The Tsar projectile
FOR NUCLEAR ARTILLERY

D. V. SHIRKOV

Almost everybody has heard about the Soviet nuclear and thermonuclear bomb projects that strengthened the victory in the Second World War and saved the world from the threat of a new global catastrophe. However, not many people know the story of the artillery fired atomic projectile or are familiar with its documentary evidence, previously classified. The author of this publication was the youngest laureate of the 1958 Lenin Prize awarded for the development of the new weapon that has played an important role in the superpowers' confrontation

Dmitry V. SHIRKOV is a theoretical physicist, Academician of the Russian Academy of Sciences (RAS).
His major scientific interests are quantum field theory and the theory of superconductivity and dispersion relations.
After the Siberian Branch of the USSR Academy of Sciences was set up, Dmitry Shirkov worked for ten years for the Institute of Mathematics, Siberian Branch; then was employed by the Joint Institute for Nuclear Research based in Dubna, Moscow Oblast, and Moscow State University.
The Lenin Prize (1958) and the USSR State Prize (1984) laureate. Author and co-author of over 200 papers

National atomic projects became a forced counter-move aimed at averting the new menace to peace which suddenly sprang at the end of the World War II. Soviet scientists and engineers, like their American colleagues, worked for the victory over the deadly peril. The triumph of the first developers of nuclear weapon though was tarnished by the barbaric and unwarranted nuclear fire against the Japanese cities. The pride many people in Russia feel for their researchers and other specialists who eliminated the threat of a new, this time atomic, world war has become even stronger in the last decades.

In August 1949, the first Soviet nuclear bomb test was successfully held, and since that time the USA lost its monopoly on nuclear weapon development. In 1953, after the world's first hydrogen aircraft bomb was tested in the USSR, the policy of a total nuclear dictate was no longer possible. Both these projects were developed by the best national scientists and specialists located in the closed town of KB-11 (or Arzamas-16, now Sarov).

Nevertheless, by the mid-fifties the American atomic arsenal remained far superior: the USA had several hundred nuclear bombs whereas the USSR had only a few. Technologically, uranium isotope separation was still a bottleneck. The possibilities of a Soviet second-strike in case of a nuclear attack were very limited.

In 1951, the USA held successful tests of artillery fired atomic projectiles. Two years later, similar research began in KB-11. In spring 1953, Academician Mikhail A. Lavrentiev was appointed head of theoretical and experimental work on developing a nuclear charge for the artillery fired projectiles. Having accumulated an impressive stockpile of achievements in mathematics and mechanics, organizational and engineering advances in experimental explosion physics and a rich experience in research administration, he appeared to be an excellent supervisor for the intricately related team of researchers, engineers, and designers. He was not only able to remember all the details and specific features of various scientific and technical auxiliary projects, but helped enthusiastically to deal with any problems arising in each of them.

Key words: nuclear weapon, artillery fired atomic projectile, nuclear explosive, implosion

Artillery self-propelled guns with nuclear ammunition at the military parade.
Moscow, November 7, 1957

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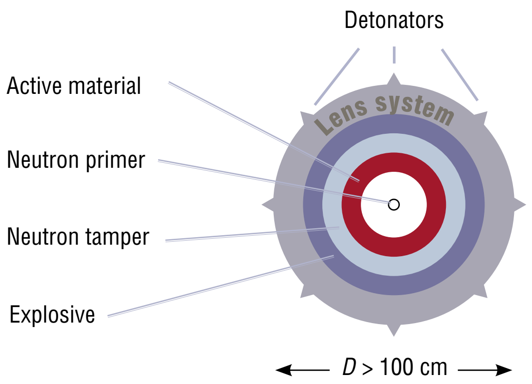
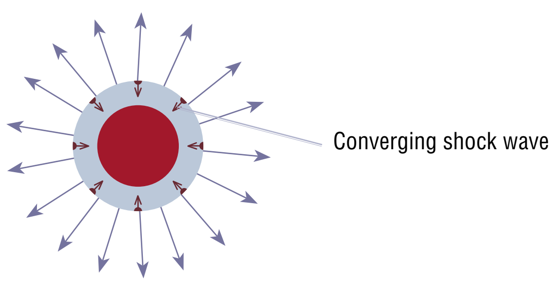




