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Soviet Atomic Project and FIAN
(on the 75th anniversary of the Atomic industry)

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Contents

Abstract. This article is based on the report delivered by B L Altshuler and V I Ritus at the scientific session, "75 years of the Atomic industry. Contribution of the Academy of Sciences," of the General meeting of the Department of Physical Sciences of the Russian Academy of Sciences (RAS) on December 7, 2020. It describes the role of the Lebedev Physical Institute of the Academy of Sciences (FIAN) in the Soviet Atomic Project and presents FIAN's research teams and specialists who participated in the project.

Keywords: Soviet Atomic Project, contribution of the Lebedev Physical Institute to the Soviet Atomic Project

1. Introduction

I dedicated the presentation of this report, which took place at the General meeting of the Department of Physical Sciences of the Russian Academy of Sciences (Moscow, December 7, 2020), to the memory of Vladimir Evgenyevich Fortov, who died of COVID on November 29, 2020, eight days before the meeting. In November 2021, *Uspekhi Fizicheskikh Nauk* (*UFN*) [*Physics–Uspekhi* (*Phys. Usp.*)] published a special issue dedicated to the memory of V E Fortov [1]. In particular, it contained one of the last articles written by my father, L V Altshuler, and by V E Fortov and R I Il'kaev [2] on the topic of Altshuler's and Fortov's main joint activity: extreme states of matter at high pressures, the exploration of which played a very significant role in the Atomic Project.

V E Fortov, a student of my father's, actively collaborated with him and helped a lot when my father was ill (he died in 2003 at the age of 90). I am very grateful to Vladimir Evgenyevich for the book about my father, *Lev Altshuler's Extreme States* [3], on the creation of which he insisted and which we prepared with him in 2011. Thanks to this book, which contains many documents and memoirs on the history of the Soviet Atomic Project, I have become an expert in this field. But I also became an expert because, in preparing for Andrei Sakharov's centenary, I again read a great deal on this topic, in particular, the materials published by *UFN* [4–16]. This report is also essentially based on V I Ritus's publications in *UFN* [17–19], in the *Priroda* journal [20], and in the collection of memoirs about A D Sakharov [21]. The unique collections of documents pertaining to the Soviet Atomic Project [22, 23], which were used in preparing this report, should also be mentioned.

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2. Introduction. Historical background

Prior to proceeding to the topic of the USSR and the Lebedev Physical Institute of the USSR Academy of Sciences (FIAN), which was involved in the creation of a hydrogen bomb in June 1948, it is worth outlining some events that occurred earlier.

On August 6 and 9, 1945, American atomic bombings of Hiroshima and Nagasaki took place (photo 1a, b). On August 9, the USSR declared war on Japan. After the atomic

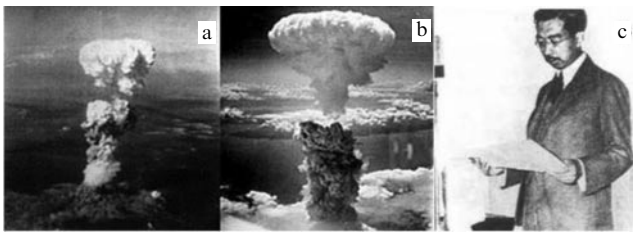

Photo 1. Nuclear 'mushrooms' above Hiroshima (a) on August 6, 1945 and Nagasaki (b) on August 9, 1945; Emperor Hirohito (c) in photo taken on August 15, 1945.

bombing of Hiroshima, the military and political leadership of Japan did not show any readiness to surrender. On August 10, after the bombing of Nagasaki and the collapse of the hope for a separate peace with the USSR, the opinions of six members of the Japanese cabinet of ministers were divided equally: three members were for surrender and three 'hawks' were against it. Decisive was the opinion of the 'divine emperor' who inclined to capitulation. On August 14, a corresponding radio address by Hirohito to the nation was prepared. On the same day, a military mutiny of 'hawks' occurred, which fortunately was suppressed. On August 15, the emperor read out on the radio an appeal for the surrender of Japan (photo 1c).

In the following days and weeks, hundreds, it should be emphasized, hundreds of Japanese senior officers went to Tokyo's central square to commit hara-kiri. Apparently, they were ready to conduct warfare to the last Japanese.

It is a historical fact that the quick surrender of Japan and the end of World War II on September 2, 1945, including due to the atomic attacks on Hiroshima and Nagasaki, saved the lives of hundreds of thousands or, perhaps, millions of people, if we speak about the people of Japan.

