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Abstract

Since 1992, the All-Russian Scientific Research Institute of Experimental Physics and the Los Alamos National Laboratory, the institutes that designed the first nuclear weapons of the Soviet Union and the United States, respectively, have been working together in fundamental research related to pulsed power and high energy density science. This collaboration has enabled scientists formerly engaged in weapons activities to redirect their attention to peaceful pursuits of wide benefit to the technical community. More than thirty joint experiments have been performed at Sarov and Los Alamos in areas as diverse as solid state physics in high magnetic fields, fusion plasma formation, isentropic compression of noble gases, and explosively driven high current generation technology. Expanding on the introductory comments of the conference plenary presentation, this paper traces the origins of this collaboration and briefly reviews the scientific accomplishments. Detailed reports of the scientific accomplishments can be found in other papers in these proceedings and in other publications.

Introduction

Throughout the nearly fifty years of the Cold War, the series of International Conferences on Megagauss Magnetic Field Generation and Related Topics has been the principle forum for scientific exchange of ideas and accomplishments in the area of magnetic flux compression technology. C. M. Fowler, a co-author of this paper, is the only scientist to attend all eight conferences. Because of collegial relationships and friendships established at the early Megagauss conferences, the Megagauss conferences were to become the foundation for one of the most remarkable scientific collaborations since the beginning of the Cold War. Megagauss conference participants have emerged as principles in a formal collaboration that has been established between the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) at Sarov (formerly

Arzamas-16), Russia, and the Los Alamos National Laboratory (LANL), the institutes that designed the first nuclear weapons of the Soviet Union and the United States, respectively.

Magnetic flux compression technology was pioneered at VNIIEF by a team originally lead by Nobel Peace Laureate Andre D. Sakharov and at LANL by a team lead by Fowler. V. K. Chernyshev and the late A. I. Pavlovskii, two co-authors of this paper, were early members of Sakharov's team. Motivated originally to evaluate any possible defense applications of flux compression technology, the two teams worked independently for many years, essentially unaware of the others' accomplishments. However, an early US publication [1] announced the achievement of magnetic fields in the 10-15 MG range and stimulated Soviet work. The Soviets followed with a report of the achievement of 25 MG [2]. In an earlier document [3], the Fowler team stated its intention to apply high-magnetic field technology to controlled thermonuclear fusion, and the dream of fusion was to remain a strong motivation for both teams in the coming decades. In fact, VNIIEF scientists have described controlled fusion as "Sakharov's fondest dream."

In early 1992, emerging governmental policy in the US and Russia began to encourage "lab-to-lab" interactions between the nuclear weapons design laboratories of the two countries. Each government recognized that as nuclear weapons stockpiles and design activities were being reduced, highly qualified scientists were becoming available to use their considerable skills in fundamental scientific research of interest to both nations. Because of their familiarity with each other's work, VNIIEF and LANL were able to respond quickly to the initiatives of their respective governments.

The changes that have happened in the world political climate in the last decade are clearly reflected by VNIIEF's role in the Megagauss conferences. In the proceedings of Megagauss-V held in Novosibirsk in 1989, and in the proceedings of the previous four conferences, VNIIEF authors' affiliation was listed as the Kurchatov Institute in Moscow, due to the very strict security regulations of the former Soviet Union. By the time of Megaguss-VI in Albuquerque in 1992, the Soviet Union had acknowledged VNIIEF's existence and Pavlovskii gave a very poignant review of Sakharov's contributions to magnetic flux compression. In addition, Pavlovskii announced that Megagauss-VII would be hosted by VNIIEF and that conference participants would have the opportunity to visit Sarov, the city that was off-limits to foreigners just a few years earlier and the city that Sakharov had called "the Installation" in his autobiography. At Megagauss-VII, VNIIEF scientists presented papers that were jointly authored with scientists from several laboratories in France and the US.

Although scientists from VNIIEF and many other Russian institutes have established many collaborations with foreign scientists in many nations, the VNIIEF/LANL collaboration remains one of the most scientifically productive. More than 10% of the papers presented at the Megagauss-VIII conference reported accomplishments of the VNIIEF/LANL collaboration.

Origins of the Collaboration

Fowler and the US team first became aware of the well-developed Soviet flux compression effort because of abstracts submitted to Megagauss-I. Chernyshev and Pavlovskii had been encouraged by Sakharov to attend the conference, but permission was denied by the Soviet government at the last moment. Nearly two decades would pass before the three pioneers would meet in person.

