one of the world leaders in this field. The assignment in 1997 of the name 'Dubnium' to element 105 of the Mendeleev Periodic Table by the International Union of Pure and Applied Chemistry was an impressive sign of recognition of the Institute's achievements.

Academician Georgii Nikolaevich Flerov pioneered a new area of fundamental research in nuclear physics — the physics of heavy ions — which is concerned with nuclear transformations in collisions of two complex atomic nuclei. Under Flerov's guidance, the Laboratory of Nuclear Reactions of JINR became a leading international center of the physics of heavy ions.

In 1968–1990, Flerov's LNR completed a series of searches for naturally occurring superheavy elements (SHEs) employing, first, much improved instrumental techniques for the detection of spontaneous fission events. The object of the study was a set of natural materials selected on the basis of the expected geochemical and chemical behavior of SHEs. A SHE detection sensitivity that was the highest in the world was achieved with ^{3}He-counter-based detectors registering instantaneous neutrons of spontaneous decay. The simultaneous registering of two or more neutrons was a signature of spontaneous decay. To guard against the background of 'false' counts produced by cosmic muons, detectors were placed in a salt mine at a depth of 1100 m of water equivalent.

This series of LNR studies was unique in its completeness and thorough approach to the selection of specimens and sensitivity levels. Carbonaceous chondrite type meteorites — the least differentiated matter in the solar system, i.e., the closest to the 'average' isotope composition over the system — were analyzed with special thoroughness. The upper bound on the mean SHE concentration was found to be 10^{-14} for $T_{1/2} = 10^{9}$ years. This is better by a factor of 100 to 1000 than the limits achieved in many other large scientific centers. The meteoritic data were collated with studies on terrestrial specimens. The LNR team studied numerous samples of ores and minerals enriched in light homologs of superheavy elements with atomic numbers $Z = 108-115$. Deep-seated iron–manganese concretions of the Pacific region, which may also contain elements from the 'cosmic dust', were also regarded as belonging to the above group.

The basic facility of the laboratory — the U-400 cyclotron — provided heavy ion beams with ion energy from 0.5 to 25 MeV per nucleon. It was applied for the acceleration of a broad set of ions, including ions of separated rare nuclides. The beam intensity in the energy range indicated remained a world record for many years. The further modernization of the U-400 cyclotron was connected with the creation in 1996 of a system of axial beam injection from an electron cyclotron resonance source at a frequency of 14.5 GHz. The gradual increase in the efficiency of this system made it possible to produce ^{48}Ca beams with an intensity of $(3-5) \times 10^{12}$ s^{-1} with only 0.4 mg h^{-1} consumption of the source material, which was of decisive importance for the successful synthesis of SHEs with atomic numbers from 112 to 118.

The SHE research program of JINR deserves special mention in view of the most recent achievements.

Yurii Tsolakovich Oganessian, Flerov's closest student and associate, was elected LNR director in 1989. At the time of this writing, Oganessian is the Scientific Leader of the laboratory.

The gas-filled separator (GFS) was built at LNR in 1989. This separator of products of nuclear reactions with a high efficiency of collection of nuclei and a high degree of purification from background products opened new prospects for investigating the stability of heavy and superheavy atomic nuclei, synthesizing new nuclides, and analyzing the structure and properties of nuclei, as well as the mechanisms of their formation in nuclear reactions.

Experiments on the synthesis and analysis of SHEs have been conducted on the GFS since 1998, in collaboration with the Lawrence Livermore National Laboratory (USA). Work on the synthesis of new heavy nuclei in the reactions of ^{208}Pb and ^{209}Bi isotopes with ions of ^{54}Cr, ^{58}Fe, ^{64}Ni, and ^{70}Zn, and also of heavy actinides with ions of elements from ^{22}Ne to ^{34}S showed that experimental sensitivity must be additionally increased by several orders of magnitude to achieve SHE production. LNR pioneered the synthesis of the heaviest isotopes ^{262}Rf ($Z = 104$), ^{265,266}Sg ($Z = 106$), ^{267}Hs ($Z = 108$), and ^{273}110.

In 1998 and 1999, experiments were run on the GFS with a new assembly of detectors with higher nuclei detection efficiency; the aim was to synthesize isotopes of element 114 in the fusion reaction between ^{244}Pu and ^{48}Ca ions at a sensitivity nearly three orders of magnitude higher than in all previous attempts. For the first time, two nuclei of the new element $Z = 114$ were indeed synthesized. The lifetimes of the new daughter nuclei of the elements 112 and 110 were found to be greater by 4 to 5 orders of magnitude than for those obtained by cold fusion of the ^{277}112 and ^{273}110 nuclides containing 8 fewer neutrons. Such a considerable increase in the stability of nuclei with an increase in the number of

neutrons may stem from the effect of spherical neutron shell $N = 184$, which can be regarded as experimental proof that a region of spherical SHE does exist.