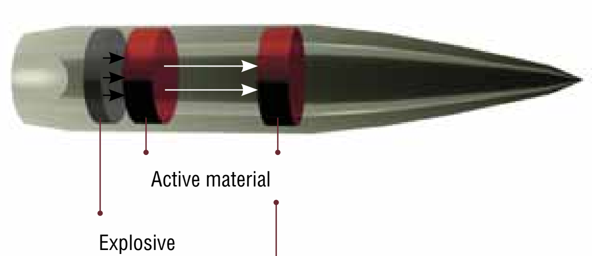
Spherical nuclear charge design (*top*) and its implosion-type blast (the shell is collapsing and the neutron primer is going off)

The physics of a nuclear bomb developed in the late 1940s was a sphere about 100 cm in diameter with a spherical nuclear charge. The nuclear charge was made out of the active material ^{235}U или ^{239}Pu and shaped as a thin-walled metal spherical shell, subcritical in the initial state. At the heart of the hollow core space was the neutron primer. On the outside, the active material was contiguous with a layer of the ^{238}U tamper; then went a layer of a solid explosive. This was surrounded with a lens system recording the shock wave from the detonators, which were located almost at the surface of the explosive's outer layer.

The bomb explosion was triggered by simultaneous initiation of the detonators. The lens system formed a virtually regular-shaped spherical shock wave converging inwards and compressing the spherical active material shell (this type of a nuclear charge blast is called *implosion*). The moment the shell collapsed into a sphere, a special primer was activated to inject neutrons into the structure, which triggered a chain reaction resulting in a blast.

Initiating nuclear interaction right at the moment of the shell collapse essentially reduced the probability of the so-called low-order detonation resulting from a premature start of the chain reaction that could be triggered, for instance, by a space radiation particle. Shock wave compression (spherical cogging and squeezing) of the active material made the critical mass much lower, which provided a noticeable economy of nuclear fuel

Gunshot approach of the active material critical mass in an artillery fired atomic projectile (USA, 1951)

