Dubna: Twenty Years of International Research in Nuclear Physics

In 1956, an agreement on the founding of the Joint Institute for Nuclear Research (JINR) was signed in the Presidium of the USSR Academy of Sciences. The Joint Institute has developed into one of the leading international research centres in nuclear physics. In this report prepared for the IAEA Bulletin, the achievements and current status of the Joint Institute are reviewed.

Twenty years have passed since the Joint Institute for Nuclear Research, the first international scientific centre of the socialist countries, was established.

The Joint Institute for Nuclear Research was founded in response to a proposal of the Soviet Government, which assigned to it two research institutions of the Academy of Sciences of the USSR that were located in Dubna, not far from Moscow. At the Institute of Nuclear Problems, Soviet scientists since 1949 had been performing investigations with a proton accelerator, a 680 MeV synchrocyclotron, and the construction of a large accelerator, a 10 Gev synchrophasotron, was being finished at the Electrophysical Laboratory. As a basis for creating both of the accelerators the principle of phase stability proposed by Professor V.I. Veksler was used. These two establishments enabled the international personnel of scientists of the new institute to immediately begin experimental investigations in the field of high energy physics.

After the Institute had been created, next came the founding of the Laboratory of Theoretical Physics with a calculating department, the Laboratory of Nuclear Reactions where the construction of a cyclotron for accelerating heavy ions was begun, and at the Laboratory of Neutron Physics where the construction of a fast neutron pulse reactor was started. The cyclotron and reactor came into operation in 1960. The development of the Institute required the establishment of a Laboratory of Computing and Automation which was set up in 1966. A Department of New Methods of Acceleration was founded in 1968.

Today the Joint Institute for Nuclear Research is known as a leading scientific centre, one of the largest in the world. Because of their size and scope of work, each of the laboratories can be called an institute. The staff of the laboratories and its workshops consist of more than 6 thousand persons. The scientists of the Institute have carried out a series of important investigations in a wide region of modern science: in theoretical physics, elementary particle physics, nuclear and neutron physics, in the development of accelerator techniques and physical apparatus.

The success of the Joint Institute for Nuclear Research is stipulated by the democratic principles of its organization and activities, the availability of a unique experimental base, the wide international relations of the Institute and, in the first place, the work of its gifted scientists. At present there are five Members of Academies of Sciences, eight Corresponding Members of Academies of Sciences, 90 Doctors of Sciences and 380 Candidates of Sciences among the 900 scientists of the Institute.

The scientists of JINR have written more than 50 monographs. Every year the Institute's members publish about 1600 preprints and articles in scientific journals and proceedings of conferences, and they have made about 17 discoveries. Among the scientists of JINR there are Lenin and Nobel prize laureates. A number of scientific achievements of the JINR personnel have been awarded prizes and honourary medals of the Institute's Member States

ELEMENTARY PARTICLE PHYSICS

The theoreticians of the Institute have proposed new ideas and methods in their investigation which have stimulated further research both at JINR and other scientific centres. In the field of elementary particle physics, the principles of mathematically rigorous approach to the quantum field theory have been formulated and thus the method of dispersion relations has been justified. This method has influenced the development of elementary particle physics, particularly the theory of strong interactions. The quasi-potential method in the scattering and bound-state theories was created at the Institute. Among the research connected with the fundamental principles of theory, there are investigations on the geometry of space-time at short distances, the causality principle, etc.

On the basis of the ideas and methods developed in the quantum field theory and the theory of superfluidity, a semi-microscopic (or superfluid) model of the nucleus has been constructed, which helps in understanding the nature of the quasi-particle and collective states of the deformed nuclei. The predictions have been supported in series of experiments in Dubna and other centres.

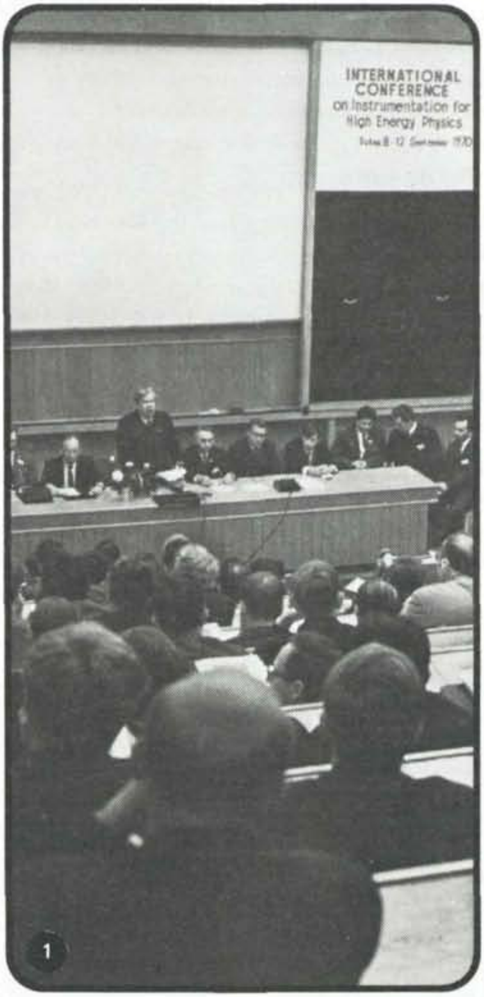
A large part of the experiments with the synchrophasotron are devoted to the study of the production of strange particles at energies up to 10 GeV. In 1960 the scientists of the Institute discovered a new particle — the anti-sigma-minus hyperon.

