Revisiting Vyacheslav Danilenko: His Origins in the Soviet Nuclear Weapons Complex

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While at Chelyabinsk-70 from the 1960s until the late 1980s, Vyacheslav Danilenko developed deep expertise in high explosion compaction (compression) methods which had been developed for application in nuclear weapons and high speed diagnostics of high explosive phenomena. While at this premier nuclear weapons site, Danilenko worked with many of the greats of Russian nuclear science. He applied this knowledge to the explosive formation, compaction, and sintering of diamonds. Initially, according to Danilenko himself, experiments aimed at methods for diamond synthesis were highly classified because they depended on considerable knowledge applicable to the design of nuclear weapons. For security reasons, the methods were initially contained only in secret reports from Chelyabinsk-70. Danilenko also conducted additional research while at Chelyabinsk-70. He is listed as involved in research that applied explosive devices and techniques for studying dynamic compaction/compression of many different metals and alloys other than nanodiamonds or diamonds. Overall, his knowledge of nuclear weapons related technologies and methods would have been highly valuable to the nuclear weapons program of a proliferant state, such as Iran.

In order to understand the world in which Danilenko worked for many decades, one must take a short trip back in time. Danilenko worked at Chelyabinsk-70 (All-Russian Research Institute of Technical Physics), or VNIITF, a site dedicated to nuclear weapons research and development and to the applications of nuclear weapons. The new institute's organizer was one of I.V. Kurchatov's closest associates, USSR Academy of Sciences Corresponding Member Kirill Ivanovich Shchyelkin, who was appointed as the institute's scientific director and chief designer. The core of this new institute came from the collective of devoted scientists, designers, and material and process engineers brought in from the staff of the VNIIEF (All-Russian Research Institute of External Physics), which is located in Sarov. Within a few years, VNIITF made its mark and received the Lenin Prize for one of its developments.

In 1995, Muzyrya and Nitikin wrote a short history of Chelyabinsk-70 and according to them in "September 1955 the first train dropped off career personnel (mainly, theorists, mathematicians and physicists) on the platform at the place where the famous radiobiologist Timofeyev-Resovskiy used to work. The location for it was chosen by the institute's first director, Dimitry Yefremovich Vasilyev. The young collective gathered strength, and very soon it began demonstrating worthy results. A large fraction of the developments of Chelyabinsk-70 went into the military inventory."[1]

Gas Dynamics Groups

Danilenko would join the gas dynamics group at VNIITF, although the exact date when he did join is uncertain. Its work was described in the 1995 journal article which stated "The physics of explosions is one of the main areas of activity of Chelyabinsk-70. In the 35 years of its existence, the institute has accumulated a significant amount of experience and created unique explosive devices with yields from milligrams to megatons of TNT. Using nuclear bursts for industrial purposes is the most important area of the institute's work. The institute has been the head institute for development of nuclear devices for industrial purposes for a long time. The development of these devices is based on deep research and modeling of explosive processes.

The institute holds the priority in the discovery, study and practical uses of a number of phenomena of gas dynamics. In particular, energy accumulation and diamond phase synthesis in explosion products. Accomplishments in studying the properties of matter at extreme values of thermodynamic parameters enjoy the recognition of the scientific community."[1]

Under the leadership of E.I. Zababakhin and others, Chelyabinsk-70 demonstrated a deep interest in expanding the application of high explosive compression techniques in the design of nuclear weapons. "Back in the 1950s the question was brought up of causing combustion in the hydrogen unit without a fission reaction, by compressing and heating central layers with a shock wave. Research into this problem resumed in the early 1960s in Chelyabinsk-70, but for civilian uses and with considerable amendments. E.I. Zababkhin was an enthusiast of research into the peaceful uses of nuclear devices. Zababkhin always took tremendous interest in industrial uses of nuclear explosions and design concepts that minimized radioactivity. He dreamed of a device that would leave no radioactive fragments at all and of thermonuclear reaction triggered with conventional explosives, successively from the hot center of what has become known as the "multi-layer cake". In 1953, the work was stopped. Later, we returned to the idea of thermonuclear detonation, however on a new basis. I am referring to a device that permits you not only to heat each successive layer with the energy of the previous one, but also to strongly compress matter before the detonation. The degree of compression would be hundreds and even thousands of times more, in contrast to ordinary compression that a shock wave is capable of."[2]

The specialists also worked on a less ambitious device useful in nuclear weapons. For 22 years Academician Leo Feoktistov worked at Chelyabinsk-70 where he made a direct contribution to the creation of a large number of "special items".[2] When talking about the initiation of a nuclear explosion he wrote "A small amount of solid material containing deuterium is placed at the center of the nuclear charge. The shock wave produced by the chemical explosive triggers a deuterium-deuterium nuclear reaction and a release of neutrons. Experiments have shown that the amount of neutrons produced in this fashion is enough to initiate a chain reaction."[2]