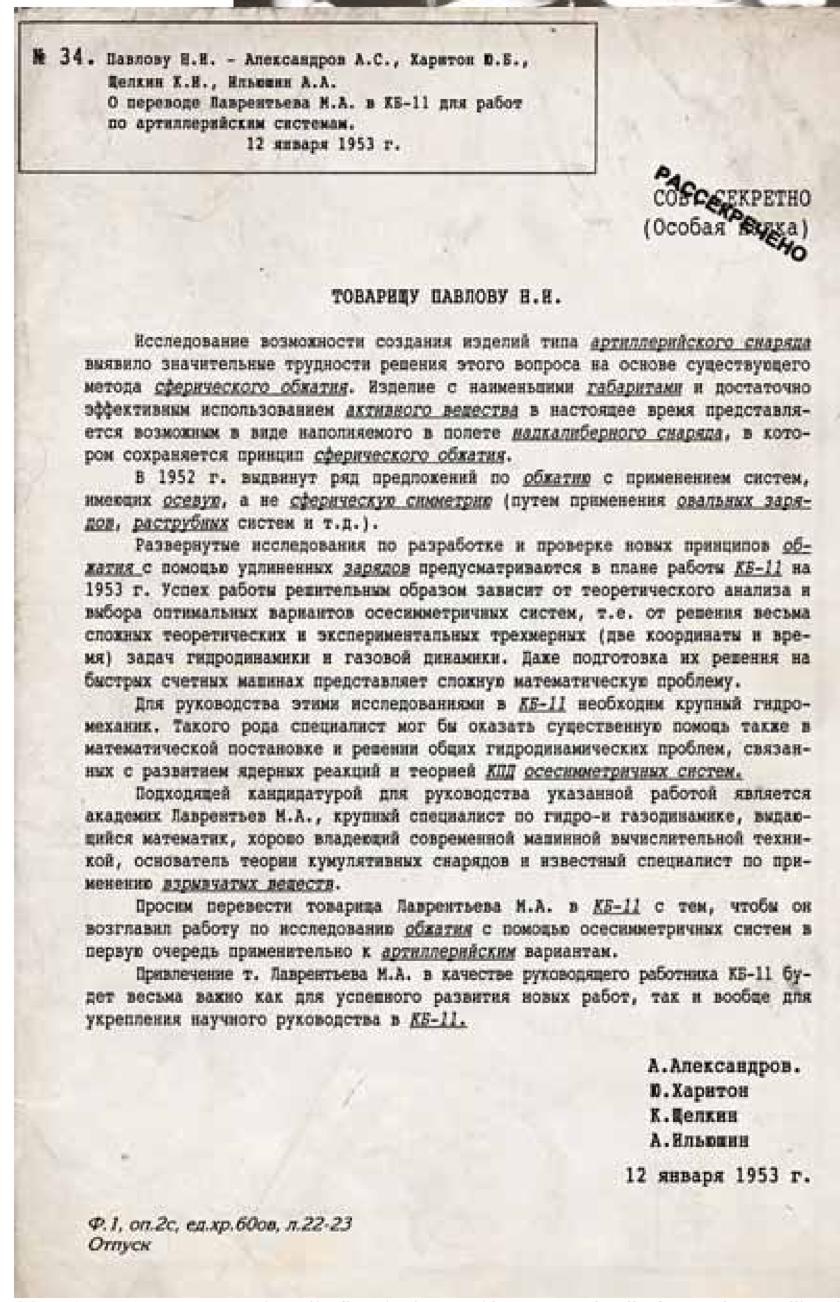


Nuclear stuffing for an artillery projectile about 40 centimeters in caliber could be done in different ways. Nuclear charge of the American 1951 projectile was triggered by the gun approach of two components of the critical mass active material in the flying projectile interior. The weaknesses of this way were low efficiency and high probability of a low-order burst. The Americans, having a sizeable stock of nuclear fuel, could afford such luxury. We may say that it was a projectile for the rich.

An implosion-type artillery fired atomic projectile (USSR, 1956)

The design of the nuclear charge developed by M. A. Lavrentiev's team looked rather like a melon that was to be positioned inside a cylinder artillery projectile. In actual fact, this was kind of a spherical charge considerably elongated along the polar diameter. In this case, the order of inner envelopes and the physics of the burst basically remained the same as for the spherical nuclear charge. We may say this was a projectile for the poor: its design was dictated by dire necessity

Academician M. A. Lavrentiev, a prominent Soviet mathematician and expert in mechanics and an outstanding administrator of national science, headed the USSR artillery fired atomic projectile project



№ 34. Павлову Н.И. – Александров А.С., Харитон Ю.Б., Щелкин К.И., Ильюшин А.А.
О переводе Лаврентьева М.А. в КБ-11 для работ по артиллерийским системам.
12 января 1953 г.

РАССЕКРЕЧЕНО
СОВ... СЕКРЕТНО
(Особая ...ка)

ТОВАРИЩУ ПАВЛОВУ Н.И.

Исследование возможности создания изделий типа артиллерийского снаряда выявило значительные трудности решения этого вопроса на основе существующего метода сферического обжатия. Изделие с наименьшими габаритами и достаточно эффективным использованием активного вещества в настоящее время представляется возможным в виде наполняемого в полете надкалиберного снаряда, в котором сохраняется принцип сферического обжатия.

В 1952 г. выдвинут ряд предложений по обжатию с применением систем, имеющих осевую, а не сферическую симметрию (путем применения овальных зарядов, раструбных систем и т.д.).

Развернутые исследования по разработке и проверке новых принципов обжатия с помощью удлиненных зарядов предусматриваются в плане работы КБ-11 на 1953 г. Успех работы решительным образом зависит от теоретического анализа и выбора оптимальных вариантов осесимметричных систем, т.е. от решения весьма сложных теоретических и экспериментальных трехмерных (две координаты и время) задач гидродинамики и газовой динамики. Даже подготовка их решения на быстрых счетных машинах представляет сложную математическую проблему.

Для руководства этими исследованиями в КБ-11 необходим крупный гидромеханик. Такого рода специалист мог бы оказать существенную помощь также в математической постановке и решении общих гидродинамических проблем, связанных с развитием ядерных реакций и теорией КПД осесимметричных систем.

Подходящей кандидатурой для руководства указанной работой является академик Лаврентьев М.А., крупный специалист по гидро-и газодинамике, выдающийся математик, хорошо владеющий современной машинной вычислительной техникой, основатель теории кумулятивных снарядов и известный специалист по применению взрывчатых веществ.

Просим перевести товарища Лаврентьева М.А. в КБ-11 с тем, чтобы он возглавил работу по исследованию обжатия с помощью осесимметричных систем в первую очередь применительно к артиллерийским вариантам.