As a result of the extensive investigations of particle resonance states, several new resonances have been discovered and the properties of previously discovered resonances have been studied. One of the achievements is the detection of φ^0-meson decay of the electron-positron pair.

The long-term study of elastic and inelastic scattering of elementary particles has given important information about their structure and has permitted the checking of the fundamental predictions of contemporary theory.

Experiments with the synchrophasotron have recently taken a new direction involving relativistic nuclear physics, making possible the study of nuclear collisions at high energies.

Pioneer investigations of elastic nucleon-nucleon scattering carried out with the synchrocyclotron in an energy range up to 680 MeV have given important information about nuclear forces. The law of charge independence of nuclear forces has been confirmed by investigations of pion-nucleon interactions. The causality principle has been experimentally proven and the pion-nucleon interaction constant has been determined.



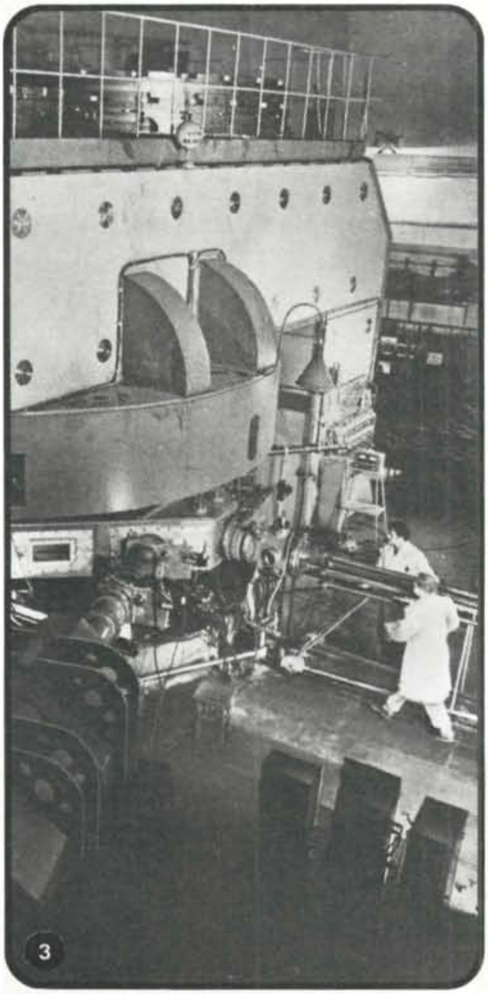
1 The Joint Institute for Nuclear Research at Dubna organizes about 60 scientific meetings a year. Shown here is an international conference on instrumentation for high energy physics which was attended by more than 200 scientists from 27 countries.

2 The measuring centre, which has a BESM-4 computer, of the Laboratory of Neutron Physics accumulates and processes data from the neutron beams of a pulse reactor. Data which require processing on more powerful computers are transferred to the Institute's measuring centre.

3 The U-300 cyclotron accelerates ions of elements from carbon-12 to zinc-66 with an energy of about 10 MeV per nucleus.

4 Installation of the chamber body of a two-metre hydrogen chamber, "Ludmila", used in experiments with the Serpukov accelerator.

5 The synchrophasotron, the largest accelerator at the Institue, accelerates protons to 10 GeV, deuterons to 11 GeV and particles to 22 GeV.



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Experiments on rare processes involving mesons have confirmed the deductions of the universal weak interaction theory. The beta decay of pions was discovered by the scientists of the Institute. In experiments on muon capture in He^3, recoil nuclei from muon neutrinos have been observed and the muon-electron symetry has been confirmed. A new physical phenomenon — the double pion-nucleus charge exchange — has been discovered.

For almost 20 years nuclear spectroscopy investigations of isotopes produced by the irradiation of targets have been performed with the synchrocyclotron. The JINR physicists have identified more than 100 new radioactive isotopes.

