J. Aerosol Sci., Vol. 24, No. 5, pp. 563–579, 1993
Printed in Great Britain.

0021-8502/93 $6.00+0.00

THE STATE OF AEROSOL RESEARCH IN THE FORMER SOVIET UNION: HISTORY, ACHIEVEMENTS, CURRENT PROBLEMS AND PERSPECTIVES

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(*First received* 16 *November* 1992; *in final form* 9 *December* 1992)

Abstract—Starting from the initiation of the well-known pioneering investigations at the N. A. Fuchs Laboratory in Moscow, and, further, for the recent 60 years, aerosol researchers from the former Soviet Union have made significant contributions to the development of this field worldwide. The paper contains information on the structure and history of the development of aerosol science and its applications in the former U.S.S.R. Recent political and economic changes have resulted in the breakup of the structure of Soviet science and industry as well as a tremendous reduction of financial support for research. The effect on the state of aerosol research in Russia, Ukraine and other post-Soviet republics is discussed in this paper.

INTRODUCTION

The pioneering investigations in many key areas of aerosol science were initiated in the early 1930s by Professor N. A. Fuchs and his colleagues of the Karpov Institute of Physical Chemistry in Moscow. Nikolai Fuchs was the founder of aerosol science in Russia and an important and recognized co-founder of this discipline throughout the world. In 1932, he started the aerosol laboratory where new methods of measuring particle size, charge, and filtration characteristics were developed. During the following decades, dozens of aerosol laboratories appeared within the framework of the Academy of Sciences as well as in several prominent universities and research institutes in Russia (Moscow, Leningrad—now St Petersburg, Obninsk, Novosibirsk, Tomsk, Kalinin—now Tvyer, Sverdlovsk—now Ekaterinburg), Ukraine (Odessa, Kiev), Byelorussia (Minsk), Estonia (Tartu, Tallinn), Lithuania (Vilnius), Kazakhstan (Karaganda) and other republics of the former Soviet Union (the map of the former U.S.S.R. is shown in Fig. 1).

Despite the high level of interest of the first Soviet aerosol scientists in the applied sciences (and their significant achievements in experimental methods and techniques), fundamental research in the 1940s and 1950s developed more efficiently than its applications in industry. Since that time (and still today), basic research in aerosol physics and chemistry has prevailed over applied research in the U.S.S.R. for at least two reasons: (1) the shortage of laboratory and industrial equipment; and (2) the strengths of several advanced theoretical schools which have long dominated the scientific establishment in Russia and Ukraine.

Recent positive political changes in the former Soviet Union have unfortunately resulted in great reduction of support for scientific research. The strictly-organized structure of Soviet science fell apart with the disintegration of the political and economical structures. On the one hand, it was beneficial to eliminate the Soviet scientific bureaucracy and open doors for hundreds of researchers to the world scientific community. On the other hand, this led to the disintegration (and even disappearance) of many nationwide research programs and scientific schools.

The old centralized system of government planning and financing research programs had existed in the U.S.S.R. for a long time. But the distribution of all kinds of equipment had an

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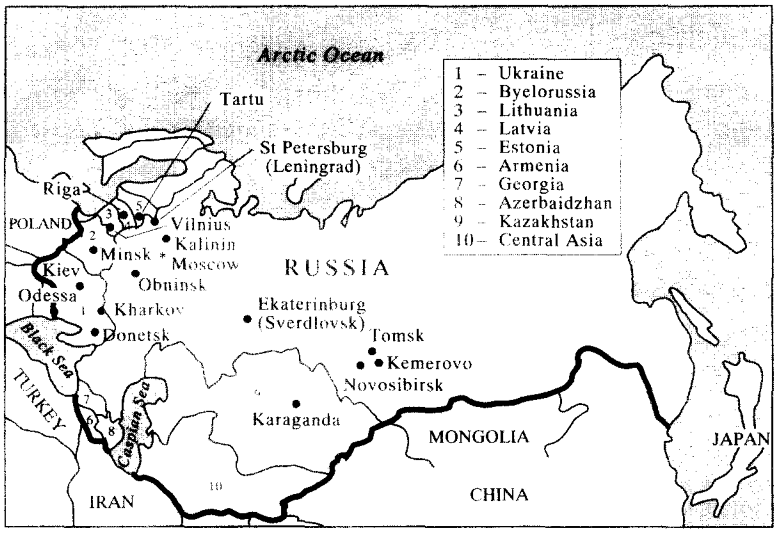

Fig. 1. Map of the former Soviet Union.

unnatural, artificial and non-market character. Indeed, the whole system was quite artificial, as were similar ones in Eastern European countries. The universities and institutes showed no initiative and everything came "from the top". Even the largest laboratories had no hard currency to buy foreign-made instruments and computers. Even minor changes in the activities of laboratories required the permission of Ministries and State Committees. The power of bureaucracy was extremely strong. At the same time, the levels of competence and professionalism of governmental authorities who represented Soviet science and technology was usually extremely low. Therefore, the scientific community was very excited about the new perspectives which *perestroyka* promised. However, the new situation brought new problems to Soviet science because all research and education programs in the former Soviet Union had been developed within the structure of the union of republics and not in each republic separately. The system of science and technology development that existed in the Soviet Union until 1990 contained the following units:

- the State Committee of Science and Technology, with dozens of sub-committees, scientific councils and departments; basically, this Committee was a main distributor of government financial support for research;
- the consortium of institutions, which belonged to the Academy of Science; these institutes were involved mostly in basic research;
- the Ministry of Education, which was in charge of several hundred universities and technical colleges; this was responsible for successful combination of research and educational programs, providing jobs for 100% of higher school graduates; and
- research institutes, which represented different fields of industry, transport, agriculture, medicine, etc.; these provided for the technical application of scientific results.

The organization of the research and its applications in the former U.S.S.R. are schematically shown in Fig. 2. The effective interaction of the elements of this system and their significant interinfluence within this structure developed during the past several decades. In the republics, there were no separate research programs in aerosol science and technology during the entire history of the U.S.S.R. Funds were distributed by the State Committee, irrespective of the republic of any given institute or laboratory. Institutions and scientists got used to the centralized planning, and this mechanism worked (more or less). It was the only system in place, and Soviet science never had any experience with how to do without the All-Union structure. Many questions immediately arose when the Soviet Union collapsed. Who would coordinate management and marketing (taking into account the abilities of the various research institutes) with the practical needs of the national economy?

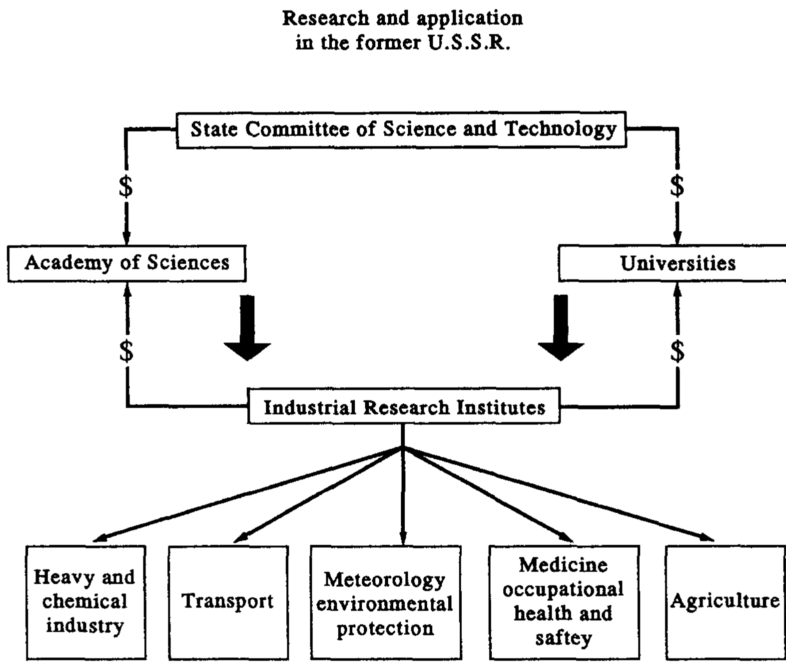

Fig. 2. The organization of the research and its applications in the former Soviet Union.