Fowler had hoped to meet Pavlovskii at the second Megagauss conference, but the security regulations of the Soviet Union again prevented Pavlovskii from attending. Instead Pavlovskii's papers were read at Megagauss-II by Gennadi A. Shvetsov, who would, along with V. A. Titov, subsequently host Megagauss-III and Megagauss–V and who would later, in 1992, play an important role as facilitator in the establishment of the VNIIEF/LANL collaboration. The helical flux compression generator performance reported by Pavlovskii at Megagauss-II stimulated subsequent helical generator work at Los Alamos.

Pavlovskii and Fowler met for the first time in 1982 at a conference at the Lavrentyev Institute of Hydrodynamics in Novosibirsk. Both have recalled the excitement they both felt at their very first face-to-face contact. They met again at Megagauss-III when Fowler lead a LANL delegation that included Dennis Erickson, a Megagauss Institute member who would later, in 1992, play an oversight role in the formative stages of the VNIIEF/LANL collaboration.

Pavlovskii and Fowler would subsequently meet occasionally on Fowler's visits to Russia and on Pavlovskii's first visit to the US in 1988. In the decade following their first meeting, as each was educating a new generation of scientists, their friendship would continue to grow, although the political differences between their two nations would stand as a barrier to that friendship. Nevertheless, each shared a dream that someday they could work together.

In a letter dated June 30, 1989, Pavlovskii wrote to Fowler expressing his regrets that Pavlovskii's health prevented him from participating in the Megagauss-V conference and expressing his opinion that "it seems that it is high time to think about a joint program of works on both super-high magnetic fields cumulation and experiments setting in such fields." On the subject of "joint works," Pavlovskii asked Fowler, "what is your opinion?" but Los Alamos security regulations prevented Fowler from responding.

At Megagauss-V, Pavlovskii's and Chernyshev's groups reported remarkable advances in high-current generation. I. Lindemuth and R. Reinovsky, understudies of Fowler, met Chernyshev for the first time at Megagauss-V. Those initial discussions would focus on Chernyshev's disk explosive magnetic generator (DEMG) and a fusion-related paper co-authored by Chernyshev [4]. As a parting comment, Chernyshev offered, prophetically, "maybe some day we can do an experiment in which you and your colleagues design the load and we provide the generator."

In September, 1990, Fowler returned to Novosibirsk and again met Pavlovskii. At this meeting, Pavlovskii informed Fowler that, should LANL be

interested, Pavlovskii could get the LANL Director, and possibly Fowler, into Pavlovskii's "explosives firing area." Telegrams were exchanged in the months following, but a visit to VNIIEF did not materialize.

Pavlovskii and Chernyshev traveled to the United States in June, 1991, to participate in the Eighth IEEE International Pulsed Power Conference, which was held in San Diego, California. At this conference, the Soviet visitors initiated discussions on possible collaborative efforts. Among the participants in the collaborative discussions were Academician G. A. Mesyats, J. Degnan and G. Kiuttu of Phillips Laboratory (now Air Force Research Laboratory), M. DiCapua of the Lawrence Livermore National Laboratory, and Lindemuth and Reinovsky. At the conference, Chernyshev reported [5] VNIIEF's progress in controlled thermonuclear fusion and Reinovsky reported [6] LANL's initial studies of the utility of the DEMG, a study that had been prompted by VNIIEF's Megagauss-V publications.

Following the IEEE Pulsed Power Conference, Pavlovskii and Chernyshev visited Phillips Laboratory and were hosted at Los Alamos by Fowler. In the subsequent discussions, controlled thermonuclear fusion emerged as a subject of mutual interest because of the scientific "grand challenge" nature of the topic and the fact that it was an appropriate unclassified application of the skills developed in the nuclear weapons programs of both nations. The Russian visitors particularly emphasized approaches that had no direct counterpart in the US national controlled fusion program, approaches known as MAGO in Russia and now known as Magnetized Target Fusion (MTF) in the US.

Until September, 1991, all collaborative discussions had been at the "scientist-to-scientist" level, and US officials did not know how seriously to take the Russian overtures. However, in September, as Lindemuth returned through Moscow from the Second International Youth School on Plasma Physics and Controlled Fusion held in Sochi, Russia, Chernyshev, V. N. Mokhov and several colleagues traveled to Moscow to deliver a formal written proposal for collaboration in MAGO/MTF and related topics.