Привлечение т. Лаврентьева М.А. в качестве руководящего работника КБ-11 будет весьма важно как для успешного развития новых работ, так и вообще для укрепления научного руководства в КБ-11.

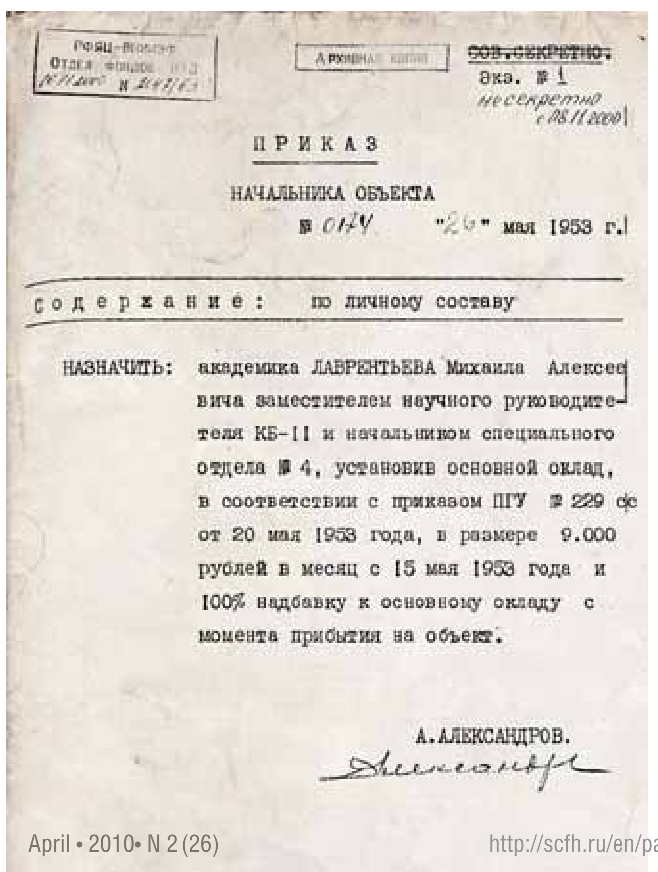
А.Александров.
Ю.Харитон
К.Щелкин
А.Ильюшин

12 января 1953 г.

Ф.1, оп.2с, ед.хр.60ов, л.22-23
Отпуск

The letter dated January 12, 1953 to General-Major N. I. Pavlov, a leader of the USSR Ministry for Nuclear Weapon Development and Production, stating the necessity of Academician M. A. Lavrentiev's involvement as a scientific supervisor of the artillery fired atomic projectile project. The letter was signed by KB-11 Director A. S. Aleksandrov, Scientific Supervisor Yu. B. Khariton, and Vice Directors K. I. Shchelkin and A. A. Iliushin

For M. A. Lavrentiev, management of the intricate scientific and organizational project was an important prelude to his lifework: setting up the Siberian Branch of the USSR Academy of Sciences.
From left to right: M. A. Lavrentiev, A. A. Deribas, and L. V. Ovsiannikov conducting an experiment at the Institute of Hydrodynamics, Siberian Branch, USSR Academy of Sciences (Novosibirsk)



Архивная копия

~~Сов. секретно.~~
Экз. № 1
несекретно
с 08.11.2000

ПРИКАЗ

НАЧАЛЬНИКА ОБЪЕКТА
№ 0174 "26" мая 1953 г.

Содержание: по личному составу

НАЗНАЧИТЬ: академика ЛАВРЕНТЬЕВА Михаила Алексеевича заместителем научного руководителя КБ-11 и начальником специального отдела № 4, установив основной оклад, в соответствии с приказом ПГУ № 229 сс от 20 мая 1953 года, в размере 9.000 рублей в месяц с 15 мая 1953 года и 100% надбавку к основному окладу с момента прибытия на объект.

А. АЛЕКСАНДРОВ.

Trouble with the "melon" design

The nuclear charge developed at KB-11 had to adhere to exceptionally rigid specifications not only in terms of size but also in terms of integrity of all its components, which was to be many times superior to that of the previously developed nuclear weapons in order to be able to cope with the huge overload.

