Cryogenics in Russia

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The actual state of Russian cryogenics is described, including academy and government institutes, universities as well as the industry. After the catastrophic break-down of funding following Perestroika and the ensuing brain drain, during the last few years things began to change for the better. The Russian cryogenic industry developed rapidly, above all the air separation industry. In the production of high-purity rare gases Russia belongs to the big players. Scientific institutes successfully use their excellent design and production capacity for by-order manufacturing of high-tech equipment for large research projects around the world. Moreover, new funding programs support their recovery

INTRODUCTION

The low temperature research and cryogenic engineering have a long tradition in Russia. Every physicist or engineer working in this field certainly knows the name of Peter (Pjotr) L. Kapitza, who built one of the first helium liquefiers with expansion engine in 1934, and who in 1978 received the Nobel Prize. He actively promoted the development of low temperature R&D in Russia by founding a number of research institutes and was during his later years head of the large Russian Institute in Moscow devoted to all aspects of low temperature R&D which now bears his name. Another large Low Temperature Institute in Kharkov, Ukraine, was since 1960 headed by Boris Verkin (and is now named after him), whose interests ranged from solid state physics to many aspects of low temperature application. For example, he initiated, founding of perhaps the first independent Institute of Cryobiology and Cryomedicine. Other Russian physicists well-known in low temperature physics are Lev Landau (Nobel Prize 1962), Vitaly Ginsburg (Nobel Prize 2003) and Alexey Abrikosov (Nobel Prize 2003), who all essentially contributed to the theoretical understanding of superfluidity and superconductivity.

Although many reports appeared in the media during the last fifteen years and much information is accessible via the internet today, the knowledge of conditions in the Russian Federation (in the following shortened to Russia) is still limited. This holds especially for the organisation of research and development (R&D). Quite a number of Russian scientific institutes are famous and have international contacts, but nevertheless it seems to be still difficult for scientists abroad to understand the structures in the different fields of science and technology, and to find out who should be approached for making contacts, for getting information on national conferences or for distributing information on international conferences. Therefore, with cryogenics taken as example, the special organisation as well as the actual situation of R&D in Russia are described in this paper.

SCIENCE AND TECHNOLOGY IN THE FORMER SOVIET UNION

For understanding the actual situation it is necessary to have a look at the past. The structures of scientific research and technical development in the former Soviet Union (USSR) developed differently from those in most Western countries. In the West numerous university laboratories, research institutes of different size – independent as well as national or international – and industrial laboratories are all engaged in research on a varying scale, and many of them are striving for application of their results in technical developments. The different research groups have ample possibilities for exchange of ideas at conferences or in direct interaction, and co-operation of different parties in specific projects has always been quite common, is encouraged by the government and to a large part promoted by special funding programs.

Other than in the West, in the USSR the universities' task was in the first line education while R&D was concentrated in very large governmental institutes, often with a staff size of up to several thousand and a wide variety of research areas. They usually started at a small scale with a specific field of interest and then grew and diversified more and more. This process is well described in a book published in 1998 on occasion of the Ioffe Physico-Technical Institute's 80th anniversary [1]. It originated from the Physico-Technical Department of the State Institute of X-Rays and Radiology founded at St. Petersburg in 1918, became an independent institute devoted to fundamental and applied research with "a staff numbering in tens" in 1923, and then grew bigger and bigger taking up more areas of research, partly due to new fields of science opening up, but also to government demands regarding development of the country's industry and later military issues.

The development of the other governmental research institutes with activities in cryogenics like the Kapitza Institute in Moscow and the Verkin Institute in Kharkov, which were mentioned before, the Budker Institute of Nuclear Physics at Novosibirsk, the Ioffe Institute at St. Petersburg or the Kurchatov Institute in Moscow followed much the same pattern.

These large institutes were a kind of rather independent universes, where almost everything was made in-house, ranging from screws over laboratory equipment to the manufacture of complete products like satellites or Tokamaks and the likes. Consequently, in addition to their high-standard research departments all of them had large design departments and industry-size workshops or better production sites – a feature which clearly distinguishes them from comparable large research institutes in the West where production as far as possible is given to the industry. The Russian research institutes did high-level research, educated graduate students, developed and built any size of experimental or technical equipment, all in parallel, and partly also served the surrounding industry. The Verkin Institute supplied, for example, tons of cryogenic liquids to industrial users in Kharkov and its surrounding. And these institutes worked mostly independent of each other, although occasionally specific services, e.g. radiation treatment of materials, were mutually provided.