The VNIIEF proposal presented to Lindemuth had been signed by VNIIEF's director, V. Belugin, and had been discussed with high-ranking officials of the Soviet Ministry of Atomic Energy (MINATOM) and other Soviet government organizations. VNIIEF and Russia had clearly elevated the collaborative discussions to a higher level. Upon delivery of the proposal to LANL, Stephen M. Younger, then Program Director for Above Ground Experiments, was appointed LANL's administrative point-of-contact for Russian collaborative issues. Global events that quickly followed precluded Los Alamos from making a formal response to VNIIEF's proposal.

In late 1991, Chernyshev had arranged for Lindemuth and Reinovsky to participate in the Second Zababakhin Scientific Talks, held in January, 1992, and hosted by VNIIEF's sister laboratory, the Institute of Theoretical Physics (VNIITF). Following the Zababakhin Talks, Lindemuth and Reinovsky traveled

to VNIIEF, presented seminars on LANL's pulsed power and fusion activities, and continued the collaborative discussions.

During their January, 1992, Russian visit, Lindemuth and Reinovsky delivered messages from LANL's director S. Hecker to the directors of VNIIEF and VNIITF inviting the Russian directors to travel to the United States for high-level collaborative discussions. Key guidance on how to deliver Hecker's important messages was provided to Lindemuth and Reinovsky by Younger and D. Erickson, who was then LANL Deputy Associate Director for Nuclear Weapons Technology.

Pavlovskii accompanied the VNIIEF director to LANL in March, 1992. At LANL, Pavlovskii presented what Younger would later describe as the most fascinating scientific speech he had ever heard. During the March visit, LANL and VNIIEF were clearly finding much in common and many topics appropriate for collaboration were being identified.

Following a May, 1992, high-level "government-to-government" meeting in Moscow, in which Younger participated, Fowler, Lindemuth, Reinovsky, and Younger visited VNIIEF in June, 1992, where they were hosted by Pavlovskii and Chernyshev. G. A. Shvetsov accompanied the LANL team from Moscow and served as a facilitator in a week of intense discussions. Collaborative topics appropriate for initial "lab-to-lab" collaboration were delineated and action items for both institutions were agreed upon. Essentially all of the topics were topics that historically have fallen under the umbrella of the Megagauss conferences.

During the June visit, the LANL team witnessed an MC-1 high magnetic field experiment at Pavlovskii's firing point. Pavlovskii asked Fowler to push the button that set off the experiment, and Fowler was presented a bottle of vodka as payment for his services to VNIIEF.

A large delegation of VNIIEF scientists participated in the Megagauss-VI conference held in Albuquerque in November, 1992. In his opening address, J. Pace VanDevender of Sandia National Laboratory noted that US/Russian collaboration in Megagauss conference areas appeared to be a real possibility and particularly emphasized that "Russian technologies can build a new discipline between magnetic and inertial fusion."

Following the Megagauss-VI conference, Pavlovskii and Chernyshev lead a VNIIEF delegation to LANL. The VNIIEF delegation included N. Bidylo, M. Dolotenko, L. Gerdova, L. Panevkina, A. Petrukhin, O. Tatsenko, and V. Rogatchev. Chernyshev, Pavlovskii, and Younger signed a Technical Memorandum of Agreement that defined mutually agreeable conditions that would lead to the first joint experimental activities.

The November 1992 meeting in Los Alamos would be the last time Chernyshev, Fowler, and Pavlovskii--the three pioneers whose work had provided the foundation for the VNIIEF/LANL collaboration—would be together (Fig. 1). The unfortunate death of Pavlovskii in February, 1993, provided a set-back to the fledgling collaboration, but Pavlovskii's VNIIEF and LANL

colleagues were determined to carry out the work that Pavlovskii had been so instrumental in formulating.

Accomplishments of the Collaboration

On September 22, 1993 (the day after Boris Yeltsin disbanded the Russian Parliament), the first joint experiment was performed at VNIIEF when a joint VNIIEF/LANL team assembled, executed, and diagnosed a complex generator/fuse/liner system centered on VNIIEF's unique pulsed power capability, the DEMG. In December of the same year, five VNIIEF MC-1 high-magnetic field generators were used at LANL in a series of joint high-temperature superconductivity experiments.

Since that time, following a "step-by-step" process, more than a dozen additional joint experimental campaigns have been performed either at VNIIEF or at LANL. Key events of the collaboration are summarized in Table I. The results of the experimental campaigns have been well-documented in the scientific literature (see, e.g., these proceedings, the proceedings of the Megagauss-VII conference, and [7]). The data obtained has increased our understanding of the role magnetic flux compression technology can play in accessing the realms of high-energy-density physics.