Further experimental efforts were focused on synthesizing element 116 in the $^{48}Ca + ^{248}Cm$ fusion reaction; the latter nuclide is heavier by one α-particle than the previously used ^{244}Pu nuclide. Consequently, the α-decay of the mother nuclei had to produce nuclides that were obtained previously by irradiating ^{244}Pu. Three α-decay chains of the $^{293}116$ nucleus were recorded, and the properties of daughter nuclei coincided completely with those of nuclei obtained directly in the 'daughter' $^{244}Pu + ^{48}Ca$ reaction. This greatly increased the reliability of the results on synthesizing element 114. The production cross section of the $^{293}116$ nucleus was 0.5 pb, which is three orders of magnitude better than the experimental sensitivity of the 1980s. The authors of this work submitted applications to IUPAC on certifying the priority of the discovery of elements 114 and 116.

In 2002, experiments were conducted on the synthesis of element 118 in the reaction $^{249}Cf + ^{48}Ca$. High-intensity beams of ^{48}Ca nuclides (6×10^{12} s^{-1}) were obtained with highly economical consumption of ^{48}Ca (0.3 mg per hour). A single event was observed, consisting of a signal of implantation of a heavy nucleus in the detector, two consecutive α-decays and spontaneous fission with high energy release, which correlated in coordinates and time. The energies and times of α-decays of the mother and daughter nuclei were shown to agree with the expectation for the $^{294}118$ nuclide and its daughter $^{290}116$ nucleus that were to form after the evaporation of three neutrons from the composite $^{297}118$ nucleus.

The validity of these results was confirmed at the beginning of 2003. The target now was ^{245}Cm which differs from ^{249}Cf by one α-particle. Three decay chains of an isotope of element 116 were registered; its properties coincided with those of the nucleus observed after the α-decay of the $^{294}118$ isotope in the reaction $^{249}Cf + ^{48}Ca$. Therefore, the synthesis of the $^{290}116$ isotope confirmed the results of experiments on element 118. Furthermore, two decay events of another isotope of element 116 ($^{291}116$) were also recorded.

Other experiments in 2003 were concerned with measuring the production cross sections of element 114 in the reaction $^{244}Pu + ^{48}Ca$ followed by the evaporation, depending on the ion energy, of 3 to 5 neutrons from the excited composite $^{292}114$ nucleus. This factor was important for the continuation of the SHE research because one of the reactions synthesized, at the same time, three different isotopes of element 114. The properties of one of them, $^{289}114$, confirmed the results obtained in 1999 – 2001. Further on, two other isotopes, $^{288}114$ and $^{287}114$, were synthesized, of which the latter, $^{287}114$, was observed earlier after the α-decay of the $^{291}116$ isotope synthesized in the reaction $^{245}Cm + ^{48}Ca$. The energies of the ^{48}Ca ions, for which the yields of various isotopes of element 114 reached maximums, were also determined. It turned out that the production cross section may reach 5 pb, which is 10 times greater than the value measured in 1999 when the energy of ^{48}Ca ions was below the optimum. The results of this experiment extended substantially our understanding of the concepts controlling the reaction mechanisms of total fusion.

It was assumed in the past that superheavy nuclei can only survive at ^{48}Ca-ion energies close to the fusion barrier, and that the cross sections of such reactions can hardly exceed 1 pb. However, irradiation of a lighter ^{242}Pu isotope with ^{48}Ca ions also synthesized nuclei of element 114 with cross sections up to 4 pb at ^{48}Ca energies 10 to 15 MeV above the fusion barrier. Isotopes synthesized in this reaction were $^{286}114$ and $^{287}114$. Both were observed previously after α-decays of the $^{290}116$ and $^{291}116$ nuclei in the reaction $^{245}Cm + ^{48}Ca$, while $^{287}114$ nuclide was also observed in the $^{244}Pu + ^{48}Ca$ reaction.

The measured excitation functions for nuclear reactions of total fusion followed by the subsequent evaporation of several neutrons made it possible to be more certain about the choice of ^{48}Ca-ion energies for the subsequent experiment aimed at synthesizing element 115 in the reaction $^{243}Am + ^{48}Ca$. Two isotopes, $^{287}115$ and $^{288}115$, were produced at two energies of the ^{48}Ca ions. It should be emphasized that for the first time one experiment synthesized two new SHEs since the isotopes of element 113, $^{283}113$ and $^{284}113$, were products of the α-decays of the $^{287}115$ and $^{288}115$ nuclei.