Feoktistov wrote "The design that ensured combustion in strongly compressed deuterium eventually gave birth to a new type of a civilian product. Even radioactivity induced by thermonuclear neutrons in materials, was made to be minimal. That was achieved primarily through the strictest selection of material. In a far more remarkable experiment staged in the field we managed to find out the minimal size of a ball capable of self-sustaining combustion. Civilian devices continued to be perfected, in the first place, in terms of reducing radioactivity. In the end there emerged a device so unusual, that we could hardly believe it was possible. The radioactivity of fissile products was several dozen times lower. That special initiating device, called SINUS for short, was subsequently improved on many occasions and proved very reliable."[2]

Danilenko wrote "The scientific dean of Chelyabinsk-70, E.I. Zababkhin – an excellent gas dynamics expert, dreamed of staging an explosion that would turn a heap of graphite into a diamond placer. Zababkhin was particularly enthusiastic about various phenomena that are accomplished by a high concentration of energy in a limited space in a short period of time."[3] It is believed that Danilenko joined Chelyabinsk-70 in the late 1950s or early 1960s. Danilenko states that "specialists from the VNIITF, a research institute were the first in the USSR to start studies on diamond synthesis in 1960. The merit of these studies is due to Academician E.I. Zababkhin who headed the VNIITF." Owing to Zababakhin's initiative and close support, scientists from the gas dynamics group, including K.V. Volkov, V.V. Danilenko and E.I. Elin carried out the following pioneering work in diamond synthesis in 1960-1965:

(1) Diamonds were obtained by shock compression of graphite and carbon black in spherical and cylindrical storage ampoules (1962)

(2) Compression of a graphite-metallic coolant mixture was used, which made it possible to increase the diamond yield by an order of magnitude (1963)

(3) The superhard wurtzite modification of boron nitride was obtained using explosives (1963)

(4) Detonation synthesis of nanodiamonds from carbon molecules of explosives was discovered and investigated (1963)

Method of Diamond Synthesis Highly Classified

Danilenko writes "In 1963-1965, about 100 successful experiments were carried to analyze the effect of explosion conditions, as well as the composition and configuration of charges, on UDD (ultra-dispersed diamonds) synthesis and the properties of the UDD produced. At that time, experiments aimed at methods for diamond synthesis were highly classified because they depended on considerable knowledge applicable to the design of nuclear weapons. For security reasons, the methods were initially contained only in secret reports from the VNIITF. Only in 1987 were parts of those reports forwarded to other members of the diamond club."[3]

Danilenko writes that "in 1960-1980, a sort of diamond club of research centers was formed in the USSR, where dynamic methods for producing superhard materials were devised."[3] The club incorporated the following institutes:

All-Union Research Institute of Technical Physics (VNIITF)

Institute of Chemical Physics, Academy of Sciences of the USSR

Institute of Hydrodynamics, Siberian Division, Academy of Sciences of the USSR, Novosibirsk

Institute of Superhard Materials, Academy of Sciences of the UkSSR, Kiev

Institute of Problems of Materials Science, Academy of Sciences of the UkSSR, Kiwv

Dnepropetrovsk Institute of Mines

Pepekin, Semenov Institute of Chemical Physics, Russian Academy of Sciences, Moscow, states that "a fundamental scientific advance was the development of a detonation method of diamond synthesis, first accomplished in Russia in 1962, directly during the detonation of organic explosives. Closely related to the problem considered above is the question of feasibility of using dynamic approaches to produce other refractory materials that contain other elements in addition to carbon."[4]

Drobyshev, Institute of Chemical Physics, Chernogolovka, stated that "the overwhelming majority of known methods for producing superhard materials under dynamic conditions are based on the use of shock waves. The original materials are placed in a planar or cylindrical rigid metal container. Shock waves are produced in the container walls by detonation of explosive charges placed in contact with the walls, or by collision on the walls of bodies driven to high velocities by explosive detonation products. The shock waves enter the materials to be converted and compress it until the temperatures and pressures required for the phase conversion are achieved. Thus, explosive detonation is used indirectly as the external energy source for shock-wave production."[5]

In 1973 "conditions were achieved for detonation synthesis of superhard materials (diamond and dense boron nitride phase). Free mixed charges were detonated within an explosion chamber. At present (1983), data have been obtained on the effect upon degree of conversion and properties of the superhard materials of the nature and size of the original material particles, the qualitative and quantitative composition of the explosive and various inert additives, and certain parameters of the mixed charges. In addition the physiochemical properties of the diamond and dense boron nitride modifications have been studied."[5]