Who would be responsible for laboratory supplies? Who would take care of finances? Who would provide jobs for young professionals? And so on. For this reason, it was a shock for the scientific establishment when, in one moment, these familiar relationships disappeared. Moreover, it happened under conditions of great shortages of instruments and materials, when the old economic system was almost dead, but the free market economy had not yet been developed. Thus, the break-up of the bureaucratic structure of State Committees, Ministries, and the Academy of Sciences in the former U.S.S.R. caused not only positive, but also many negative, consequences.

The strange paradox of the current situation in the former U.S.S.R. is that it is now easier to make international scientific contacts (e.g. with Germany or the U.S.) than to renew the scientific exchange between the former republics. For instance, since January 1992, the Russian government has not permitted continued financial support for projects if they are completely or partially conducted within Ukrainian institutions; all exchange programs between Russia and the Baltic States (Lithuania, Latvia, Estonia) are frozen; and the civil war in the Caucasus stopped any communication between Armenia and Azerbaidzhan.

At present, however, despite all the pessimistic predictions, a number of aerosol research laboratories still exist and continue to operate successfully. The bulk of research institutes and universities in the former U.S.S.R. became open to cooperation with foreign colleagues. As a result, dozens of new international research projects in different fields have started recently in Moscow, St Petersburg, Novosibirsk, Odessa and other places. In spite of the disappointment of the people of the post-Soviet republics, the scientific tradition and intellectual potential of scientists still remain quite strong and there is cause for optimism. Aerosol science may turn out to be a good area for international cooperation.

HISTORY OF DEVELOPMENT AND MAIN ACHIEVEMENTS OF AEROSOL SCIENCE IN THE FORMER U.S.S.R.

The establishment of a new scientific branch (1930s–1950s)

At the end of 1920s, when combustion physics, chemical kinetics, and atmospheric research in the Soviet Union was developing, it became obvious that progress of these fields would be impossible without a comprehensive study of the physical and chemical processes in disperse systems (i.e. aerosols and suspensions). At that point, the world scientific community had not yet worked out the concept of how to develop aerosol science (except for a few theoretical results which were obtained during the first two decades of this century in Europe). As with any new field of research, aerosol science required significant investments. During the entire history of the U.S.S.R., the military industry served as the main source of financing for new scientific projects. For this reason, the first three government aerosol-related scientific programs were supported mainly by the Soviet Ministry of Defence. The program titles, corresponding fields of application, and time periods when research was conducted were as follows:

• atmospheric aerosol and nucleation, supported by the military aircraft industry, 1929–1934;
• distribution of toxic aerosols at the ambient atmosphere, aerosol filtration, and effect of aerosols on human health, supported by the military chemical industry, 1931–1936; and
• chemical kinetics and combustion of aerodisperse systems in power apparatus and machines, supported by the military and heavy industry, 1931–1936.

The first fundamental investigations were carried out mostly in the Karpov Institute of Physical Chemistry, in fruitful collaboration with some other laboratories in Moscow. They were devoted to the following problems:

• methods of measuring the size and charge of fine aerosol particles, the theory of evaporation and droplet condensation growth in the atmosphere; the theory of coagulation (N. A. Fuchs);
• the theory of particle collision and "particle–surface" interaction (B. V. Derjagin); and
• the theory of aerosol penetration through organic fibers and the creation of new filter materials, recognized now as "Petryanov's Filters", FP (I. V. Petryanov-Sokolov and N. D. Rosenblum).

At the same time, during the 1930s and early 1940s, significant progress was achieved in the study of heat and mass transfer in aerosols under high temperature conditions. The important elements which characterize evaporation, the combustion of particles in the air, and physical processes in chemically-active disperse systems were found theoretically and experimentally by Y. B. Zeldovich, N. N. Semyeonov, and their colleagues in top secret research institutes of the Academy of Sciences. The results of these fundamental pioneering investigations were not widely published for a long time because of their military applications. As a result, they unfortunately did not become immediately available to the world scientific community.

The period of 1937–1953, notoriously known as the "Stalin persecution period", affected all branches of Soviet science. Many researchers were executed in Siberian concentration camps. This time was very difficult for Professor N. A. Fuchs and his family because he was imprisoned for 10 years and, after that, was not permitted to work in the Karpov Institute until 1959.

It is necessary to emphasize that during the 1930–1940s (i.e. at the beginning of aerosol research history in the U.S.S.R.), aerosol projects were not spread all over the country, but were concentrated geographically, mainly in Moscow and the Moscow area, namely at:

• Karpov Institute of Physical Chemistry (fundamental research on aerosol generation, particle measurements, air filtration and aerosol separation);
• Institute of Physical Chemistry of the Academy of Sciences (evaporation and condensation, particle collision and particles' surface effects);
• Institute of Chemical Physics (heat and mass transfer in aerosol systems with chemical reactions on the particle surface and in the gas volume, combustion in aerosols and suspensions);
• Mendeleyev Institute of Chemical Technology (aerosol generation, particle evaporation accompanied by low- and high-temperature chemical reactions); and

• Research Institute of Labor Hygiene and Occupational Diseases (aerosol measurement and analysis of respirable aerosol fractions, air pollution control and protection, health effects).

This geographical centralization of aerosol research reflected the so-called tendency of "Moscow monopoly" which was typical at that time for other fields as well. However, after World War II and especially in the 1950s, the geography of aerosol research in the Soviet Union significantly expanded and included a number of institutions from the rest of the country. Several of them which carried out applied research are listed as follows:

• Main Geophysical Observatory in Leningrad, Russia (the first aerosol project on atmospheric aerosols and nucleation was initiated in 1952; the long-term project on optical properties started in the middle of the 1950s in collaboration with Leningrad University);
• Institute of Technical Heat Physics in Kiev, Ukraine (heat and mass transfer in turbulent, highly-concentrated aerosol flows and aerosol transport have been traditional topics since the institute was established); and
• Lykov Institute of Heat and Mass Transfer in Minsk, Byelorussia (aerosols and suspensions at high temperature and high pressure have been their major interests since 1950; the first big project on the development of power and technological equipment with disperse components was started in 1953).

By the end of the 1950s a lot of important experimental and theoretical data had been obtained and the basic regularities of the mechanics and fluid dynamics of aerosol systems were determined. The Soviet scientists of that period were considered by many to be well ahead of their foreign colleagues in many aspects of aerosol science, for example:

• aerosol filtration: theory and application (I. V. Petryanov-Sokolov);
• the motion of aerosol particles in the field with external forces of differing natures, particle deposition on obstacles and aerosol sampling (N. A. Fuchs and L. M. Levin);
• aerosol nucleation and condensation in clouds: physical and chemical theory (N. A. Fuchs, I. V. Petryanov-Sokolov, V. A. Fedoseyev and N. Shishkin);
• aerosol coagulation and particle agglomeration (B. V. Derjagin, P. Prokhorov, L. F. Leonov, N. Shishkin and A. D. Zimon);
• Brownian motion and diffusion of particles in gas flows, turbulent characteristics of disperse flows (A. Kolmogorov, M. Leontovitsch and G. I. Barenblat);
• combustion of suspended fuels with active chemical reaction on the particle surface (Y. B. Zeldovich); and
• optical properties of submicron aerosols (K. Shifrin).