The G N Flerov Laboratory of Nuclear Reactions at JINR headed now by Academician Oganessian has thus pioneered in the last five years the synthesis of five new superheavy elements and studied the radioactive properties of 27 new radionuclides. Many of the nuclei were therewith obtained in different (cross) reactions and the nucleus production cross sections were measured at various energies of ^{48}Ca ions (excitation functions). Both these methods are extremely important for reliable identification of the atomic numbers A and Z of the nuclides synthesized. The radioactive properties of new nuclides (energies and α-decay times) indicate that α-decays of superheavy nuclei are allowed; this is typical of spherical nuclei. For isotopes of lighter elements making their appearance as daughter products of α-decays of superheavy nuclei, more pronounced α-decay forbiddenness reveals itself. This fact indicates that the initially spherical nucleus becomes more and more deformed in the course of successive α-decays. Nuclei thus pass from the spherical to the deformed region as α-decays unfold, which provides a conclusive confirmation to the theory that predicts the existence of a region of enhanced stability of spherical superheavy nuclei.

These important discoveries capped the almost 40 years of efforts by scientists from various countries in their quest for the 'stability island' of superheavy nuclei.

An ever-greater role in nuclear – physical research is being played in recent years by beams of exotic isotopes of light elements with neutron-rich nuclei, such as ^{6}He and ^{8}He. These isotopes are only produced by nuclear reactions; they are radioactive (and often very short-lived), so that it is typical to speak about 'radioactive beams'. Used for this purpose at LNR is the U-400M cyclotron in which the beams of radionuclides required are produced via fragmentation of ^{7}Li, ^{11}Be, and ^{15}N nuclei accelerated up to the energies of 35 – 45 MeV per nucleon, and by on-line magnetic separation of reaction products. The intensity of the secondary ^{6}He and ^{8}He beams are 1×10^{6} and 2×10^{4} s^{-1}, respectively, for the energy of 25 MeV per nucleon. The DRIBs facility that is being built now at LNR will open considerably richer prospects for working with radioactive beams. At phase I of the project (DRIBs-I), a combination of the U-400M and U-400 cyclotrons and an ion guide nearly 100 m long are used to transport the beam from the first accelerator to the second one. The U-400M cyclotron serves to generate radioactive isotopes which are transferred, using an on-line ion source and low-energy acceleration, to the U-400 cyclotron to have them accelerated to the required energy. This combination of

cyclotrons will make it possible to generate ^{6}He and ^{8}He beams with energies from 6 to 16 MeV per nucleon at beam intensities of 10^{10} and 10^7 s^{-1}, respectively.

Heavy ions offer excellent tools for studying the properties of condensed media, for producing new materials and for predefined modification of materials properties, as well as for further development of nanotechnologies.

The third main avenue of our research effort falls on condensed matter physics. This rapidly expanding field of fundamental science makes use of the experimental methods of nuclear physics for studying physical phenomena in solids and liquids, and for working on novel properties of materials. The Joint Institute possesses a unique pulsed research reactor IBR-2 that allows scientists to work in the above-listed fields at a world-class level. New possibilities for studying complex-structure compounds will open through the modernization of the IBR-2 reactor; this is especially important for biology, the physics of polymers, materials science, pharmacology, etc.

A further research program at JINR in this area is largely connected with the implementation of the IREN project — a new Intense REsonance Neutron Source for fundamental and applied studies in nuclear neutron physics.

Research dealing with fundamental symmetries that manifest themselves in reactions with neutrons and the study of the neutron itself and that of neutron-involving fundamental interactions remain our highest-priority fields. Thus, the T symmetry violation in the interaction between polarized neutrons and polarized nuclei will be studied in the KaTRIn project using an original technique, suggested at JINR LNR, that makes it possible to reduce to a minimum the systematic effects that arise when neutrons and the nuclear target are polarized and when the polarization of the transmitted neutron beam is analyzed.

In addition to the three main streams of research, where the most attention at JINR is focused and where the scientific reputation of the Institute is universally recognized, we also need to point out some successful work in narrower but also important fields. A technique was devised at the Institute for producing high-purity radioactive isotopes and high-efficiency nuclear film filters, and methods of radioactive isotope and X-ray fluorescence analyses for applications in geology, medical sciences, biology, etc. were developed. Successful research is being conducted on fundamental and applications-oriented problems of radiation biology.

The Laboratory of Radiation Biology was organized in 2005 using the Division of Radiation and Radiobiological Research as a basis. The experimental equipment of the Joint Institute is used efficiently to provide sources of ionizing radiation for extremely promising radiobiological experiments. The work concentrates on the mechanisms of lethal and mutagenous effects of ionizing radiation with different physical characteristics on living cells.