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

MY BACKGROUND

I was completing my graduate studies at the Physics Department of Moscow University. In late 1948 I decided to prepare my graduate thesis under the supervision of Prof. N. N. Bogoliubov, a Corresponding Member of the USSR Academy of Sciences, who was very well-known at the University. A year before, he was awarded the Stalin Prize for his papers on theoretical physics, including the monograph Dynamic Equations of Statistical Physics.

I was given the task to simplify the kinetic transfer equation, i. e. the equation of neutron diffusion and moderation. This was a monstrous integral differential equation for the distribution function with three independent variables even for the case of spherical symmetry. In the general case, it could only be solved using cumbersome numerical calculations, and the approximations known (one-velocity, diffusion and age) were too rough for the practical applications in view. It is noteworthy that my boss just set the task without outlining any approaches to the solution.

The problem was exciting both technically and in substance: any serious advance could make numerical calculations much more economical, which would amount to a time gain. And this was a major factor in our activity: the first Soviet nuclear bomb was tested only in the August of the following year (1949).

In a few months, I made good progress in solving this problem. As the basis of a new approximation, I took simplification of the integral operator kernel, or the so-called dispersion index (I remember that the main idea hit me during the Moscow University Young Communists' meeting as I was sitting in the gallery – the place chosen specifically to be as far as possible from the other delegates – and got absorbed in thought as the spokesman rambled monotonously).

After the theoretical part of my studies was declassified in the mid-1950s, the method of the so-called synthetic nucleus in the diffusion theory and neutron moderation was published in the *Atomnaya energiya* journal. It became clear with time that the American colleagues had failed to think of anything equivalent. Powerful computer facilities seem to indulge the philosophy "If you have a computer, you don't need brain."

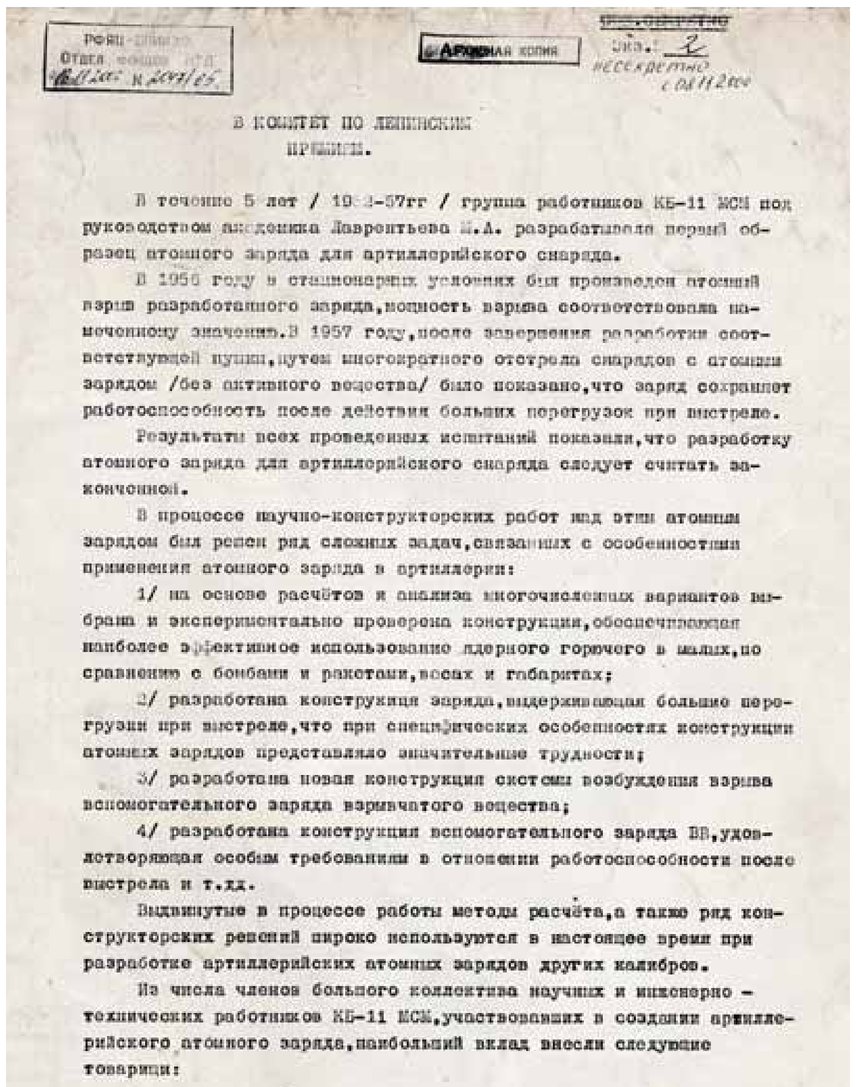
...By the time M. A. Lavrentiev made his appearance at KB-11, I was only 25 but I had gone a four-year-long way with N. N. Bogoliubov, from a graduate student to a participant in the hydrogen bomb project. I had managed to invent and tune up a simple and accurate method for reporting neutron slowdown and diffusion in the media containing light hydrogen and deuterium nuclei. I had presented this work as my candidate's thesis to a commission including I. V. Kurchatov himself and received my first award – the Order of the Red Banner of Labor – for participation in the project.