This specific organisational structure has various reasons:

• The USSR government put huge investments into its science and technology base, at a level perhaps unparalleled in other countries. That meant, however, also a large amount of control by the government and specific demands regarding support of industry and military.

• The lack of the "infrastructure" which is usual in Western countries: in a centrally steered economy with its tendency of seeing mainly the general needs and its wish for overall control, there is no room for the small- and medium-size highly specialised private companies which in the West provide special services or deliver special technical components required by research institutes or larger industries.

• A significant part of the former Soviet science base was engaged in defence-related R&D and received its funding from military sources. This resulted in the demand for strict secrecy: communication with other institutions or industry inside the country was kept at a minimum, scientists working on different projects in the same institute did not discuss their work with each other [2,3]. As quintessence of this process, which is typical for military-oriented states, so-called "Science Towns", secret closed towns, were built, which could not be found on any map (in a recent BBC report their number was given as about 60 with a total population of about 3 million [4]). This obsessive secrecy undermined the traditional control per review. Combined with guaranteed, non-competitive public funding and the lack of public accountability it had the unfortunate consequence that highest quality R&D

Table 1: Comparison of country and population size of the Russian Federation, the USA, China and Europe (rounded figures) [8]

	Russian Federation	USA	China	Europe
Size of country {Million km$^{2]}$	17	9.6	9.6	2.3
Population [Million]	144	290	1 287	361
Population density [Persons/km$^{2]}$	8.4	30	134	157

existed beside undisturbed activities at a much lower level.

• The special geographical conditions (long distances and low population density, see Table 1) made communication between research teams difficult. Realisation of complex projects with several participants was therefore time-consuming and expensive.

PERESTROYKA AND THE SITUATION AFTER 1989

The end of the Cold War was one of the most remarkable events in recent human history. In Russia it has been followed more or less immediately by a move away from the old communist centrally planned economy to a market economy. As with almost all rapid transitions, this process has been a painful one with a withdrawal of public funding from many sectors that were once relying and dependent on it, and it is and probably will remain for yet a rather long time difficult to get funding from other sources. The demand for defence-related R&D services also was reduced, and many of the Research Institutes concerned face severe economic hardship. A detailed description of the situation in the mid-90es is given in the 80 years anniversary report of the Ioffe Institute, St. Petersburg: miserable salaries which were not paid regularly, problems with the payment for electricity, heating and water, the equipment becoming out of date and needing repair [1]. The continuing financial stringencies in Russian government funding means that quite a number of research institutes may not survive.

Not only the research institutes but also the industry was hit by the change. The initial shock of Russia´s move to creating a democratic market economy, with privatisation of the former Soviet big industrial companies, their sudden exposure to competition and, in addition, the breaking away of former markets in the Eastern block, led to a collapse of many factories.

This had the negative effect of increasing unemployment and the related ills of social and economic deprivation. On the other hand, it also had the positive effect of a visibly reduced tendency towards secrecy. Today the large research institutes and also universities provide their own websites with detailed information, Russian researchers are free to communicate with colleagues abroad and can discuss at conferences or with visitors without restrictions. Although secret closed Science Towns still exist, some of them – like Sarov (formerly Arsamas-16) Novouralsk, Snezhinsk, Angarsk, Zelenogorsk, Zheleznogorsk and others – have meanwhile appeared on ordinary maps and are open to visitors, though these still need appropriate authorisation. Sarov and Los Alamos, nuclear centers of Russia and the USA, are twin towns today, something which could only be dreamed of until recently.