The image of JINR as a multidisciplinary physics center manifests itself best in its modern accelerator and reactor base. The powerful infrastructure and experimental production facilities of the Institute, the staff of experts in a wide variety of fields of knowledge, and active international cooperation allow JINR to solve problems of mind-boggling complexity at minimum cost. Here is one such an example: an oncological and radiological clinical division was set up and has been functioning in Dubna since 1999. Patients undergo post-irradiation treatment here after receiving radiation therapy with the JINR phasotron medical beams; more than 300 patients have been treated. This became possible owing to the enthusiasm and utmost dedication of the RAS Corresponding Member Venedikt Petrovich Dzhelepov, who supervised the creation of Dubna's first accelerator — the synchrocyclotron — together with another RAS Corresponding Member Mikhail Grigor'evich Meshcheryakov. All work with the phasotron's proton beam is carried out jointly by the staff of the Institute of Experimental and Clinical Oncology of the Academy of Medical Sciences of the USSR (now the Oncological Research Center of the Russian Academy of Medical Sciences) and a group of physicists from the Laboratory of Nuclear Problems of JINR.

In a number of cases, the radiological therapy of tumors fails for reasons of relative resistance of the neoplasm to radiation with low linear energy transfer, or the impossibility of guiding a sufficient dosage of radiation to the tumor in view of the risk of damage to normal surrounding tissue. Application of a hadron beam may drastically improve the geometric parameters of dose distribution and increase the destructive effect of the irradiation. Almost all such particles scatter only slightly in tissues in front of the target and have a well-defined penetration depth and small transversal scattering of the beam. The linear energy transfer increases with penetration depth and reaches a maximum at a certain depth, forming a Bragg peak, so that the dose in the target may be several times higher than the dose at the surface, even if irradiation is conducted from one direction only.

On Dzhelepov's suggestion, Russia's first proton beam with the parameters required by radiation therapy was produced at the phasotron of the JINR Laboratory of Nuclear Problems. At the moment, a multiple-cabin clinical physics facility operates at JINR. It offers the possibility of producing and shaping broad or narrow beams of protons, negative pi mesons and high-energy neutrons. The facility is equipped with all the necessary support and quality control systems for irradiation therapy. This is the first time that such a collection of medical-application beams has been obtained at the same accelerator. This configuration makes it possible to individually select the best type of irradiation for each individual patient on the basis of the dose distribution and biological characteristics of each type of particles, and the dimensions and clinical specifics of the tumor.

There are numerous examples of this at the Institute...

Information technologies are the key technologies of the modern physical experiment; they help to do 'physics at a distance'. The Institute possesses powerful and fast computer aids integrated into international networks. The central mainframe system (TsIVK) at JINR is part of the Russian GRID infrastructure and comprises an interactive cluster and the common-access computing farm, a dedicated farm for LHC experiments, a farm for parallel computing (based on the Myrinet and SCI technologies), a dedicated cluster LCG-2, and high-capacity mass memory on RAID disk arrays and magnetic tapes. The central mainframe at JINR is used for simulations and data analysis in particle physics, nuclear physics, and condensed matter physics.

The plans for 2009 envisage systems upgrades to new technology of data transfer at a rate of 10 Gbit s^{-1} in the local and external networks. The distributed Tier2 center built on the basis of JINR and of 10 Russian nuclear physics centers implements GRID technology utilizing new-generation high-speed networks. It will be integrated into the European and world GRID structures and will comply with the requirements of the largest-scale physics experiments, including new-

generation experiments on the nuclotron (JINR), LHC (CERN), RHIC (BNL), Tevatron (FNAL), and HERA (DESY).

JINR at the moment is the only research center on Russia's territory that practices multilateral cooperation in fundamental sciences. The Institute's partners in Russia are 154 research and educational establishments in 45 cities; they use extensively the potential of the unique scientific base of JINR. The JINR's entire activity upholds the prestige of Russia, especially among the industrially developed countries, its partners in the G-8: Germany, Italy, France, USA, Japan, etc.

More than 200 research centers, universities and industrial enterprises from ten CIS member states participate in implementing the research program of the Institute. JINR can be realistically regarded as the common science center of this commonwealth; it operates successfully at the international level.

The Joint Institute provides excellent conditions for the training of talented young specialists. The JINR Educational and Research Center organizes research experience annually at the Institute's facilities for 270 students from higher-educational institutions in Russia and other countries. In 1995, the JINR postgraduate education program was launched for 50 to 60 postgraduate students annually.

Our Institute has always fulfilled its educational role and will continue to do so in the future — this is its important function as the highest-level school for scientists of the member states. For example, a very interesting program of advanced education for young theoretical physicists is being organized now (DIAS-TH). The Institute also strives to help university education. JINR is extending its ties with the Dubna University and with its traditional partners — MGU, MFTI, MIFI, and universities in Tomsk, Tver', Voronezh, Saratov, and other towns.

For 50 years JINR has been a sort of bridge between the West and the East, promoting the development of broad international scientific and technical cooperation among dozens of countries.

The Joint Institute for Nuclear Research has thus arrived at its 50th anniversary with new discoveries in physics and its research facilities modernized; its work now unfolds in a society that is guided by adequate concepts of the role that fundamental sciences should play.