Many general concepts were formulated by Professor N. A. Fuchs in his seminal book, *The Mechanics of Aerosols*. The first edition appeared in Russia in 1955. Later, this book was published many more times in different languages. Thus, by the end of the 1950s aerosol research in the U.S.S.R. was shaped into a science with relatively complete sets of concepts and methods of investigation.

Development of new research centers (1960s–1970s)

The further development of aerosol science in the former Soviet Union was closely connected with the creation of new research groups and laboratories in different regions of the country. In the 1960s and 1970s, several laboratories were developed in Odessa (Ukraine), Obninsk, Novosibirsk and Sverdlovsk—now Ekaterinburg (Russia), Tartu and Tallinn (Estonia), and other regions.

Extensive theoretical and experimental aerosol research was started in Odessa at the beginning of the 1960s. Odessa State University and Odessa Technological Institute had already made certain achievements in aerosol generation and the measurement of particle characteristics, as well as in the study of heat and mass transfer of aerosols and suspensions.

In 1961, the Laboratory of Aerodisperse Systems was started by Professor V. A. Fedoseyev at the Physics Department of the University of Odessa (Odessa State University). Later, it became one of the biggest and best-recognized aerosol laboratories in the entire country. Professor Fedoseyev and his colleagues conducted a nationwide research program on "Evaporation and Combustion of Aerosols" which was supported directly by the State Committee of Science and Technology. Significant contributions were made to the theory of combustion of disperse systems as well as on the evaporation and condensation of solution droplets (V. A. Fedoseyev, D. I. Polishchuk, V. V. Kalinchak, A. N. Zolotko, N. Glushkov and others). Some new methods and techniques of monodisperse particle generation were developed (S. M. Kontush and K. V. Romanov). Thermodiffusiophoretic effects in aerosols were also extensively studied (G. N. Lipatov). The successful activity of this laboratory attracted the attention of leading research centers throughout the country. This determined the choice of Odessa as the place for regular nationwide conferences such as "Contemporary Problems of Aerodisperse Systems". Indeed, since the end of the 1960s, Odessa has accommodated the participants of all 15 aerosol conferences. The Laboratory of Aerodisperse Systems, like only a few other research centers in the former U.S.S.R., enjoyed the right to compile an annual All-Union journal of selected papers in aerosol science (*Fizika Aerodispersnih System*).

At approximately the same time, an extensive study on aerosol transport and heat exchange in suspensions was started by Professor Z. R. Gorbis at the Odessa Technological Institute of Food Industry and, later, at the Odessa Institute of Refrigeration Industry. In the 1970s, he organized the Department of Heat and Mass Transfer, where he gathered a good team of researchers with diverse experiences and backgrounds in physics and engineering. The primary interest of this team was focused on theoretical and experimental investigations of turbulent gas flows with suspended solid particles. He was the first to consider disperse flows (at particle concentrations ranging from diluted to highly-concentrated fluidized systems) as a separate field with specific regularities. He analyzed all of the dynamic characteristics of particles moving in a gas flow. A number of important results obtained by Z. R. Gorbis and his colleagues have been applied in power engineering, the powder industry, chemical technology, and other fields. Professor Gorbis, being a highly educated and energetic scientist, prepared many graduate and post-graduate students, and his department soon won deserved recognition throughout the scientific community. Unfortunately, since 1980 (when Professor Gorbis left Odessa) the activity of this department has become less extensive. Later, Z. R. Gorbis moved to the U.S. and now continues his research at the University of California at Los Angeles. To summarize and analyze a great number of results obtained on heat and mass transfer in turbulent aerosol flows, Professor Gorbis (together with F. E. Spokoyny) prepared a new monograph "Heat and Momentum Transfer in Turbulent Gas Flows with Suspended Solid Particles" which will be published at the end of this year.

In the early 1960s, a new center on meteorological research was established in Obninsk (an academically-oriented town near Moscow), which soon became one of the most well-known town/campuses in the U.S.S.R. The extensive study of atmospheric aerosols was started there by two laboratories of the Institute of Experimental Meteorology. During a relatively short period in the 1960s and 1970s, a wealth of fundamental results was obtained on coagulation and condensation (Y. S. Sedunov and V. M. Voloshchuk), aerosol fluid dynamics (L. M. Levin and V. M. Voloshchuk) and other fields of prior importance in aerosol science. Several comprehensive monographs, which were published by these scientists in the 1970s became classics for a whole generation of aerosol researchers in the Soviet Union. The most significant contribution was made to the theory of aerosol sampling (S. P. Belyaev, L. M. Levin and V. M. Voloshchuk). New methods and techniques for measurement of particle size and charge were developed for application in the field (V. V. Smirnov and others). The first high-volume aerosol chamber was built at the Institute of Experimental Meteorology for the comprehensive study of ice crystal nucleation and particle growth in supersaturated atmospheres. However, more than 50% of aerosol research projects of the Institute were connected to top secret military projects. Among these were the active seeding of fog and clouds, artificial precipitation, maintenance of radioactive aerosols in the atmosphere, large-scale aerosol transport, and other applications which, in the early 1970s, were known in the West as "meteorological war". Therefore, the exchange of scientific information between the Institute of Experimental Meteorology and other aerosol research centers was not very effective because many researchers of this institute were not allowed to present their original data at regular open conferences or publish them in widely-read Soviet or international journals at that time.

The period of the 1960–1970s is known in the former Soviet Union as the time of the fast and effective development of the Siberian Branch of the Academy of Sciences. Two prominent research centers, the Institute of Chemical Kinetics and Combustion (ICKC) and the Institute of Heat Physics (IHP), were organized in Novosibirsk during this period.

As a result of ICKC activity, very significant progress was achieved in the 1970s in the following directions: fine particle generation and measurement by diffusion batteries, chemical and morphological analysis of submicron airborne particles, and homogeneous and heterogeneous condensation in high-concentrated aerosol systems. The long-term government project known as "Pesticides" was accomplished by the ICKC aerosol research group in collaboration with the University of Novosibirsk. Within the framework of this project, high-volume aerosol generators were developed and applied to an agriculture business for field soil enrichment. At that time, the Soviet political leaders attached extreme importance to the Agriculture Program and, therefore, this project was the prime focus of aerosol research in the Soviet Union during several years. The results and application of the project were highly appreciated, and the principal investigator, Professor K. P. Kutsenogiy, was given the State Award, one of the highest awards in the former U.S.S.R. However, later it turned out that the so-called "pesticide attacks" improved the soil quality but, at the same time, caused serious illnesses among farmers because the health effects of pesticides had not been evaluated at that time. This fact motivated the Academy of Sciences to pay more attention to aerosol research in occupational hygiene and medicine as well as ecological research which had never previously been of the significant national interest. As a matter of fact, the first aerosol research group in the Siberian Branch of the Academy of Sciences dedicated to the study and solution of environmental and health problems was started at ICKC with the help of K. P. Kutsenogiy.

The research of IHP resulted in important contributions to the theory of particle migration in turbulent multiphase flows and the model of heat exchange in fluidized flows, among others. Applications were developed for highly-concentrated aerosol systems in recuperators and regenerators, nuclear power stations and chemical technology.

In the mid-1970s, aerosol science "came" to Ural State University in Sverdlovsk—now Ekaterinburg, the biggest center for research and education in the Ural region of Russia. Two departments, Mathematical Physics (Y. A. Buyevich) and Molecular Physics (P. E. Suetin, S. A. Beresnyev and V. G. Chernyak), started the theoretical investigation on aerosol mechanics and mass transfer in suspensions. The extensive study of phoretic effects (which later became a traditional topic of the aerosol laboratory at Ural State University) also began at this time.