An indication of the importance of detonation chemistry to dual-use applications was described in a 1998 conference presentation. In this presentation, Victorov and Gubin, Moscow State Engineering Physics Institute, wrote that "carbon phase state in detonation products depends on their temperature and pressure and affects to detonation parameters of explosives because distinct carbon phases have different thermodynamic properties, Therefore, knowledge of carbon phase state in detonation products is important for accurate predictions of HE detonation characteristics."[6]

Petrov (New Technologies, Chelyabinsk) and Shenoderova (International Technology Center, Raleigh, North Carolina) stated that "in 1986-1988 experiments using large mass detonation charges were performed by Danilenko at VNIITF. By that time, in 1989, Danilenko had left VNIITF, and continued his career at the Institute for Material Science Problems, Ukraine. Based on the patent related to the detonation chamber of a special construction, large-scale technology for producing UDD was implemented at the commercial plant of the ALIT company. The main part of the plant was an explosion chamber $100m^3$ in volume with water cooling of the UDD designed by Danilenko."[7]

According to Danilenko "In 1991at the VNIIEF, a unique experiment on UDD synthesis by exploding a charge with a mass of 140kg in a water jacket was carried out in a chamber 300m3 in volume."[8] The results of these experiments were published in three different journal articles. Two of these articles have been translated into English but the third and probably the most important article is available only in the original Russian. An abstract of the article in which Danilenko was listed as a coauthor follows: "Synthesis of ultrafine diamonds in detonation waves in explosions of cylindrical and ball-shaped charges of solid explosives trotyl-heoxogen, T-H, at the ratio 40/60 and 70/30, was experimentally studied at the explosive mass (mE) 0.2-140kg. With increasing the ratio of the inert medium mass (M) to mE, the ultrafine diamond yield increased. The maximum yield at T-H rations 50/50 and 40/60 was 8-10%. Size of cubic diamond particles 4-20nm was independent of the charge sizes, the largest particles being 60-90nm. An increase in the charge size gave polycrystalline, lamellar, rectangular and lumpy particles."[8]

Mazanov, a scientist at VNIIEF, presented details of experiments that were carried out jointly between VNIITF and VNIIEF. "To study the effects of the inter-gas mass and thermophysical processes on the yield of condensed carbon and the content of ultrafine-dispersed diamonds, we used spherical explosion chambers 0.65-1.2m in diameter (space volume 0.14-$800m^3$). Charges of a trinitrotoluene-hexogen TG50/50 alloy 0.05-140kg in weight were exploded in vacuum, a nitrogen or a helium atmosphere, the atmosphere of explosion products, atmospheric air and water shells. The mass of a cooling gaseous or water medium was varied from 10^4 to 20 times the explosive mass. To determine the parameters of the medium, we recorded the pulse and quasi-static pressure with pressure tranducers."[9]

High Speed Diagnostics

In September 1992, Danilenko and others from VNIITF presented a number of papers at the 20th International Congress on High Speed Photography and Photonics. Danilenko is listed as the coauthor on two important papers presented at the conference. The first paper deals with the use of optical fiber gauges for gas-dynamic investigations. The abstract states "the work of two types of optical fiber gauges on the basis of polymeric light guides was developed and investigated for registration of x,t –diagrams of shock waves moment in solids, liquids and free surfaces of moving bodies."[10]

The second paper deals with a multichannel optical fiber system to measure time intervals at investigations of explosive phenomena. The abstract for this paper states "Investigation of shock-wave processes requires multichannel means to measure time intervals. By using measured intervals, velocity and shape of front surface of shock and detonation waves, and that of moving bodies are determined."[11]

"In this paper one of these optical fiber systems is presented. Polymeric light guides, served for retransmission of optical signals, are used as gauges. The essence of the described system is that the point image of the surface of any form in it, which is arbitrary oriented in space, is converted into a flat (linear) recorded with a chronograph. The results of system information potential investigation, including a number of recorded signals, time resolution, and measurement errors, as well as sensitivity of the method depending on signal parameters, photochronograph and photographic films characteristics, and the results of an experiment, are presented. The developed system enables to register up to 6000 channels in the same experiment, time resolution of which does not exceed 20 ns."[11]

One of the references in this paper is to a 1989 paper that Danilenko coauthored on errors during measurements of time intervals by the SFR-2M. The SFR-2M refers to a high speed camera used in experimental research when studying the dynamics of fast systems including implosion phenomena.[12]