D. V. Shirkov in May 1950, upon arrival at KB-11

I believe it was owing to these results, N.N. Bogoliubov's reference, and approval of high authorities that I was entrusted with calculating the chain reaction development from the moment of the implosion wave convergence towards the center and possibility of a low-order detonation. This was how I became a member of M.A. Lavrentiev's team, where I worked for the following three years on the development of nuclear filling for an artillery fired projectile.

...Nuclear charge tests at the Semipalatinsk test site held in March 1956 were postponed by several days because of improper weather conditions (the wind was blowing towards the town). Waiting for the appropriate weather at the bank of the Irtysh River, Lev V. Ovsiannikov and I invented the "chess gamble" (a game of chance in which one should throw the dice before every move, which was designed to counterpoise his excellence and my adventurism) and discussed non-classified science. Lev got interested in the functional equations of the renormalization group in the quantum field theory I was then involved in, and in a few days found a solution. A paper with his results was presented by N. N. Bogoliubov to the *Doklady Academii Nauk (Proceedings of the Academy of Sciences)* only three weeks after our nuclear charge was successfully tested under Semipalatinsk.

World War II veterans, laureates of the Lenin Prize (1958) for the development of the artillery fired atomic projectile (from left to right): L. V. Ovsiannikov (hydrodynamic cogging and squeezing calculations), V. M. Nekrutkin (development of hydrodynamic cogging and squeezing), and A. I. Abramov (designer)



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АРХИВНАЯ КОПИЯ

Экз. № 2
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В КОМИТЕТ ПО ЛЕНИНСКИМ ПРЕМИЯМ.

В течение 5 лет / 1952-57гг / группа работников КБ-11 МСМ под руководством академика Лаврентьева М.А. разрабатывала первый образец атомного заряда для артиллерийского снаряда.

В 1956 году в стационарных условиях был произведен атомный взрыв разработанного заряда, мощность взрыва соответствовала намеченному значению. В 1957 году, после завершения разработки соответствующей пушки, путем многократного отстрела снарядов с атомным зарядом /без активного вещества/ было показано, что заряд сохраняет работоспособность после действия больших перегрузок при выстреле.

Результаты всех проведенных испытаний показали, что разработку атомного заряда для артиллерийского снаряда следует считать законченной.

В процессе научно-конструкторских работ над этим атомным зарядом был решен ряд сложных задач, связанных с особенностями применения атомного заряда в артиллерии:

1/ на основе расчётов и анализа многочисленных вариантов выбрана и экспериментально проверена конструкция, обеспечивающая наиболее эффективное использование ядерного горючего в малых, по сравнению с бомбами и ракетами, весах и габаритах;

2/ разработана конструкция заряда, выдерживающая большие перегрузки при выстреле, что при специфических особенностях конструкции атомных зарядов представляло значительные трудности;

3/ разработана новая конструкция системы возбуждения взрыва вспомогательного заряда взрывчатого вещества;

4/ разработана конструкция вспомогательного заряда ВВ, удовлетворяющая особым требованиям в отношении работоспособности после выстрела и т.д.