In the 1970s, several aerosol projects began in Estonia. The atmosphere there of research work and idea exchange was much more calm and liberal than in Russian or Ukrainian institutions. A comparatively small—but very productive—research group was created by H. Tammet at the University of Tartu (one of the oldest and most famous universities in Northern Europe). This group was focused on the experimental study of electrical and optical properties of atmospheric aerosols as well as the development of methods and instruments for atmospheric measurements. The extensive applied investigations of heat and mass transfer in flows with suspended particles were carried out in another Estonian research center—the Institute of Heat Physics (Thermophysics) and Electrical Physics in Tallinn.

In the 1960s and 1970s, new aerosol research laboratories were also started in several different universities. For instance, in Kiev, the capital of Ukraine, the Laboratory of Physics of Aerodisperse Systems was organized by Professor Y. I. Shimanski and developed by V. M. Nuzhnyj at the Department of Molecular Physics, Kiev State University. Due to effective collaboration with the Karpov Institute (Moscow), the University of Odessa (Ukraine) and some other institutions, this laboratory became recognized as one of the centers for homogeneous and heterogeneous nucleation study. The same problem was worked out in a new laboratory, started in Kalinin—now Tvyer (Russia) when the University and Polytechnical Institute there joined forces to study thermodynamics in aerosol systems. At approximately the same time, the Academy of Sciences and State Committee of Science and Technology provided financial support for aerosol research and development in different regions:

- Tbilissi, the capital of Georgia (Institute of Geophysics: meteorological applications);
- Vilnius, the capital of Lithuania (Institute of Physics: characteristics of radioactive aerosols, aerosol measurement);
- Karaganda, Kazakhstan (Kazakh Academy of Sciences: combustion in aerosols and suspensions, applications in occupational hygiene); and
- Kemerovo, Russia (Institute of Coal: instruments for atmospheric aerosol measurement, homogeneous nucleation, condensation in near-ground atmospheres).

Side-by-side with the creation of new laboratories for aerosol research in different regions throughout the country, the period between 1960 and 1980 was characterized by the successful development of basic and applied investigations in traditional aerosol research centers in Moscow. Two of them held leading roles in the country: the Karpov Institute of Physical Chemistry and the Institute of Physical Chemistry at the Academy of Sciences.

Since 1959, when Professor N. A. Fuchs was again permitted to work in the Karpov Institute after a long break, significant progress has been achieved there in the Laboratory of Physics of Aerodisperse Systems. For instance, the formation of condensation aerosols has been studied theoretically and experimentally, the process of deposition of highly-dispersed aerosol particles was quantified, the coagulation efficiency of particles in free molecular regime was measured, the original technique of dust dispersion determination was worked out and the theory of aerosol filtration was significantly modified. At that time, many talented scientists joined forces under the leadership of N. A. Fuchs in his laboratory. One of them, Alexander Sutugin (who became a leading Soviet aerosol scientist in the 1980s) joined the laboratory in 1964 as a young researcher. His first papers, published in co-authorship with N. A. Fuchs a few years later, attracted the attention of many researchers. In the 1960s, he contributed greatly in such fundamentals of aerosol science as properties of highly-disperse particles, kinetics of aerosol coagulation and the development of multichannel diffusion batteries. His experimental study of the penetration of highly-disperse particles through a diffusion battery gave an opportunity to measure the coagulation efficiencies at the free molecular regime and to quantify the effect of van der Waals forces on coagulation kinetics. Later, in the 1970s, his major interests focused upon diverse topics (e.g. transformation processes in aerosols, theoretical and experimental study of the homogeneous nucleation, optical properties of aerosols, and transport and transformation of atmospheric aerosols). This research gave Alexander Sutugin recognition in the U.S.S.R. and in other countries. Professor Sutugin had a wonderful combination of skills both in experimental research and theoretical studies. Together with Professor A. A. Lushnikov (presently, one of the major Russian experts in aerosol science) and Dr L. Stulov, he developed the diffusion chamber and then discovered and explained the phenomenon of homogeneous nucleation at low supersaturation. In 1974 A. G. Sutugin became a Chief of a newly-organized and extremely productive aerosol laboratory in the Karpov Institute, which was known as the Laboratory of Aerocolloids Dynamics. Since the end of the 1970s, this laboratory began to play an important role in the coordination of aerosol research in the U.S.S.R.

Another well-recognized center of aerosol research in Moscow was being continuously developed by Professor B. V. Derjagin in the Department of Surfactant Phenomena, Institute of Physical Chemistry of Academy of Sciences. The pioneering investigations in such fields as physical and chemical properties of aerosol systems with surfactant substances, thermodiffusiophoresis, evaporation and condensation in aerosols accompanied by chemical reactions and many others have been carried out by Professor Derjagin and his colleagues (L. F. Leonov, P. Prokhorov, Y. I. Yalamov, S. P. Bakanov, D. V. Fedoseyev, etc.). A number of presently well-known Russian aerosol scientists, such as Professor Y. I. Yalamov (Krupskaya Pedagogical Higher School, Moscow), started their careers in the Institute of Physical Chemistry in the 1960s and 1970s and, later on, organized their own aerosol laboratories. Professor Derjagin, holding the position for many years of Editor-in-Chief for the scientific journal "Kolloidniy Zhurnal" (*Journal of Colloid Science*), contributed to focusing this journal on aerosol research and helped it gain respectability in the scientific establishment.

The development of new aerosol instruments and techniques has resulted in the necessity of their standardization. A special Committee chaired by a representative of the Academy of Sciences, Dr I. V. Petryanov, was responsible for aerosol standards. To accomplish this project, the Aerosol Laboratory was set up in the All-Union Research Institute of Physical, Technical and Radiotechnical Measurements. The founder and the first head of this laboratory was Dr L. S. Ruzer (who now lives in Berkeley, California, working for Lawrence Berkeley Laboratory). Dr Ruzer and his colleagues developed equipment and new methods for aerosol generation and measurement which became a reference and, therefore, gave an opportunity to evaluate all other aerosol instruments commercially available in the U.S.S.R. The newly-developed aerosol standard served in reproducing and preserving the unit of concentration of artificial and natural radioactive and non-radioactive aerosols ranging from cluster size to 200 μm-particles. Leading Soviet experts in the field of aerosol research and radiation dosimetry participated in this project. Finally, after 10 years work, the U.S.S.R. State Committee on Standards approved a special state standard for aerosols. The development of new methods and apparatus for standardization, as well as the original contribution of Dr Ruzer's laboratory to occupational hygiene and study of radioactive aerosols, raised a high level of interest in the scientific community. Even though foreigners had but limited access to the Institute's achievements, the Aerosol Laboratory was frequently visited by delegations from other countries. Of particular importance was the visit of a delegation from the U.S. National Bureau of Standards in 1972 during President Nixon's official visit to Moscow.

An extensive theoretical study of atmospheric aerosols and nucleation was conducted in the 1970s at the Institute of Applied Geophysics, Institute of Atmospheric Physics, Central Aerological Observatory, Theoretical Problem Department of the Academy of Sciences and some other institutions in Moscow and the Moscow area. At that time, such scientists as E. L. Alexandrov, I. P. Mazin and V. I. Smirnov published the most important data that they had obtained for the phase transfer of hygroscopic solution droplets, ice crystal nucleation and cloud–aerosol interaction in the atmosphere. The first results were published on the physics of clusters (extremely small particles containing several to several hundreds atoms). Professor Y. I. Petrov started this innovative study in the 1970s in Moscow.

At the beginning of the 1970s two new fields of application were found for the aerosol science: the nuclear industry and the microelectronics industry. The requirements of the gas, cleaned of aerosol particles, became much more rigid. Several challenging projects on super-effective filtration of submicron aerosols were conducted at that time in the Karpov Institute and Kurchatov Institute of Atomic Energy (A. A. Kirsh and I. B. Stechkina).

The wide spread of aerosol research in the former U.S.S.R. during the 1960s and 1970s created an efficient consortium of research institutes and universities in various areas of aerosol science and its diverse applications. The special Council that was organized at the State Committee of Science and Technology coordinated the strategy of research in this field.

