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Academician Nikolai G. Basov: the Father of inertial fusion. A scientific and human approach

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I would like to thank Academician Krokhin for this invitation. It is for me an honour to pay a tribute to Academician Basov, one of the greatest scientists of the last century and a good friend of mine.

I met Academician Basov twenty years ago when he came to Madrid, invited by the Spanish Council of Scientific Research. By that time, my research group had been working for seven years in the development of codes for numerical simulation of the processes involved in inertial confinement fusion, but due to the possible military applications of inertial fusion, a strict classification was imposed for the nuclear nations, thus making our research very difficult.

For this reason, I was very interested in the opinion that Basov could have about it. So I invited him to visit our Institute of Nuclear Fusion. I explained him our codes of integrated NORCLA systems for unidimensional calculations in inertial fusion, and Basov talked to me about the results obtained with the KALMAR laser and the starting experiments with the new DELFIN facility.

When our conversation was over, it was already night. During the dinner, Academician Basov spoke to me very proudly of the educational system of the Soviet Union and the highly scientific and technical level of its universities that was, by that time, probably the highest in the world. He was also very proud of his research group at the Lebedev Physics Institute.

As we were talking about Russia, I remembered my stay in Akademgorodok, near Novosibirsk, 14 years before and I was telling him about the hospitality and the warm welcome I had received. As I was talking, the expression of Academician Basov's face became somewhat friendlier. He looked apparently distant, but it was not true. He was an openhearted man. He kept deep in his heart the special personality of the Russian people, of the Russian soul: the deepness of his feelings, the admiration for values such as the family, the colleagues and above all his love for the Mother Russia, his country, to which he gave the best of himself.

Two years later and due both to his outstanding work to solve the grave energy problems by means of using laser in nuclear fusion, and to his open spirit for scientific collaboration, I proposed Academician Basov as Doctor Honoris Causa of our Polytechnical University of Madrid. He came to Madrid in 1984 with his wife Ksenia and we enjoyed a very nice time together. Following his visit, we signed a cooperation agreement between the Lebedev Physics Institute and our Institute of Nuclear Fusion.

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This was the starting point of a very fruitful collaboration between our both Institutes. Thanks to this agreement several scientists of the Lebedev Physics Institute worked at the Institute of Nuclear Fusion in Spain in the following years, among them Professors Starodub, Rozanov, Skilzkov, Gus'kov, Shikanov, Gamaly, Isakov, Lebo, Vergunova and Demchenko. On the other hand, Basov invited several colleagues of mine and myself to visit and lecture at the Lebedev Physics Institute and the Kurchatov Institute in Moscow and at the Ioffe Institute in Leningrad. He made available for us the possibility of checking our theoretical model.

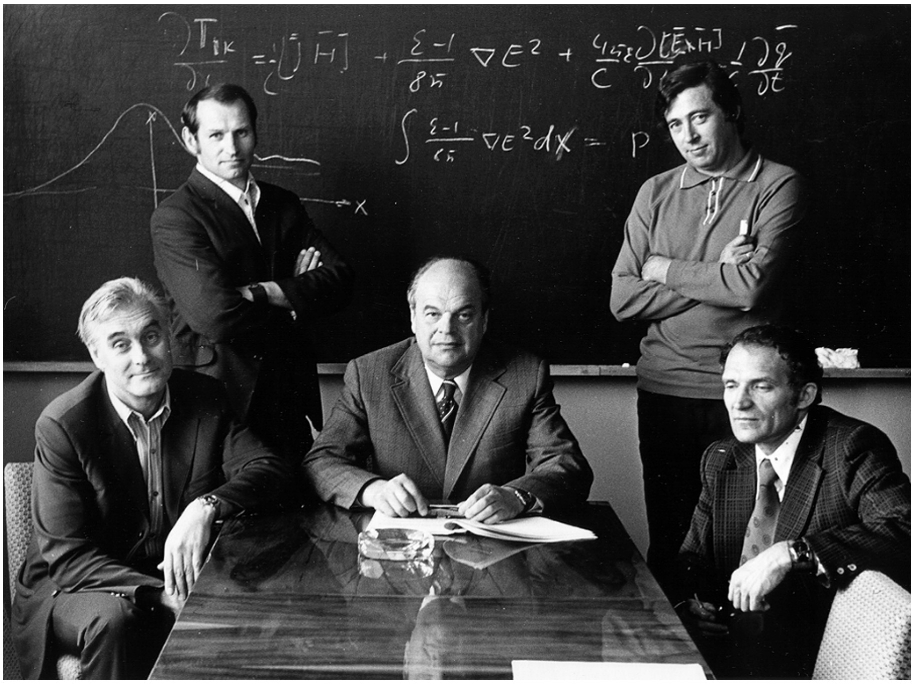
The result of all this has been a long and very satisfactory exchange of mutual research interests. As an anecdote, I would like to tell you that by then, all my colleagues had started to learn the Russian language with a Russian professor. They did it for two years, but after trying very hard, they gave up when they realised that it was more difficult to learn Russian than to work in inertial fusion.