ANTIMATTER

A comprehensive programme of investigation is being carried out with the 76 GeV accelerator at the Institute of High-Energy Physics in Serpukhov. The investigation of proton-proton and proton-deutron scattering has been carried out on it. The two-metre bubble chamber has been exposed in a 40 GeV pion beam. At present the two metre hydrogen bubble-chamber "Ludmila" is operating in an antiproton beam. Experiments are also carried out with the filmless spark spectrometer and 5-metre magnetic spark spectrometer made in Dubna. A series of investigations carried out by the Institute scientists have resulted in a new step in the investigation of antimatter: experimental discovery of the antitritium nucleus.

After the 400 GeV proton accelerator had been put into operation in Batavia (USA), one of the first experiments on it was the joint experiment by Dubna and Batavia physicists on proton-proton and proton-deuteron scattering at small angles. The experiments were performed using a jet target made in Dubna and then adjusted in experiments with the Serpukhov accelerator. The experiments have given important information about the nucleon structure and the nuclear forces in proton interactions in a wide energy range up to 400 GeV.

The JINR scientists continue experiments at the Serpukhov, Erevan and Batavia accelerators.

The JINR three-metre cyclotron provides acceleration of intense ion beams of elements from boron to zinc. In Joint operation of the cyclotron with a two-metre isochronous cyclotron, U-200, still heavier ions up to xenon were accelerated.

In heavy-ion induced reactions the JINR scientists have synthesized various isotopes of the heaviest elements. The study of chemical properties of short-lived transuranium elements is carried out by the method of gas chromotography evolved in Dubna. One of the investigation trends is the search in nature for superheavy elements with Z from 114 to 126.

Long-term experiments with heavy ions have led the JINR scientists to the discovery of new physical phenomena: spontaneous fission of nuclei with anomalously short half-life from the isomer state and a new type of radioactive nuclear decay — emission of delayed protons. More than 30 new neutron-rich isotopes of light elements have been synthesized using transfer reactions with heavy ions.

The fast-neutron pulse reactor IBR-30 is a unique source of periodically repeating short and intense pulses of neutrons which are a convenient tool for physical experiments performed by the time-of-flight method. Extensive information about neutron resonances, particularly about the spins and radiation widths of these states have been extracted from spectrometric investigations. A beam of polarized neutrons of an energy up to 10 KeV has been obtained, which made it possible to study the interaction between polarized neutrons and polarized nuclei. Original methods were used to measure the magnetic moments of highly excited nuclear states, to investigate the alpha decay of neutron resonances, and gamma-rays in radiative capture of resonance neutrons.

The JINR scientists have carried out experiments on the discovery of ultra-cold neutrons and their storage in closed "bottles". The dynamics of solids and liquids is being studied by means of neutron beams with the aid of special methods developed in Dubna.

COMPUTER COMPLEX

The Joint Institute has a computer complex with 60 computers of various sizes. The main computer centre is linked by communication channels with the measuring centres of the laboratories where mini- and medium-sized computers are used. The computer complex carries out a wide-range of work including the processing and analysis of experimental data, control and operation of the Institute computer facilities, solution of mathematical problems, etc.

The extensive volume of information coming in from track chambers is processed with the aid of an automatic device with mechanical "moving ray" scanning, a spiral meter, an automatic electron-ray tube device as well as with the aid of a system including 15 semi-automatic devices and scanning tables. All these units work on line with the computer systems.

Many of the investigations being carried out at the Institute are connected with the improvement of present accelerators and the development of new accelerator techniques. The first Dubna accelerator — the synchrocyclotron — is on the eve of reconstruction into a high-current phasotron. The acceleration of deuterons, helium and carbon nuclei has been performed at the synchrophasotron which has thus become the first relativistic accelerator of nuclei, and an extensive programme of investigations on the beams of these particles is being carried out. The JINR scientists are working out a project of a new cyrogenic relativistic accelerator of nuclei — the "Nuclotron".

Heavy ion acceleration techniques are developing successfully at the Institute. After the construction of the 3-metre classical cyclotron, a 2-metre isochronous cyclotron with high magnetic field was build at Dubna. At the present time a new powerful 4-metre cyclotron is under construction.

Many of the investigations of the JINR scientists are connected with the designing of high-current accelerators with spatial magnetic-field variation. A relativistic cyclotron — "Supercyclotron" — is being designed.

A principally new method of acceleration — the collective method — has been proposed at JINR. Theoretical grounds of the method have been worked out and experiments are being carried out.