Recent and current situations (1980–1991)

The formation and development of numerous scientific fields during the past decade as well as the extensive study in traditional fields gave a new positive impulse to the aerosol research in the former U.S.S.R. A multitude of innovative results were obtained in many directions. For example:

• kinetics of aerosol transformation (A. A. Lushnikov and V. A. Zagainov, Karpov Institute; B. Z. Gorbunov, Institute of Chemical Kinetics and Combustion, Novosibirsk; V. M. Voloshchuk, A. S. Stepanov and V. M. Merkulovich, Institute of Experimental Meteorology, Obninsk; M. P. Anisimov, Institute of Coal, Kemerovo; V. M. Nuzhnjy, Kiev State University, Kiev; V. Y. Smorodin, Lomonosov State University, Moscow; V. V. Ryazanov, Institute of Nuclear Research in Kiev, and others);
• phoretic effects in aerosols (G. N. Lipatov, E. A. Chernova and A. S. Skaptsov, Odessa State University, Odessa; Y. I. Yalamov and E. R. Shchukin, Krupskaya Pedagogical Higher School; S. A. Beresnyev and V. G. Chernyak, Ural State University in Sverdlovsk—now Ekaterinburg); and
• optical properties of smogs (A. G. Sutugin, Karpov Institute; L. M. Ivlev, Leningrad University in Leningrad—now St Petersburg, and others).

In the mid-1980s, extensive investigations were also carried out into the modeling of small-scale aerosol transport in the near-ground atmosphere. A number of institutions contributed to the solution to this problem: Institute of Atmospheric Physics in Moscow, Main Geophysical Observatory in St Petersburg, Central Aerological Observatory in Dolgoprudny (the Moscow area), Institute of Experimental Meteorology in Obninsk, Tartu University (Estonia). In addition, special attention was given to generation and measurement techniques for aerosols with different chemical components under atmospheric conditions (S. E. Paschenko and B. Z. Gorbunov, Institute of Chemical Kinetics and Combustion, Novosibirsk), as well as aerosol sampling and transport (S. A. Grinshpun and G. N. Lipatov, Odessa State University, Odessa). Extensive efforts were made to develop new commercial aerosol measurement devices (Professor Turubarov, Institute of Aircraft Instrumentation, St Petersburg; Professor Petrov, All-Union Research Institute of Physical, Technical and Radiotechnical Measurements, Mendeleyevo, the Moscow area; Dr Girgzdys, Lithuanian Academy of Sciences, and others). Several aerosol research centers in Moscow, St Petersburg and Kiev also became actively involved in international cooperation on occupational hygiene and health effects.

Figure 3 (a–i) presents the leading institutions which at that time coordinated aerosol-related research and its applications in such fields as air pollution control, meteorology, powder technology, etc. Several of these institutes (see Table 1) offered a high-level training for aerosol researchers.

The picture of the development of basic aerosol research in the period of 1965–1989 is shown in Fig. 4. As seen from these diagrams, the relative contribution made by the universities increased significantly during those 15 years.

The diversity of scientific journals that published papers in aerosol science and technology (see Table 2) as well as a number of aerosol conferences, regularly held in the U.S.S.R. (Table 3), illustrates the structure of information circulation and exchange which existed in the U.S.S.R. in the 1980s.

A number of previously-secret nuclear projects in aerosol applications were published in regular Soviet and international scientific journals during the second half of the 1980s, especially after the notorious Chernobyl accident. One of these projects has been carried out by Professor O. A. Volkovitsky and his colleagues at the Institute of Experimental Meteorology in Obninsk. The behavior of aerosol components has been studied through the simulation of accidents in nuclear power stations accompanied by seal failure in high-pressure circuits. A high-volume aerosol chamber (about 3000 m^3) has been developed and used for this purpose. The project has been part of an extensive research program supported by Soviet Government that aimed at the safety of nuclear power installations (a similar program, "DEMONA", was being developed at the same time in Western Europe).

Another top secret governmental program, started in the 1980s, related to the theoretical simulation of consequences of a nuclear war. This was termed a "nuclear winter" (the Program "Consequences" supervised by E. P. Velikhov, Vice-President of Soviet Academy

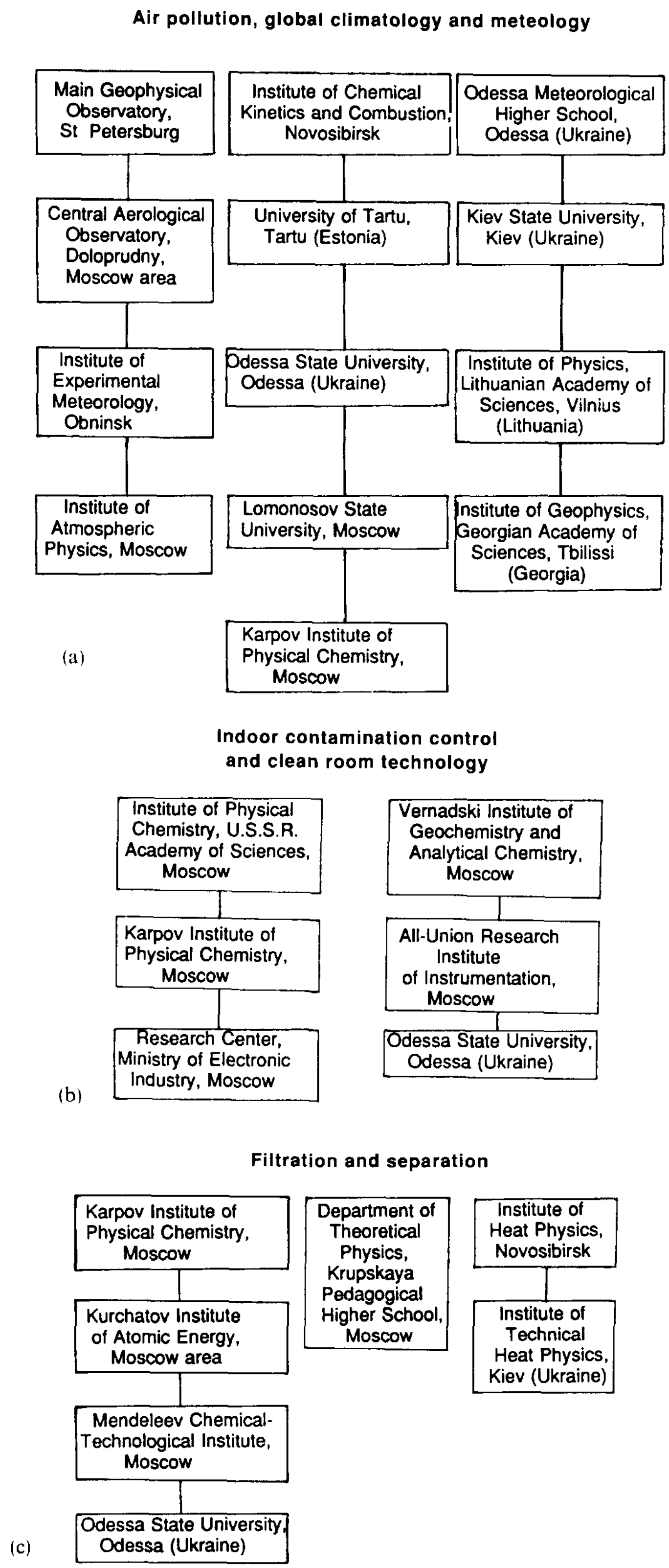

Fig. 3. Soviet institutions which coordinated the aerosol related research in:

a—air pollution, global climatology and meteorology; b—contamination control and clean room technology; c—filtration and separation; d—powder technology; e—atomization and spray technology; f—power installations, combustion and chemical processes; g—space research; h—agriculture; i—medicine, occupational hygiene.