Brain drain

In view of the difficult economic situation, the abolition of travel restrictions was followed by emigration at a rather large scale, either for good or for a limited period of time. Depending on the source, the figures differ slightly, but an estimated loss of about 2.5 Million people (including 400 000 Jews and 800 000 repatriated people of German origin) after Perestroyka should be rather correct. Emigration unavoidably means a brain drain, since many of those who decide to go are among the most talented and active ones. According to Russian Government statistics, before the break-up of the Soviet Union there were about 800 000 scientific researchers in Russia as a whole, while today their number is only 426 000, the estimated number of scientists who emigrated (those who do not expect to return) during the period 1991-2001 was 20 600, and approximately 80 000 to 100 000 left for temporary contract work during the same period [5]. The emigration of Russian scientists reached a maximum between 1995 and 1996 but has stabilised thereafter. The Director of the Moscow State Lomonosov University, Victor Sadovnichi, was quoted as commenting the brain drain as „one of the most serious Russian problems“ [6].

The consequences for a specific institute are described in the Ioffe Institute's report of 1998. They had to give "leave" to more than 100 experienced and active researchers with academic degrees who went to Europe or USA for scientific work. "Earlier, just these scientists had played the most active role in the education of future scientific generations, implementation of the ideas, and laying foundations for new scientific ideas" [1]. A serious consequence of the loss of young talented scientists is the disproportionate number of rather old and lesser talented ones among those who stay. According to S. A. Tsyplyayev, representative of the President of the Russian Federation in St. Petersburg, half of all science workers in St. Petersburg are 40 years or older, and 50% of those holding the doctorate are already receiving pensions [7]. The National Science Foundation, a funding agency for R&D, stated that most of the Russian scientists best known abroad are reaching the end of their research careers, and that these are extraordinarily difficult times for young scientists to take their place [7]. A German daily newspaper gave the average age of the Members of the Russian Academy of Sciences as about 72 years and that of most teachers and researchers at universities and research institutes as near to retirement with an average of about 57 years [6].

In the long run, the brain drain also may have positive aspects, however. The scientists abroad, even those who plan to stay there, keep contacts to their former institutes in Russia and can thus help to improve international contacts and exchange. Some of them are working in joint projects with participation of both sides and the exchange of ideas and results. And those who return after some time abroad will come home with international experience and new impressions which will certainly be helpful for the future development of R&D in Russia. Similar experiences have been made in Germany after World War II and in China during the last 20 years.

As one answer to the brain drain Russia's efforts regarding education have been intensified. Traditionally the Russian education system is achievement-oriented: talented children attend better schools, and the best of them later study at the best universities. As a consequence the range of differentiation among schools and universities is rather wide, and Perestroika even intensified competition between them. The highly valued "Special Schools" of Soviet times, schools focusing on special fields, have developed into so-called Lyceums, Colleges and Gymnasiums, most of them with entrance examinations for keeping a high standard. Competition-based selection combined with specific and systematic training of the students depending on their individual talents makes education in Russia very efficient. The number of dropouts is rather low. An important feature of Russian education is the

Table 2: Government Research institutes with cryogenic activities in Russia and the Ukraine

Institute	Location Website	R+D and Production in Cryogenics
Russian Research Centre Kurchatov Institute	Moscow www.kiae.ru	• Cryogenics for Tocamacs • Superconducting magnets • Applied cryogenics
P.L.Kapitza Institute for Physical Problems	Moscow kapitza.ras.ru,	• Applied cryogenics
P.N.Lebedev Physical Institute Russian Academy of Sciences	Moscow www.lpi.msk.su	• Applied cryogenics
Bochvar Institute – All-Russian Scientific Research Institute of Inorganic Materials	Moscow www.bochvar.ru	• High temperature superconductors
Joint Institute for Nuclear Research	Dubna (Moscow area) www.jinr.ru	• Cryogenics for high energy accelerators • Superconducting magnets • Applied cryogenics
Institute for High Energy Physics	Protvino (Moscow area) www.ihep.su	• Cryogenics for high energy accelerators • Superconducting magnets • Applied cryogenics
State Research Center of Russian Federation – Troitsk Institute for Innovation and Fusion Research	Troitsk (Moscow area) www.triniti.troitsk.ru	• Cryogenics for fusion • Superconducting magnets • Applied cryogenics
Ioffe Institute	Saint-Petersburg www.ioffe.rssi.ru	• Applied cryogenics
The Budker Institute of Nuclear Physics	Novosibirsk www.inp.nsk.su	• Cryogenics for accelerators • Superconducting magnets • Applied cryogenics
B.Verkin Institute for Low Temperature Physics and Engineering	Kharkov, Ukraine www.ilt.kharkov.ua	• Space cryogenics • Applied cryogenics

cooperation between institutions: integrated projects of schools/universities and scientific centres/industrial companies, in which schoolchildren and students attend lectures of leading scientists and work actively in the institutes' laboratories, are aimed at keeping a high educational level [1].