The first stage of this work is the construction of a heavy ion accelerator. To this end a powerful linear electron accelerator, a number of different types of ring bunch cohesor devices, high-current comutators and ring diagnostic apparatus have been constructed. A system of cryogenic resonators and superconductive magnets — "Coltsetron" — for electron-ion ring acceleration is being built.

INTERNATIONAL CO-OPERATION

International scientific co-operation is the basis of the Joint Institute for Nuclear Research activity. During the 20 years of the development of the Institute the co-operation has been considerably extended in many different forms. Today the international groups of scientists and engineers are engaged in almost all the spheres of physics. The number of investigations carried out by JINR in co-operation with the national laboratories of the JINR Member States is becoming larger year by year. On the basis of such co-operation theoretical and experimental investigations are being carried out, and physical and radio-electronic apparatus are being designed and constructed. Eleven states are members of the Institute: Bulgaria, Hungary, German Democratic Republic, Korean People's Democratic Republic, Cuba, Mongolia, Poland, Romania, USSR, Czechoslovakia and Viet-Nam.

A collaboration, which was later called "physics at a distance" has been developing from the first years of the Institute. Radio-active samples received at the Dubna accelerators are delivered to laboratories of different countries for research work. The co-operation between laboratories is being extended for simultaneous treatment of a great amount of experimental material: photo-emulsions irradiated at the JINR accelerators, bubble-chamber films and records of the results of measurements made on magnetic tapes in the experimental electron facilities.

The Joint Institute develops its scientific contacts with the institutes of the JINR Member States, as well as with research centres of non-member states and international organizations. The co-operation is especially fruitful with the European organization for Nuclear Research (CERN), the Niels Bohr Institute, Institute Laue-Langevin in Grenoble, scientific centres of France, Italy, Finland, England, Switzerland, India, Yugoslavia and FRG. Scientists of JINR together with American physicists have carried out a number of experiments with the accelerators in Serpukhov and Batavia.

The scientists of the Joint Institute participate in all the large international scientific conferences and many of the national meetings, symposia etc. The Joint Institute organizes yearly about 40 scientific and methodical meetings, conferences, schools, etc. More than 1000 specialists from different countries come to Dubna every year for carrying out joint work, consultations, participation in meetings. In turn, more than 500 scientists from the Joint Institute yearly visit the JINR Member States and other countries.

JINR AND THE IAEA

In 1973 a protocol was signed on collaboration between the Joint Institute for Nuclear Research and International Atomic Energy Agency which envisages not only exchange of information but also other forms of co-operation, i.e. the Joint Institute affords the Agency the opportunity to hold scientific meetings at Dubna; JINR participates in the Agency's International Nuclear Information System (INIS); the Joint Institute makes available to the Agency fellowships for training physicists from Member States of the Agency; JINR specialists take part in the conferences, symposia and scientific meetings organized by IAEA and the International Centre for Theoretical Physics in Trieste.

The questions of collaboration are systematically discussed during the visits of IAEA Director General S. Eklund and other members of the IAEA to Dubna and members of the JINR Directorate to Vienna. From the moment of its establishment the Joint Institute has been afforded the opportunity to send a representative on a regular basis and in the capacity of an observer to the annual sessions of the Agency's General Conference. There is a continuous exchange of scientific information and information on scientific meetings between IAEA and JINR. Meetings of IAEA have been held several times in Dubna.

A number of JINR scientists have taken part in the IAEA meetings on INIS, in the sessions of the Committee on Nuclear Data and on the problems of utilizing nuclear methods in science and technology.

Though the main tasks of IAEA and JINR do not coincide, nevertheless they have common interests as to the problems of experimental techniques (nuclear electronics); automatization of the processes of nuclear data handling; on-line computer control of complicated systems; processing of experimental data; the use of nuclear methods of measurement in nuclear techniques, industry, agriculture, natural sciences and medicine.

The experience gained by JINR in these fields can serve as a basis for a further development of co-operation between IAEA and JINR.

In summing up the 20 year activity of JINR, it should be noted that the merit of the Institute is not only in the outstanding results of its scientific investigations and technical achievements, but also that the Institute has become a unique school for scientists and engineers of its Member States and also a school of high qualifications in many fields of modern physics. Many of the specialists who had taken part in the research work at Dubna are now scientific leaders of groups, departments or institutes, and many have become professors and members of Academies of Sciences.

The Joint Institute for Nuclear Research has begun to fulfil its fifth five-year plan. Recently, a new plan of the development of the Institute has been adopted, the basis of which is the creation of a modern first-class experimental base and the development of new branches of the modern theory of physics. This plan is a reflection of great importance which is attached to the Institute's activity by its Member States and the attention they devote to it.