Nikolai Basov was born in December 14, 1922 in a small town of Usman, in the Lipetsk region. His father was a professor at the Voronezh State University. After his high school graduation in 1941, he served in the Soviet Army as lieutenant of the Sanitary Corps during the Patriotic War, which during five difficult years was for him, as for the rest of the Soviet citizens, a terrible and dramatic experience, in which this country proved its courage and its capacity for survival. As a matter of fact, he was involved along his life in the destiny of Russia.

After the War, in 1948, Basov joined the Lebedev Physics Institute as a laboratory assistant. Two years later, he graduated from the Moscow Institute of Physical Engineering. In 1956, he received a doctorate in mathematical physical science. In 1963, he was appointed the head of the Quantum Radiophysics Laboratory, and two years later he became the director of the Lebedev Physics Institute, where he remained up to the end of his life. He loved this Institute, which kept essentially the Russian research tradition.

As it is widely known, the Russian physics field began to grow during the first third of the last century. Both in Moscow and in Petersburgh, under the leadership of Vladimir Verdnadsky, Nikolai Semenov, Abram Ioffe, Piotr Lebedev and other outstanding scientists, the kernel of Russian physics institutes began to form. On March 16, 1911 Piotr Lebedev, along with other physicists colleagues such as Umov, Lazarev and Eijevald founded the Moscow Physical Society and the first Russian physics school.

Basov's contribution to science in Russia and throughout the world is highly recognised. He received the Lomonosov Gold Medal (the highest award of the Russian Academy of Sciences). He was elected a Corresponding



The pioneers in the development of laser inertial fusion, N.G. Basov with his colleagues: on the left are O.N. Krokhin and E.G. Gamaly (standing); on the right are V.B. Rozanov and Yu.V. Afanas'ev (standing).

Member of the Soviet Academy of Sciences in 1962 and a Full Member (Academician) in 1966. He was also a member of the national academies in many countries, and Doctor Honoris Causa of several universities as well. Academician Basov was the Chairman of the 'Znanie' (Knowledge) Society; the Editor-in-Chief of the journal Priroda (Nature) and the founder and Editor-in-Chief of the journal Kvantovaya Elektronika (Quantum Electronics).

In 1959 Basov and Prokhorov won the Lenin Prize, Soviet Government highest award in science, for the discovery of a new principle of generation and amplification of electromagnetic radiation by quantum systems. In 1964 they, together with the American scientist Charles H. Townes, won the Nobel Prize in Physics for fundamental research in the field of quantum electronics, which led to the discovery of masers and lasers.

In 1952 Basov and Prokhorov were the first to demonstrate theoretically the feasibility of constructing oscillators and amplifiers of electromagnetic waves, based on stimulated emission of quantum systems employing energy levels with population inversion. As early as 1955, they proposed a highly efficient principle for achieving population inversion based on the use of three energy levels with the lifetime of the intermediate level greater than that of the upper level. One year later, Basov was awarded Doctor of Science degree for this thesis entitled 'A Molecular Oscillator', which produced a notorious impact among the Russian scientific community and so did later in the international community. This thesis had got the positive approval of the Nobel winner (1958) Ilya Frank.

Basov was the first person in the world to propose in 1961 the use of semiconductors as an active medium for a laser excited by several methods including injection across a $p-n$ junction. This injection diode laser is the most commonly used in science and technology. Presently, hundreds of millions of lasers of this kind are being manufactured.

Since then, Basov and his colleagues made an intense and fruitful work on the research and development of a broad family of new lasers: electron-beam, excimer, chemical, photodissociation (iodine), in which a shock wave is used to excite an active medium, etc. Academician Basov was also a pioneer in the application of lasers for nuclear fusion with the energy production. In March 1962, Academicians Basov and Krokhin in a report presented to the Presidium of the Soviet Academy of Sciences, proposed the idea of achieving a thermonuclear fusion reaction by laser irradiation of a small pellet. One year later, they reported their theoretical results, for the first time, at the Third Conference on Quantum Electronics held in Paris.

As all the great ideas, this was very simple. The theoretical studies showed that it is possible to obtain laser irradiation of up to exawatts per square centimetre; pressures of up to giga atmospheres; densities of up to thousand grams per cubic centimetre; and temperatures of hundred millions degrees, producing the necessary conditions for an efficient thermonuclear reaction.

However, at that time, laser output energies were so small, that initially the idea seemed unrealistic. Basov said: *'It was considered as a far perspective in the spirit of Jules Verne, but not as a today's problem.... I just remembered that one of our first reports submitted to the conference on controlled thermonuclear fusion had not been accepted by the Organizing Committee, since its subject has been considered not belonging to the conference topic'.*

Despite the skeptical reaction of the scientific community, several scientists were enthusiastic about this kind of nuclear fusion. Reports started to be published in Europe, the United States and Japan. In Europe: Berry at the CEA in Limeil in 1964, Caruso at the ENEA in Frascati in 1964, Mulser and Witkowski at the MPQ in Munich in 1969, etc. In the United States due to the possible military applications of the ICF, these works were classified, although in 1964 Dawson published a report on the production of plasma by giant pulse lasers. At the beginning of the 1970s, some declassification policy allowed the publication of some important theoretical and experimental works carried out during the former decade by Teller, Nuckolls, Kider, Brueckner, Jorna, Fraley, Bodner, etc. at Lawrence Livermore, Los Alamos and Naval Research Laboratories. In Japan, Yamanaka from the Institute of Laser Engineering at the Osaka University carried out an excellent work which was the leap forward a very active program.