A third paper from VNIITF researchers described experimental measurements for the radial distribution of a ball sample material density under explosive spherical compression. The abstract reads "In the given paper the procedure for experimental measuring the radial distribution of a ball sample material density under explosive spherical compression is presented. Sample materials are iron (Fe), and lead (Pb). The technique was developed for measurement under material dynamic compaction. Measuring was conducted by a pulsed radiography method. Object simplest open X-raying was applied without use of collimating elements or equalizer filters."[13]

Two of Danilenko's earlier coauthors (Kozeruk and Telichko) presented a paper at a 1999 SPIE conference in which they discussed investigations into high-speed interaction of plates with cylindrical and plane indenters. The abstract reads "By the pulse X-ray diffractometry method the interaction process of the plates, accelerated by the charge of explosive up to velocities in the range from 1.5 to 5 km/s, with the cylindrical and plane indenters was investigated. For obtaining a rather high spatial resolution and the X-ray diffraction contrast the pulse X-ray apparatus with 1 MV generator and the recording system based on fine-grained fluorescent screens has been used. In experiments the process registration in the mutually perpendicular directions has been performed. This makes possible to register the plates moving along the axis of exposure as well as perpendicularly to it and to investigate some interesting processes, namely: the interaction of indenters having small cross-sections sizes, the motion instability of plates made of low-strength materials, the brittle failure of the plates in the zone of the lateral load action."[14]

Referring to Danilenko's earlier journal articles and conference presentations, Kozeruk states "When carrying out gas-dynamic researches there is often a problem of measurement of throwing bodies free surface velocities or velocities of shock and detonation waves. Electro-contact method is the most generally used for these purposes. Moments of locking of wire or foil contacts by the surface of flying body, screen are registered in this method. Contacts located on different levels allow to register x, t- exploring surface or wave motion diagram. The value of desired velocity is determined a result of processing x,t- diagram. In order to increase the measurement accuracy it is necessary to increase a number of levels and a quantity of sensors in a level. Each contact located in a protective cover – holder, is a striker for flying sample. Interacting with a sample, the contact creates a crater, disturbance area, jets on its surface. This area is saved under motion up to the following levels. Therefore reasonable selection of minimum allowed distance between contacts of different levels is necessary at which their mutual influence would be excluded."[14]

Danilenko's Colleagues

Searching through the open source scientific literature for Danilenko's coauthors revealed that all had connections to the design group headed by E.A. Kozlov at VNIITF. This group authored a number of dual-use nuclear design related journal articles and conference papers. Tarzhanov (Tarjanov), Telichko and others presented a paper at the 2005 Zababakhin Talks on stress relaxation of elastic precursor for unalloyed uranium and some uranium-based alloys. The abstract reads "The new data are presented on relaxation of an elastic precursor in unalloyed depleted uranium and two of its alloys. Results were obtained under low-intense explosive loading. Statistic thermofluctuational model was used for the approximation of experimental data. The inversion of strength properties of the tested U-Mo, and U-Fe-Ge alloys at their quasi-static and high-rate loading was revealed."[15]

A 2009 paper described incipient and developed spall fractures of wedge samples of U-1.5%Mo alloy. The abstract reads "Data on the setup and results of explosive experiments aimed to determine the spall strength of the cast alloy U-1.5%Mo with the varying amplitude and duration of the loading pulse are presented. Explosive loading conditions realized on wedge samples allowed both incipient, and developed spall fracture to occur in these samples. These loading conditions allowed us (i) to register by optical lever method both elastic and plastic waves attenuation through the wedge thickness, and changes of the spall signal parameters; (ii) to recover samples after low-, and high-intensive explosive loading for their subsequent metallographic investigation and (iii) to measure distribution of hardness and microhardness through the sample thickness."[16]

Probably the most important conference paper coauthored by Tarzhanov was for the 6th US-Russian Pu Science Workshop held in July 2006 at Lawrence Livermore National Laboratory. The abstract reads "In this article, we give brief overview of some earlier published data demonstrating how mechanical behavior of some transition and 5f-metals, as well as alloys depend on the content of impurities and alloying elements. The blank fabrication technology, aging, pressure, temperature, low, and high strain-rate-deformations. Control over stability of mechanical properties, particularly the shear and spall of the material, is demonstrated to be of critical importance. Effect of phase transitions on the features of spherical shells behavior under explosive loading is shown to be possible."[17]

The paper mainly deals with the properties of plutonium but also goes into detail of an alloy that "is interesting as a model (surrogate) material for studying the degradation of strength properties at long-term (up to 10 years) and superlong (up to 100 and more years) storage under different temperatures."[17] Also covered were behavior of the alloy under spherical explosive compression.