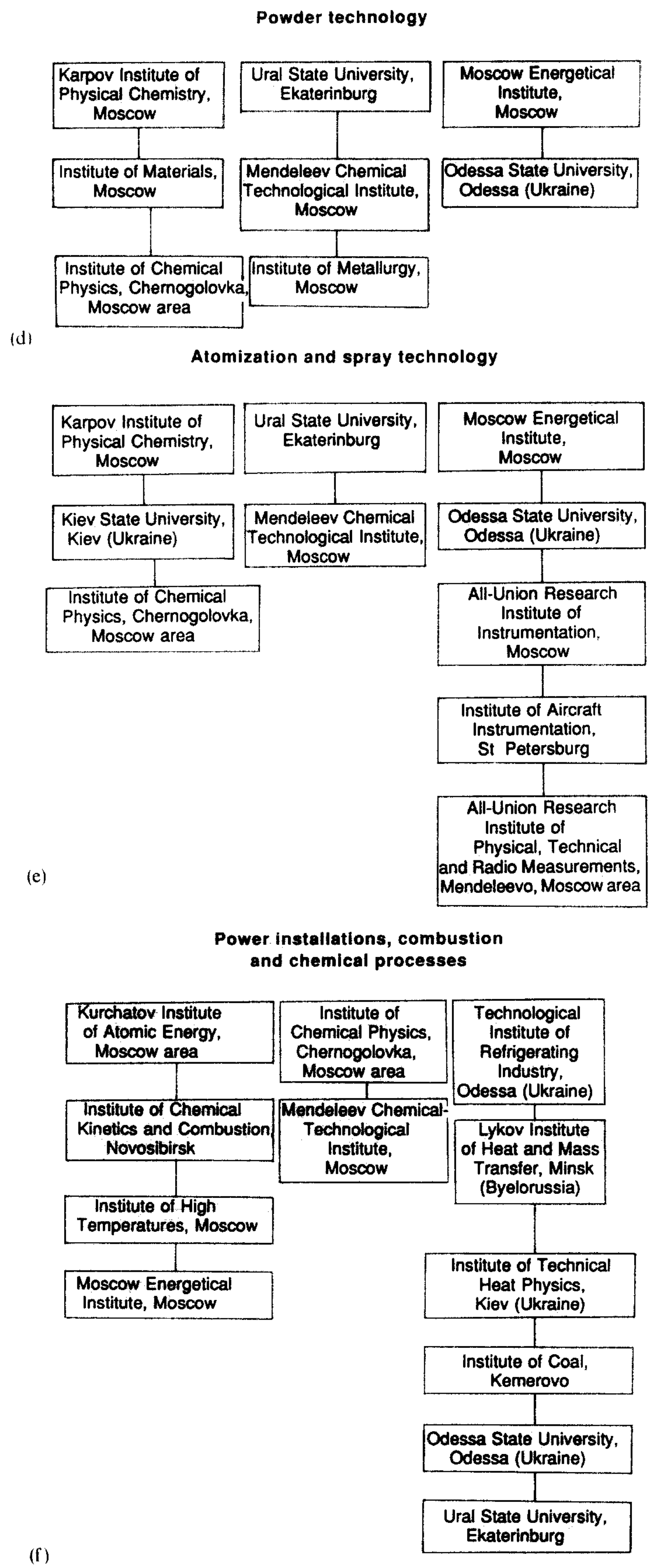
Powder technology
Karpov Institute of Physical Chemistry, Moscow
Ural State University, Ekaterinburg
Moscow Energetical Institute, Moscow
Institute of Materials, Moscow
Mendeleev Chemical Technological Institute, Moscow
Odessa State University, Odessa (Ukraine)
Institute of Chemical Physics, Chernogolovka, Moscow area
Institute of Metallurgy, Moscow
(d)
Atomization and spray technology
Karpov Institute of Physical Chemistry, Moscow
Ural State University, Ekaterinburg
Moscow Energetical Institute, Moscow
Kiev State University, Kiev (Ukraine)
Mendeleev Chemical Technological Institute, Moscow
Odessa State University, Odessa (Ukraine)
Institute of Chemical Physics, Chernogolovka, Moscow area
All-Union Research Institute of Instrumentation, Moscow
Institute of Aircraft Instrumentation, St Petersburg
All-Union Research Institute of Physical, Technical and Radio Measurements, Mendeleevo, Moscow area
(e)
Power installations, combustion and chemical processes
Kurchatov Institute of Atomic Energy, Moscow area
Institute of Chemical Physics, Chernogolovka, Moscow area
Technological Institute of Refrigerating Industry, Odessa (Ukraine)
Institute of Chemical Kinetics and Combustion Novosibirsk
Mendeleev Chemical-Technological Institute, Moscow
Lykov Institute of Heat and Mass Transfer, Minsk (Byelorussia)
Institute of High Temperatures, Moscow
Moscow Energetical Institute, Moscow
Institute of Technical Heat Physics, Kiev (Ukraine)
Institute of Coal, Kemerovo
Odessa State University, Odessa (Ukraine)
Ural State University, Ekaterinburg
(f)

Fig. 3. (*Contd.*).

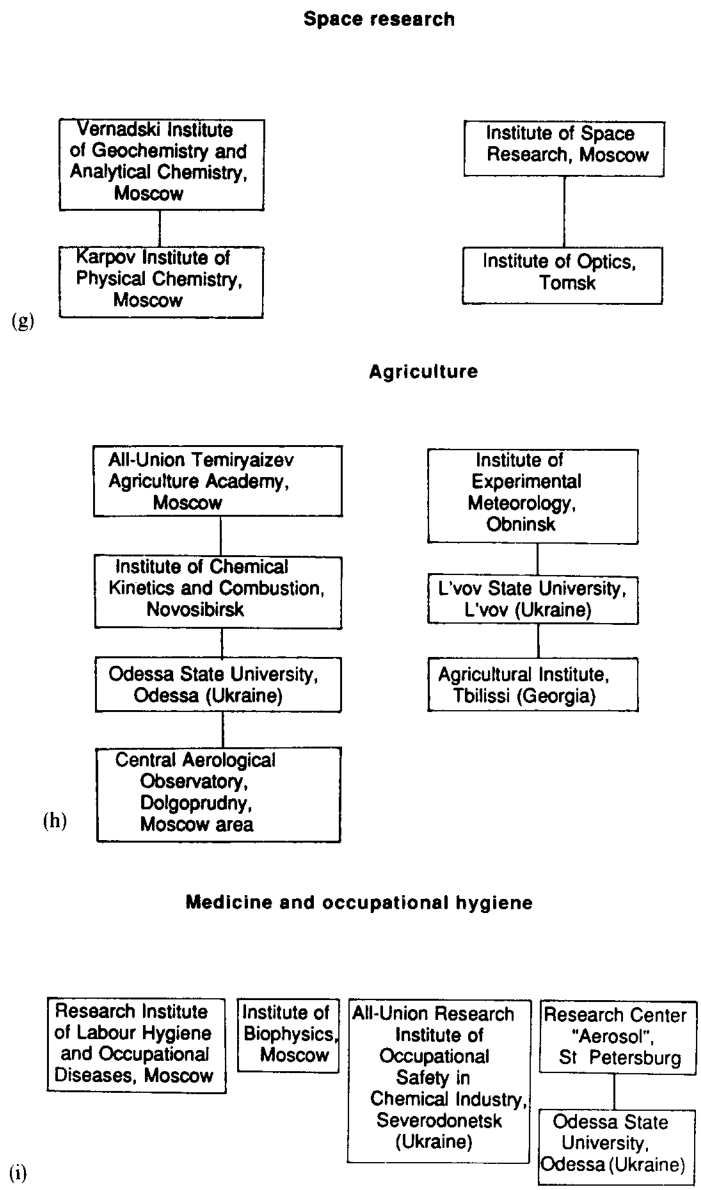

Fig. 3. (*Contd.*).

of Sciences and V. Moiseyev, Academy Presidium Member). Aerosol problems were of major importance within this program. The aerosol transformation in radioactive environment, atmospheric particle transport and global climatology under the nuclear winter conditions have been extensively studied by Professor Sutugin and his colleagues in 1982–1988. The results of the "nuclear winter" studies, obtained in the Soviet Union as well as in some other countries, played an important role in the formation of new political thinking and new conception of a world global security. The Program "Consequences" helped in the understanding of the idea that there cannot be a winner in a global nuclear war.