The collaboration described in this paper would not have been possible without the support and encouragement of many officials of the governments of Russia and the United States and many administrators at VNIIEF and LANL. Most importantly, the collaboration would not have been possible without the technical expertise of our VNIIEF and LANL colleagues, unfortunately far too many to name.

Perhaps equally or more significant than the scientific accomplishments is the fact that the VNIIEF/LANL collaboration has demonstrated that the nuclear weapons design laboratories of Russia and the United States can work effectively "side-by-side as equals" to bring demonstrable scientific benefit to both nations. Because VNIIEF and LANL developed the first nuclear weapons of their respective nations, it is perhaps symbolic of a future of reduced global tensions that VNIIEF and LANL have started their second half-century working together. The participants in the collaboration are continually cognizant of the comment made by former LANL Director Norris Bradbury: "the whole object of making nuclear weapons is not to kill people, but to find time for somebody to find other ways to solve these problems." The trust and respect developed through this collaboration have provided a foundation for broader interactions between the nuclear weapons laboratories of the two nations [8].

The Megagauss series of conferences has been the basis for these remarkable events.

Table I. Key events in the LANL/VNIIEF collaboration

6/92: defined topics (VNIIEF)
11/92: signed first contracts (LANL)
9/93: first joint experiment (VNIIEF)
12/93: 5 high-B experiments (LANL)
4/94: magnetized plasma experiment (VNIIEF)
8/94: isentropic compression experiment (VNIIEF)
10/94: 2 magnetized plasma experiments (LANL)
2/95: x-ray source experiment (VNIIEF)
8/95: isentropic compression experiment (VNIIEF)
9/95: magnetized plasma experiments (VNIIEF)
5/96: Dirac-I high-magnetic-field experiments (LANL)
5/96: High I generator test (VNIIEF)
8/96: high energy liner experiments (VNIIEF)
9/96: isentropic compression experiments (VNIIEF)
6/97: Dirac-II high-magnetic-field experiments (LANL)
10/97: isentropic compression experiments (VNIIEF)
12/97: 2 liner stability experiments (LANL)
7/98: isentropic compression experiments (VNIIEF)
8/98: magnetized plasma experiments (VNIIEF)
2/99: 2 liner stability experiments (LANL)

References

[1] "Production of very high magnetic fields by implosion," C. M. Fowler, W. B. Garn, and R. S. Caird, J. Appl. Phys. 31, 588 (1960).

[2] "Magnetic cumulation," A. D. Sakharov *et al.*, Sov. Phys. Dokl. 10, 1045 (1966).

[3] In *Atomic Energy Research in the Life and Physical Sciences*, available from the US Government Printing Office, Washington DC, p. 104.

[4] "Possible solution of the controlled thermonuclear fusion problem based on magnetogasdynamic energy storage," V. Mokhov, V. Chernyshev, V. Yakubov, M. Protasov, V. Danov, E. Zharinov, Sov. Phys. Dokl. 24, 557 (1979).

[5] "On the progress in the creation of powerful explosive magnetic energy sources for thermonuclear target implosion," V. Chernyshev, V. Mokhov, in Proceedings of Eighth IEEE International Pulsed Power Conference, R. White and K. Prestwich, Eds. Piscataway, NJ: IEEE, 1991, p. 395.

[6] "Future explosive pulse-power technology for high-energy plasma physics experiments," R. Reinovsky, I. Lindemuth, S. Marsh, *ibid*, p. 415.

[7] "US/Russian collaboration in high-energy-density physics using high-explosive pulsed power; ultrahigh current experiments, ultrahigh magnetic

field applications, and progress toward controlled thermonuclear fusion," I. Lindemuth, C. Ekdahl, C. M. Fowler, R. Reinovsky, S. Younger, V. Chernyshev, V. Mokhov, A. Pavlovskii, IEEE Transactions on Plasma Science 25, 1357 (1997).

[8] "Russian-American collaborations to reduce the nuclear danger," N. Cooper, Ed., Los Alamos Science 24 (1996).

Fig. 1. Three pioneers in magnetic flux compression science and technology. From left to right, Vladimir K. Chernyshev (VNIIEF), C. Maxwell Fowler (LANL), Alexander I. Pavlovskii (VNIIEF). This photo was taken in Los Alamos in November 1992, and was the last time the three would be together.