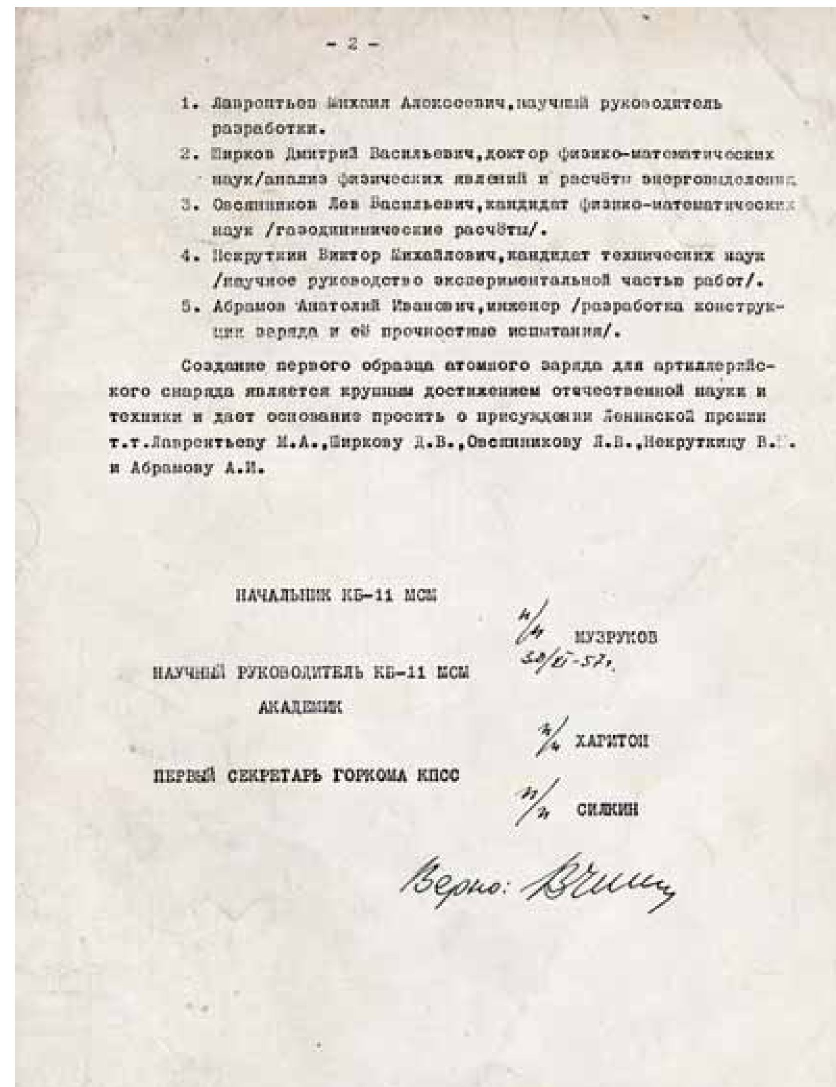
Выдвинутые в процессе работы методы расчёта, а также ряд конструкторских решений широко используются в настоящее время при разработке артиллерийских атомных зарядов других калибров.

Из числа членов большого коллектива научных и инженерно-технических работников КБ-11 МСМ, участвовавших в создании артиллерийского атомного заряда, наибольший вклад внесли следующие товарищи:

Letter of November 30, 1957 to the Lenin Prize Committee to the effect of putting forward for the high award KB-11 scientists and engineers who had contributed most to the development of the artillery projectile nuclear charge

the transformation of the originally hollow thin-walled shell of the active material together with the adjoining neutron-reflecting heavy ^{238}U shell into a supercritical two-layer slightly elongated quasi-spherical body, into which neurons from the primer were injected. This design, basic for a nuclear explosion, is axisymmetrical and not spherically symmetrical. The additional variable arising in this situation essentially complicated the estimates, done at the time virtually without computers. As a result, the theoreticians had not only to find simplified physically adequate models (equations) but also to transform them to the form that lent itself easily to arithmometer calculations. The requirements imposed on the numerical methods used in the estimates were high as well: they had to be simple, economical, stable and sufficiently accurate. An important role was played by the mathematician V. S. Vladimirov, a future Academician and Hero of Socialist Labor.

Physical research into the new product and its design were assigned to distinguished physicists-experimentalists, experienced designers and engineers who had taken part in the development of the atomic and hydrogen bombs. At the same time, M. A. Lavrentiev entrusted fundamental theoretical research to a young team, whose oldest member L. V. Ovsiannikov (in charge of hydrodynamic calculations) was 34 years old. Last spring, in Novosibirsk's Academgorodok, we congratulated the Advisor of the Russian Academy of Sciences, Academician L. V. Ovsiannikov on his 90th anniversary.