RUSSIAN CRYOGENICS TODAY

The following overview reflects the momentary situation, and the picture may be different in a couple of years since changes in Russia's scientific and industrial landscape will probably continue. However, since R&D institutes and universities as well as industrial companies are meanwhile present in the Internet, new developments can more easily be followed in the future.

Research institutes

Several large research institutes are active in cryogenics (Table 2, see former page; the Verkin Institute, Ukraine, is listed here for its national importance in the former USSR). All of them have a wide range of interests in research, and thus a good basis for various applications in cryogenic R&D. Differences as well as overlapping of focus areas in cryogenics reflect the allocation of definite tasks during Soviet times.

These research institutes include huge well-equipped high-standard design departments, workshops and production facilities, which have a first-class scientific back-up by their research departments. They turned out to be a valuable asset after Perestroyka. Even during Soviet times, in spite of all difficulties regarding external contacts, many of these institutes had international connections not only with countries in the Eastern block but, depending on their area of work, also in Western Europe and the USA. These could now be intensified, and soon a number of them – for example the Kurchatov Institute and the Budker Institute – became contractors for large research installations at national and international institutions around the world. They deliver all kinds of equipment, much of it involving ultra-high vacuum and cryogenics, and are known and estimated for high quality, reliability, in-time delivery and, last but not least, economic prices. Institutes or institute departments which are taking part in this new line of business are better off than in old times, they can pay higher salaries and buy modern equipment, which in turn leads to less problems regarding brain drain.

This also demonstrates the potential for the development of new, highly specialised industries which can successfully compete in the world market. In the West many successful companies in high-tech areas started as offspring from academic institutions, and similarly new cryogenic companies may soon be founded in Russia.

Universities

The total number of universities and colleges in Russia is 1100, of which about 600 are state universities and state colleges. The number of technical universities is more than 100. The actual total number of students is about 4.1 Mio, which corresponds to about 280 students per 10 000 residents. Compared to 180 students/10 000 (1991) before Perestroyka this is a remarkable increase. It reflects the fact that the number of colleges increased essentially in this time – several hundreds of private universities and colleges were founded, which are now in hard competition with the state system of higher education.

Table 3 (see next page) lists Russian Universities with teaching as well as R&D in cryogenics. It can be seen that the interest in refrigeration and cryogenics is wide spread, and students can specialise in these areas at different schools and with different focus. The Odessa State Academy of Refrigeration (OSAR), Ukraine, which also is listed in the table, is even completely devoted to this field. After Perestroyka the demand for cryogenic engineers declined and with it also the number of students in this field. As a consequence, many of the of the former Departments of Cryogenics have meanwhile changed into Departments of Refrigeration and offer education not only in cryogenic engineering but also in conventional refrigeration, air conditioning and other related areas.

According to the annual rating of Russian state universities, five of those listed in Table 3 (see next page) entered the first ten in the year 2002 (exceptions: Moscow State University of Ecological Engineering, Odessa State Academy of Refrigeration and Saint-Petersburg State University of Refrigeration and Food Technologies).