After this, several institutes and laboratories were founded: KFK and GSI in Germany; Laboratory of Laser Engineering at the Rochester University in the USA; CLF at the Rutherford Appleton Laboratory in the U.K.; LULI at Ecole Polytechnique in France; DENIM in Spain, etc.

In 1968, at the Lebedev Physics Institute the first thermonuclear laser neutrons were generated by an Nd-glass laser irradiating a lithium – deuteride plane target. One year later, the emission of about one thousand neutrons were reported by Limeil. But the problems also appeared. Since the inverse bremsstrahlung absorption cross section decreases with increasing the plasma temperature, it seemed doubtful that the laser radiation would be adequately absorbed by the laser plasma.

Fortunately, these pessimistic conclusions proved to be wrong because the nonlinear character of laser-plasma interactions had not been considered. Robert Dautray at Limeil, scientists at the Lebedev Physics Institute and Yamanaka at the Osaka University demonstrated unambiguously this nonlinear effect.

In 1972, new experiments with the nine-channel laser Kalmar using spherical targets were started at the Lebedev Physics Institute. Basov, Krokhin, Skilzkov, Fedotov et al. observed the neutron emission in the D – D and D – T reactions. The same year, Teller, Nuckolls, Wood and Zimmerman at the Lawrence Livermore National Laboratory proposed the supercompression by means of time-profiling the laser pulse.

In 1974, Basov, Gamaly, Krokhin and Rozanov at the Lebedev Physics Institute and other scientists at the Keldysh Institute proposed an alternative plan for low-entropy compression of a high-aspect ratio multilayer target.

In 1982, experiments were carried out at the Lebedev Physics Institute with the 108-channel Delfin laser. Basov, Sklizkov and Fedotov demonstrated the possibility of a stable compression of shell targets with an aspect-ratio of 100, attained a density of 8 grams per cubic centimeter. The group of Yamanaka at the Osaka University performed similar experiments at higher energies.

The next step was the conversion of laser radiation into X-rays. Indirect targets (hohlraums) were used at the Lawrence Livermore National Laboratory and cannonballs in Osaka. Fast ignition is a promising solution for direct targets.

During these years, new lasers have been built increasingly higher in power and two powerful lasers of 1.8 MJ are under construction at the Lawrence Livermore National Laboratory and at the CEA at Bordeaux.

Presently, scientists and engineers throughout the world are seriously worried because of the energetic crisis that affects mankind. The reserves of oil and natural gas will be exhausted by the end of this century and even though coal reserves could last several centuries, the carbon dioxide emission and the grave greenhouse effect produced, would limit its future use.

The alternative sources of energy (solar, eolic, geothermal, biomass, etc) will be able to provide only a small percentage for the future demand on energy. Advanced nuclear fission reactors could serve as an intermediate energy source until we are able to develop and commercialise nuclear fusion reactors.

To solve the existing gap between the present nuclear fission reactors and the future inertial fusion reactors, two types of hybrid reactors were proposed. Both of them use a subcritical fission reactor with a powerful neutron source, enabling the total system to operate in a steady-state regime. The subcritical operation regime provides safety in any emergency situation. Basov, always concerned with energy problems, proposed a hybrid fission – fusion reactor whose neutron source is a laser fusion reaction. The requirements for the laser power are reduced by nearly twenty times as compared to a purely thermonuclear laser reactor. The other type, proposed by Carlo Rubbia, is the hybrid reactor where neutrons are produced in collisions of protons with a lead target. Both projects require the international collaboration. But presently, it is preferred to go directly from fission reactors to fusion ones.

In 1986, Basov was one of over 200 scientists to sign the Madrid Manifesto, in which we proposed the international collaboration and the banning of the classification status on inertial fusion energy research. He also participated very actively in the creation of the Inertial Fusion Energy Society, whose Board of Directors included Basov, Dautray, Nuckolls, Yamanaka, Hora and me. Academician Basov, giving an example of modesty proposed that I was appointed as Chairman. Unfortunately, all these good intentions were not fulfilled due to the negative opposition exerted by some nuclear nations.

The last time I saw Academician Basov, late in the nineties, I realised that he was seriously worried because of the Russian transition problems to a free-market economy. He knew that it was being a painful process for the people and feared that the economic difficulties could affect directly the research centers, and particularly his beloved Lebedev Physics Institute. Academician Nicolai Basov passed away on July 1, 2001.

Four months ago, Mrs. Basova gave me a very special present, the personal watch of Academician Basov. It is for me a great token of the very long and beloved friendship between Basov and myself.

I would like to finish this talk with a feeling of nostalgia. We miss you Academician Basov, as one can miss a great friend, a great Russian, a great scientist, a great man.

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