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1. Лаврентьев Михаил Алексеевич, научный руководитель разработки.
2. Ширков Дмитрий Васильевич, доктор физико-математических наук/анализ физических явлений и расчёты энерговыделения.
3. Овсянников Лев Васильевич, кандидат физико-математических наук /газодинамические расчёты/.
4. Некруткин Виктор Михайлович, кандидат технических наук /научное руководство экспериментальной частью работ/.
5. Абрамов Анатолий Иванович, инженер /разработка конструкции заряда и её прочностные испытания/.

Создание первого образца атомного заряда для артиллерийского снаряда является крупным достижением отечественной науки и техники и дает основание просить о присуждении Ленинской премии т.т. Лаврентьеву М.А., Ширкову Д.В., Овсянникову Л.В., Некруткину В.М. и Абрамову А.И.

НАЧАЛЬНИК КБ-11 МСМ — п/п МУЗРУКОВ 30/XI-57.

НАУЧНЫЙ РУКОВОДИТЕЛЬ КБ-11 МСМ АКАДЕМИК — п/п ХАРИТОН

ПЕРВЫЙ СЕКРЕТАРЬ ГОРКОМА КПСС — п/п СИЛКИН

Верно:

Lev V. Altshuler, a World War II veteran, was awarded the Stalin Prize of the first and second degree for determining the density and maximum pressure at the center for the first atomic and hydrogen bomb explosions as well as for testing the shock wave cogging and squeezing of the structural elements. He has contributed greatly to the atomic projectile project

Artillery self-propelled vehicles from which atomic projectiles were to be fired, developed by the Ivanov Design Bureau; now kept at the War and History Museum of Artillery, Engineer Troops and Signal Corps of the Russian Defense Ministry (St Petersburg)

Nuclear Weapons Museum in Sarov. From left to right: the first national nuclear (1949) and production-line nuclear (1953, *top*) bombs, the world's first hydrogen (thermonuclear) bomb (1953); an artillery fired atomic projectile (1956)

Projectile test successful

By late 1955, all the mathematics, theoretical grounding, and hydrodynamic studies of the nuclear charge had been completed. Also, a bulk of experimental work had been carried out including testing the construction for integrity. Since at that time KB-11 had no equipment appropriate for conducting such tests, new appliances had to be developed. At the head of these developments M.A. Lavrentiev put experimentalist B.V. Voitsehovskiy, the future Academician and author of over a hundred inventions, whose ingenuity impressed the most experienced KB-11 designers: he was able to find easy solutions to the problems that many specialists considered unsolvable.

The main test of the new nuclear charge was held at the Semipalatinsk test site in March 1956. Present at the test were the specialists charged with the development of the construction, including theoreticians. This tradition was attributed to the need for getting prompt and comprehensive advice in case of an emergency. However, this time it was not necessary. The nuclear charge detonation demonstrated the peak of its estimated capacity. This was a total and well-deserved success.

Completion of the development of tactical atomic artillery, however, took some more time. The production of self-propelled guns, capable of firing atomic projectiles took longer than expected; experimental shooting with billets was conducted only in late 1956, at the Rzhev test site. Those were dynamic reaction pieces of ordnance (Design Bureau of V.G. Grabin, who had developed the legendary Katiusha) and conventional recoil weapons (I.I. Ivanov Design Bureau).

After the cumbersome self-propelled systems were finalized, they were displayed to the world at the military parade on the occasion of the 40th anniversary of the October revolution: two huge artillery vehicles designed to fire atomic projectiles crawled across the Red Square. The foreign defense attaches present at the parade were astounded. That was that, however. Artillery fired nuclear weapons were never produced on a full scale – the era of missiles began!

Two years later, our achievement was crowned with high governmental awards. The main participants of the project from M.A. Lavrentiev's team received the Lenin Prize, resumed in 1957.

The list of the Lenin Prize laureates for the year 1958 included Mikhail A. Lavrientiev (head of the project), Anatoly I. Abramov (designer of the construction), Victor M. Nekrutkin (development of hydrodynamic cogging and squeezing), Lev V. Ovsiannikov (hydrodynamic cogging and squeezing calculations), and Dmitry V. Shirkov (nuclear reaction calculations).

By right, Lev V. Altshuler (measurement techniques and execution of simulated hydrodynamic cogging and squeezing) should have been on the list – put forward for the award, he was crossed out later for making a stand for genetics.

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The editors thank the Nuclear Weapons Museum (Sarov) and its Director V.I. Lukianov for the materials presented