In the mid-1980s, an entirely new and revolutionary field of aerosol research was initiated by Professor A. G. Sutugin in the Karpov Institute. He started the study of "cosmosols"—particles suspended in a vacuum. Such new ideas, developed by Soviet scientists, attracted the attention of the State Committee for Space Research. Some first experimental data on the properties and dynamics of cosmosols were obtained within the framework of the Soviet

Table 1. Main centers for comprehensive research in aerosol science and technology in the former U.S.S.R

Institution	City and Republic	Year established
Karpov Institute of Physical Chemistry	Moscow, Russia	1934
Institute of Physical Chemistry (U.S.S.R. Academy of Sciences)	Moscow, Russia	1929
Odessa State University	Odessa, Ukraine	1961
Kiev State University	Kiev, Ukraine	1965
Institute of Chemical Kinetics and Combustion (Siberian Academy of Sciences)	Novosibirsk, Russia	1970
Institute of Experimental Meteorology	Obninsk, Russia	1965

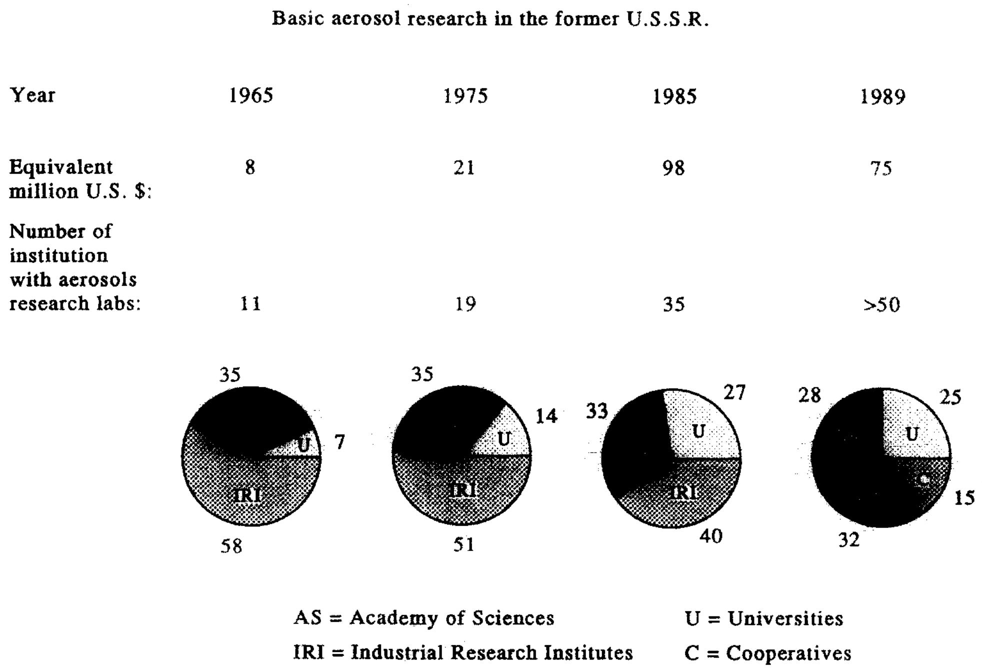

Fig. 4. Basic aerosol research in the former U.S.S.R. (1965–1989): equivalent budget and relative contributions.

and French joint space program "Venus". With his awareness of the complex character of aerosol particle behavior in the space, Professor Sutugin encouraged several Soviet science foundations to increase the financial support for the related aerosol research. These include sampling and analysis of low-concentrated aerosols, aerosol transformation under high-pressure and high-temperature conditions, measurement of optical properties of unknown nature, and physics of clusters. Alexander Sutugin was an outstanding personality and a talented scientist. Even in the 1980s, as a "big shot" in Soviet aerosol science, he managed to stay a non-bureaucratic type of an administrator, and disliked many other "apparatchiks" who administrated the scientific structure in the former Soviet Union. He applied all his experience, creativity and influence to make aerosol research in his country stronger. His dream was to create a National Aerosol Association in the U.S.S.R. Sadly, a tragic accident interrupted his life and work in 1988.

By the end of the 1980s, the idea of establishing the Soviet Association for Aerosol Research attracted many leading scientists from different republics—Russia, Ukraine, Byelorussia, Georgia, and Lithuania, among others. Dr G. N. Lipatov of Odessa University (Ukraine) became Sutugin's successor in the development of the National Association. As a very enthusiastic scientist and well-known within the country and abroad, G. N. Lipatov spent a good deal of his energy uniting the diverse number of large research centers that

Table 2. Main scientific journals in the field of aerosol science and applications

Title	Publisher	Issues per year
Physics of Aerodisperse Systems (Fizika Aerodispersnih Sistem)	"Vischa Shkola", Odessa–Kiev	2
Journal of Colloid Science (Kolloidniy Zhurnal)	Academy of Sciences, Moscow	6
Meteorology and Hydrology (Meteorologia i Gidrologia)	State Committee of Meteorology, Moscow	12
Engineering-in-Physics Journal (Inzhenerno-Fizicheskiy Zhurnal)	State Committee of Science and Technology, Byelorussian Academy of Sciences, Minsk	12
Proc. of Academy of Sciences: Physics of Atmosphere and Ocean (Fizika Atmosferi i Okeana)	Academy of Sciences, Moscow	12
Proc. of the Institute of Experimental Meteorology (Trudi Instituta Eksperimentalnoy Meteorologii)	IEM, Obninsk	2
Problems of Control and Protection of Atmosphere Against Pollution (Problemi Controlya i Zashchiti Atmosferi ot Zagryazneniy)	Ukrainian Academy of Sciences, Kiev	2
Heat Physics of High Temperatures (Teplofizika Visokih Temperatur)	Academy of Sciences, Moscow	12
Proc. of Siberian Branch of Academy of Sciences: Technical Sciences (Izvestiya Sibirskoy Akademii Nauk: Tehnicheskiye Nauki)	Academy of Sciences, Novosibirsk	6

Table 3. Main regular All-Union meetings on aerosol science and practice

Conference Title	Years	Place
Contemporary Problems of Physics of Aerodisperse Systems (1^{st}–15^{th})	1961–1989	Odessa University Odessa, Ukraine
Aerosols and Their Occupational Applications	1978–1987	Yerevan, Armenia; Karaganda, Kazakhstan; Yurmala, Latvia; etc.
Annual Meeting of All-Union Academy Council "Colloid Chemistry: Physical and Chemical Mechanics"	1975–1991	Karpov Institute Moscow, Russia

focused their interest in aerosol studies, as well as scattered aerosol groups into a nationwide association. The Laboratory of Aerodisperse Systems in the University of Odessa, one of the largest in the country, seemed to be the best choice for the Central Office of this Association. Such well-recognized aerosol scientists from Western Europe as Dr W. Kreyling of the GSF-Institute for Radiation and Environmental Research, Neuherberg, Dr W. Holländer of the Fraunhofer Institute of Toxicology and Aerosol Research, Hannover, and Professor R. Jaenicke of the University of Mainz, visited Odessa in 1989 to share the European experience of establishing and managing the Gesellschaft für Aerosolforschung (GAeF) and some other national associations for aerosol research. Finally, the Soviet Association for Aerosol Research was established in September 1989 at the 15th National Conference on Contemporary Problems of Physics of Aerodisperse Systems, held in the University of Odessa. At the first orientation meeting, Dr Lipatov, was elected Secretary General of the Association. He proposed new principles of a scientific union, as alternatives to the bureaucratic model that was common within the structure of the Soviet Academy of Sciences. Among these new goals, the major ones were to avoid the pressure of bureaucratic centers (which held a tight control over all the scientific activities) and to fairly distribute all the finances, benefits and technical supplies on the basis of open competition of research proposals.