Table 3: Universities with cryogenic activities in Russia and the Ukraine

University	Location Website	R+D and Teaching in Cryogenics
Moscow Power Engineering Institute – Technical University – (Russian: МЭИ)	Moscow www.mpei.ac.ru	• Cryogenic Engineering
State Baumann Technical University – (Russian: МВТУ)	Moscow www.bmstu.ru	• Cryogenic Engineering
Moscow State University of Ecological Engineering – (Russian: МГУИЭ бывш. МИХМ)	Moscow www.mguie.ru	• Cryogenic Engineering
Moscow Institute of Physics and Technology – Technical University – (Russian: МФТИ)	Moscow www.mipt.ru	• Applied cryogenics • Cryobiology • Cryoelectronics
Moscow State Lomonosov University – (Russian: МГУ)	Moscow www.msu.ru	• Applied cryogenics • Cryochemistry • Cryoelectronics
Moscow Engineering Physics Institute – State University – (Russian: МИФИ)	Moscow www.mephi.ru	• Applied cryogenics • Cryoelectronics
Saint-Petersburg State University of Refrigeration and Food Technologies – (Russian: Санкт-Петербургский государственный университет низкотемпературных и пищевых технологий)	Saint Petersburg www.sarft.spb.ru	• Cryogenic Engineering
Odessa Stase academy of refrigeration – OSAR – (Russian: Одесская академия холода)	Odessa, Ukraine www.osar.odessa.ua	• Cryogenic Engineering

Table 4: Cryogenic industry in Russia and the Ukraine

Company	Location Website (Language)	Products
Cryogenmash	Balashika/Moscow www.cryogenmash.ru (Russian, English)	**Large scale cryogenic equipment:** • Air separation plants (up to 70 000 m3/h) • LHe, LH2, LNG plants • Cryogenics for launch sites (Baikonur etc.) • Cryogenics for tocamac/accelerator/MHD etc. • Turbines, heat exchangers, vessels etc. • Engineering
Heliummash	Moscow www.geliymash.aha.ru (Russian, English)	**Large and medium scale cryogenic equipment:** • LHe, LH2 plants • Turbines, heat exchangers, vessels, etc • Space cryogenics • Engineering
Sybkryotechnika	Omsk www.sibcryo.com (Russian, English)	**Small scale cryogenics equipment:** • Cryocoolers for military and space applications • GM-coolers and cryovacuum pumps • Mobile air separation plants • Vessels, etc. • Engineering
Uralkryotechnika	Ekaterinburg www.cryotech.narod.ru (Russian)	**Small and medium scale cryogenic equipment:** • Vessels • Transfer lines etc.
Iceblick	Moscow www.iceblick.com (Russian, English)	**High purity rare gases:** • Neon • Krypton • Xenon • Helium
Kislorodmash	Odessa, Ukraine www.kislorodmash.com (Russian, English)	**Large and medium scale cryogenic equipment:** • Air separation plants • Heat exchangers, vessels, etc. • Engineering

Industry

With the exception of Iceblick (founded in 1990 "as a result of creative and business collaboration of companies from Russia, Ukraine and the USA" according to the website), all companies listed in Table 4 (see former page) existed long before Perestroyka (here again, an Ukrainian company, Kislorodmash, is included as an essential part of former USSR cryogenics). The different areas of cryogenic engineering were distributed among them, with the claims well staked out all over Eastern Europe. This distribution caused a lack of competition and had unavoidably some negative effects. But it had also advantages like stable order quantity, balanced workload, high turnover and extremely accelerated growth. With Perestroyka the situation changed almost overnight. With privatisation the companies faced quite suddenly the rules of a free market, and competition among each other and with Western companies as well as the search for new fields of activity became a must.

Cryogenmash is the largest of the Russian cryogenic companies. Its founding and development after World War II were actively promoted by P.L. Kapitza. At Soviet times Cryogenmash was among the biggest of its kind worldwide. In the USSR and Eastern Europe it had the monopoly for large cryogenic plants and built air separation plants as well as all kinds of large-scale cryogenic facilities for space launch sites like Baikonur (today: Kasachstan) or Plesetsk and for research projects like accelerators or fusion. The bad economic situation in the 1990es, especially in the metal-producing and chemical industry, resulted in an abrupt decrease of the demand for cryogenic, and the drastic cut in public funding for large research projects did the rest. Orders dropped alarmingly.

Thus Cryogenmash had no choice but to look for new markets outside Russia. In addition to a clever marketing policy this required above all technical improvements so that more modern and technically better solutions could be offered to the customers. These efforts led, for example, to the development of a new generation of air separation plants which can rather successfully compete with Western products. As a result new customers abroad were found and the total order value recovered. Cryogenmash delivered, for example, hydrogen liquefaction plants and the complete oxygen, hydrogen and nitrogen supply system for the Indian space launch site SHAR and the Sea Launch Site (Russia-Ukraine-USA-Norway). A 300 l/h helium liquefier was delivered to India, and in Europe Cryogenmash built a 1.5 km helium transfer line for LEP at CERN in Switzerland. Until 2003 the total turnover could be increased by the factor of 6 to about 1.5 billion Ruble, which means ca. 50 million $.