In 2003, Telichko coauthored a conference paper that gave details on the effects of long self-irradiation on change of shear strength of unalloyed plutonium under its explosive loading.[18] It is difficult to determine when many of these shock compression experiments actually took place due to Russian classification guidelines. It is believed that many took place during the 1960s and early 1970s when Danilenko was at VNIIEF and that he would have been involved in designing and developing instrumentation for these experiments.

Additional Work by Danilenko

It is a review published in 1993 that helps to shed light on additional research Danilenko carried out during his time at VNIITF, E.A. Kozlov, describes the application of explosive devices and techniques for studying the dynamic compaction/compression of materials.[19] While describing the use of explosive devices for the compression of many different metals and alloys, neither nanodiamonds or diamonds are mentioned in the review.

The "constructional variants which are found can be divided into three dependent upon the geometry of the action upon the substance being loaded: devices with planar, axisymmetric, and spherical compression…For all modes of compression the material is enclosed in a metal capsule and experiences the effect of the shock wave which develops in the capsule wall. No less important is the role of the capsule as the dynamic load is removed from the specimen, at which time it acts as a preservation method. This fact is not widely used to control shock wave action on the specimen. In addition, by preparing the capsule walls from layers with different acoustic rigidity and geometry, the level and rate of loading and unloading can be varied, providing precise regulation."[19]

"Compaction devices using axisymmetric loading are also quite widespread. In our country such devices have been studied by Ryabinin, **Danilenko**, Batsanov, Dremin, Breusov, Adadurov, Titov and many others. A characteristic feature of these devices is the presence of radially converging shock waves and deloading waves, which produce radial unloading in the specimen, up to the point of loss of continuity in the region of the axis of symmetry. Thus experimenters' efforts have been directed towards generation of required parameters and geometry in these waves."[19]

“Among axisymmetric devices we must also include cumulative charges…Still higher energy densities in compacted or normalized specimens can be obtained by using explosive devices with central symmetry…Use of an external heavy shell and a spherical system of various sizes permitted significant expansion of the range of pressure, temperature, and loading pulse duration realized in the specimens. In specimens with spherical systems varying in size by a factor of about three times, spheres of various materials were produced and studied in detail by metallographic and x-ray structural studies….Use of large-size spherical systems permits attainment of necessary pressure, temperature, or specific internal energy at higher effective radii, as well as increase in loading pulse duration when necessary.”[19]

Regarding axisymmetric detonation, Academician D.V. Shirkov is quoted in an article that discusses the development of Russia’s first nuclear artillery projectile “Non-spherical symmetry required a more sophisticated design of the detonator system. Their asynchronous ignition circuit had to provide synchronous convergence of the non-symmetric shock wave towards the center of the construction. The same problem with an extra variable had to be resolved for hydrodynamic cogging and squeezing of the nuclear charge as well as for all the nuclear chain reaction calculations. Implosion resulted in the transformation of the originally hollow thin-walled shell of the active material together with the adjoining neutron-reflecting heavy 238U shell into a supercritical two-layer slightly elongated quasi-spherical body, into which neutrons from the primer were injected. This design, basic for a nuclear explosion, is axisymmetric and not spherically symmetrical.”[20]

Conclusion

Russia is considered the world’s leader in the development of experimental explosive devices and techniques for the study of shock waves. It was not until the early 1990s that the actual details of these devices were first described in the open scientific literature.[21] In the period 1945-1966, “Al’tshuler and his colleagues (VNIIEF) were considerably ahead of their American counterparts in achieving ultra-high pressures in dynamic high pressure experiments….Confronted by this pressure disparity between US and Soviet work, in 1959, J.M. Walsh, a leading Los Alamos investigator, wrote directly to Al’tshuler with 16 questions. Al’tshuler answered 15 – the question left unanswered was “How do you achieve such high pressures?”[22] The answers lie in the research and techniques perfected by Danilenko and his fellow researchers at VNIITF, VNIIEF and other closed institutions.

Danilenko worked with many of the greats of Russian nuclear weapons science including Zababakhan, Krupnikov and Kuzlov on important national security issues. Krupnikov, who helped develop the electrical contact shock wave diagnostics for the first Russian nuclear weapon, worked on the conversion of shock-compressed graphite into diamond.[22, 23] Danilenko’s knowledge of shock compaction/compression instrumentation and techniques played a key role in the understanding of how different materials behave under varying conditions of pressure and temperature. The understanding and developing of these complex physical states of matter are an important parameter in the design of nuclear weapons. Danilenko is correct that he is not a physicist, and his contributions to nuclear weapons science should instead be looked at from the material science point of view.

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