The general political and economical concepts that prevailed at the end of the 1980s in the country turned out to be a proper basis for the development of these ideas. In addition

Table 4. Address list of selected organizations

Organization	Address and telephone numbers	Person to contact
	Russia	
Karpov Institute of Physical Chemistry	10 Obukha St., Moscow, 103064, Russia (095) 227-0014 ext. 2196 (095) 227-3186	Dr A. A. Lushnikov
Institute of Physical Chemistry (Russian Academy of Sciences)	31 Lenin Prospect, Moscow, 117915, Russia	Dr B. V. Derjagin
Krupskaya Pedagogical Higher School, Department of Theoretical & Molecular Physics	9 Radio St., Moscow, Russia (095) 261-5927	Dr Y. I. Yalamov
Moscow Chemical-Technological Institute by Mendeleev	9 Miusskaia Sq., Moscow, 125820, Russia	Dr A. N. Kabanov
Department of Theoretical Problems (Russian Academy of Sciences)	12 Vesnina St., Moscow, 121002, Russia	Dr V. I. Smirnov
Central Aerological Observatory	3 Pervomayskaya St., Dolgoprudny, Moscow area, 141700, Russia (095) 408-6058	Dr I. P. Mazin
Institute of Experimental Meteorology	82 Lenin Prospect, Obninsk, 249020, Russia (095) 546-3995	Dr V. M. Voloshchuk, Dr V. V. Smirnov, Dr A. S. Stepanov
Institute of Chemical Kinetics and Combustion	3 Institutskaya St., Novosibirsk, 630090 Russia	Dr B. Z. Gorbunov, Dr K. P. Kutsenogiy, Dr S. E. Paschenko
Institute of Coal	21 Rukavishnikova St., Kemerovo, 650099, Russia	Dr M. P. Anisimov
Ural State University	51 Lenin St., Ekaterinburg, 620083, Russia (3432) 22-8320 or 55-7541	Dr S. A. Beresnyev, Dr V. G. Chernyak, Dr Y. A. Buyevich
	Other Republics	
Odessa State University, Laboratory of Aerodisperse systems	2 Petra Velikogo St., Odessa, 270000, Ukraine (0482) 63-9787 or 23-1203	Dr G. N. Lipatov, Dr S. M. Kontush
Kiev State University, Department of Molecular Physics	Shevchenko University in Kiev, Kiev, Ukraine (044) 266-8677	Dr V. M. Nuzhnyj
Institute of Physics, Lithuanian Academy of Sciences	54 K. Pozelos St., Vilnius, 232600, Lithuania (0122) 64-1881	Dr A. Girgzdis
Tartu University, Air Electricity Lab	18 Ulikooli, Tartu, 202400, Estonia	Dr E. Tamm
Institute of Geophysics, Georgian Academy of Sciences	1 Rukhadze St., Tbilissi, 380093, Georgia	Dr T. G. Gzirishvili

to the traditional elements of the structure, such as universities, research institutes of industrial branches and of the Academy of Sciences, there appeared independent groups of scientists and engineers, termed as "research and design cooperatives" (the fourth diagram in Fig. 4 illustrates the role of newly-formed cooperatives in basic aerosol research). They made direct agreements with Ministers, controlled their budgets themselves and made direct contacts with foreign research centers without being dependent on the approval of International Departments of the Academy of Sciences and the State Committee of Science and Technology. By the beginning of 1990, a number of research and design cooperatives expressed their readiness to sponsor the new Association.

However, the break-up of the political structure of the former Soviet Union in 1990 resulted in the destruction of all Soviet organizations and associations, including—sadly—the Association for Aerosol Research which had been in existence for less than 1 year. In the face of major economic problems, the governments of newly-formed independent states had to significantly reduce the budgets of research institutes and universities. Since the traditional basic aerosol research had prevailed over the applied one, plenty of programs

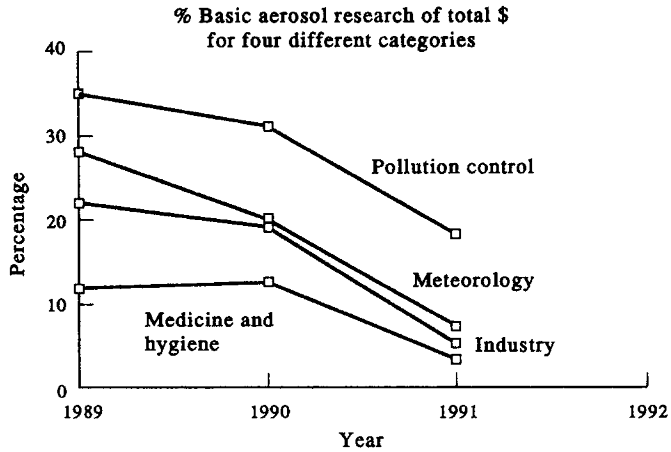

Fig. 5. Basic aerosol research of total $ for four different categories in 1989–1991.

and projects were frozen due to the drastic reduction of central funds. For instance, during 2 years (1989–1991), the budget of program on air pollution control was reduced by a factor of two. Aerosol projects for meteorology, industry, as well as medicine and hygiene were reduced by three to four times (see Fig. 5). Dozens of aerosol laboratories and departments ceased to exist.

At the same time, however, the intellectual potential of independent states, the former republics of the U.S.S.R., is still strong enough to continue the scientific projects that have been started recently. Aerosol researchers from Russia, Ukraine, Lithuania, Georgia and other post-Soviet states presented a substantial number of new and interesting ideas and results at recent international aerosol conferences in Vienna, Kyoto, Zurich, Karlsruhe, as well as in international scientific journals. The current cancellation of the restriction policy in the previously secret Soviet institutes has resulted in effective exchange of scientific information not only in basic research but also in the development of new aerosol instrumentation and technology. The presentation of modern measurement devices designed by Russian scientists at the conferences and exhibitions in Europe and the U.S. (e.g. new aerosol particle analyzer APA-03P shown at the recent AAAR-meeting in San Francisco by newly-established Siberian company "LINK") is a promising trend. In addition, several joint ventures with Western European and American companies have recently been established in Russia, Ukraine and other republics to develop new instruments for aerosol generation and measurement. Several institutions, most active currently in international cooperation, are listed in Table 4 (addresses, phone numbers and name of persons for contact are indicated).

The extensive cooperation with other advanced countries is now expected to be one of the most successful ways to overcome the political and economic crisis in the former Soviet Union. Similar gains can be expected to be made with respect to aerosol science. The survival and continued success of aerosol research in post-Soviet states will require long and thorough work by all cooperating sides, since plenty of problems will have to be worked out. It is obvious that the outdated means of communications from that part of the world have slowed down all kinds of contacts, in addition to the pre-existing difficulties associated with cultural and language differences. Nevertheless, the precedents of effective cooperation with aerosol research centers in the Commonwealth of Independent States show that in future potential benefits for Western partners can be very rewarding.

Acknowledgements—The author expresses special thanks to Dr K. Willeke for his encouragement in preparing this report; also to Ms C. Meyer and Ms N. St. Clair for their technical assistance. Finally, the author thanks his wife Vicky Appatova for her valuable help in the manuscript's preparation.