The development of the other large companies followed similar lines after Perestroyka. However, a new feature in the scenery of Russian cryogenics are a number of smaller, more specialised cryogenic companies which aim at specific demands and niche-applications like cryoequipment for medical purposes (dermatology, cosmetology, gynaecology, proctology), electronic components for high-temperature superconductor devices, special cryostats and accessories, high resolution temperature sensors and the necessary electronics, and equipment for freezing and long-term preservation of bio-products. Their success can not yet be estimated, but their existence is an indication that by and by in Russia an infrastructure in the Western sense may develop.

CRYOGENIC SOCIETIES, CONFERENCES, EXHIBITIONS

Russia is Member of the IIR, the International Institute of Refrigeration, a scientific and technical intergovernmental organisation "to promote knowledge of refrigeration technology and all its applications". IIR covers the whole range of refrigeration and cryogenics, that is, room temperature down to helium temperature. A number of Commissions represent the various aspects of low temperature generation and application ranging from air conditioning over food processing down to ultra low temperatures. The IIR and its activities are well known among the Russian specialists, and Commission Conferences as well as a General Conference, the XIVth International Congress on Refrigration (Moscow 1975), have been held in the country.

In other countries it was felt in the 1950s that the emerging field of cryogenics – technical applications in the liquid helium temperature range – with its importance and potential for new technologies needed specific representation in addition to IIR. National platforms – like the Cryogenic Engineering Conference (CEC) and the Cryogenic Society of America, the British Cryogenic Council or the Cryogenic Association of Japan – were founded, with simple administrative rules and high flexibility in reaction to new developments. However, in Russia no such national platform for furthering contacts and exchange between science and industry in this field exists until now, in spite of the long-standing, extended and successful activities in cryogenics.

A first step in this direction is a series of exhibitions beginning in 2002 and organised by the exhibition company “Mir-Expo”, which is supported by the Russian Ministry of Industry, Science and Technology. The *Cryogen-Expo 2003 – 2nd Specialised Trade Fair* was held at the All-Russian Exhibition Center in Moscow in November 2003. This exhibition is aimed at establishing and strengthening co-operation in the field of cryogenics, to exchange experience, to develop and implement applied cryogenic technologies. A two-days cryogenic engineering workshop with more than 20 presentations was part of the by-program. At the moment it is mainly a national event, but international participation is welcome: in 2003 a company from Czech Republic was among the exhibitors (more than 20, total exhibition area about 1500 m^2), and there were also some visitors from other countries. Information on the *Cryogen-Expo 2004* (Nov. 16-19) can be obtained from websites [9].

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OUTLOOK

From its founding in 1969 the International Cryogenic Engineering Committee (ICEC) always had one or two Members from the USSR. However, after Perestroyka repeated attempts at finding a new Russian Member remained unsuccessful. In spring 2002 both authors discussed in which way it might be possible to make use of the meanwhile free exchange of ideas on national and international level for improving the communication between cryogenic specialists in Russia and the worldwide cryogenic community. These discussions were continued on a broader basis between Members of the ICEC and Russian conference participants during ICEC 19 at Grenoble, and CEC-ICEM at Anchorage.

As a consequence, this paper was prepared in close cooperation with Russian colleagues in the country and all around the world. It is the result of many detailed and interesting discussions. We got to know each other better during this process, and a group of engaged persons has developed who can answer almost any question regarding cryogenics in Russia (questions can be addressed to author A.A. who will forward them for competent answers). We don’t consider our efforts to be finished with this presentation but are ready to continue and hope for lively resonance from Russia too, perhaps even proposals for an ICE Commission Member. It is planned to install an open information platform in the internet, which we hope will support the communication between Russian and foreign members of the worldwide cryogenic community, in which a stronger Russian presence is welcome and looked forward to.

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