At the same time, the horror of every normal human from the instantaneous burning of a hundred thousand people is quite natural. The atomic bombings of Hiroshima and Nagasaki became forever a severe warning and a clear demonstration of the impossibility of nuclear war. This deterrent has been 'operative' for decades, preventing World War III.

Here, it is appropriate to quote Andrei Dmitrievich Sakharov:

''By now, thermonuclear weapons have never been used against people in war. My most passionate dream (deeper than anything else) is that this would never happen; that thermonuclear weapons deter war but would never used'' [24, part I, Ch. 6].

3. USSR: impact of US atomic bombings of Japan

On August 20, 1945, to manage all the activities related to the use of atomic energy from uranium, the USSR State Defense Committee (GKO) established by its decree no. GKO-9887ss/ov a ''Special Committee under the GKO'' under the chairmanship of Lavrentiy Beria, then head of the NKVD. By the same decree, the First Main Directorate (PGU) was created under the Special Committee, which was responsible for organizing 'atomic' work under the guidance of B L Vannikov. I V Kurchatov was appointed the scientific director of the Soviet Atomic Project.

On November 30, 1945, the GKO's Special Committee approved a proposal to select a site (on the southern shore of Lake Kyzyl-Tash in the Chelyabinsk Region) for the construction of the Mayak plant (factory no. 817) for the production of nuclear weapons components.

On April 9, 1946, a decree was issued on the creation in city of Sarov of Design Bureau No. 11 (KB-11, Arzamas-16, 'the object', now the Russian Federal Nuclear Center–All-Russian Research Institute of Experimental Physics (RFNC–VNIIEF)); it was subordinate to Laboratory No. 2 of the USSR Academy of Sciences, later the Kurchatov Institute of Atomic Energy (IAE) (now the National Research Center Kurchatov Institute.) Yu B Khariton was appointed the chief designer at KB-11.

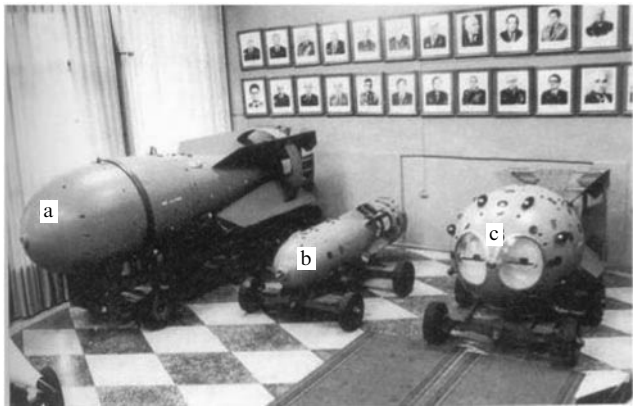

Photo 2. Three bombs (Museum of Nuclear Weapons in Sarov). Left to right: (a) World's first hydrogen bomb (RDS-6s) — Sakharov–Ginzburg 'sloika', 400 kt TE (1953); (b) atomic bomb designed in the USSR (RDS-2), 40 kt TE (1951); (c) first Soviet atomic bomb (RDS-1), 22 kt TE (1949).

The first Soviet atomic bomb (photo 2c) was successfully tested on August 29, 1949. It was an exact copy of the American 'Fat Man' dropped on Nagasaki. The bomb was designed based on intelligence data obtained from Klaus Fuchs and a number of other atomic scientists, participants in the Manhattan Project, who risked their lives to restore nuclear parity between the USSR and the USA.

The bomb shown in the center (labelled with a letter b in photo 2b), which was adopted by the army, is smaller and twice as powerful as the 'American' one; it was designed according to the famous 'Report of Four' of 1948 (L V Altshuler, E I Zababakhin, Ya B Zel'dovich, and K K Krupnikov). Shown to the left of it is the Sakharov–Ginzburg 'sloika' (puff) (labelled with a letter a in photo 2a). It is described in more detail below.

It should be noted here that the selection of the bomb to be tested first — the 'American' or the more advanced Soviet-made — was by no means decided by voting at some academic council. The recent TV series, ''Bomb,'' shows that the type of reactor for the Mayak plant was chosen exactly in this way, and it looks laughable. The decision to make the first bomb based on intelligence information was taken by L P Beria himself. He understood better than anyone else what Stalin would do to him if the test failed and could not allow risky 'amateur activity' on this issue.

The specialists at the facility (with the exception of Yu B Khariton, Ya B Zel'dovich, and probably K I Shchelkin) had no idea whatsoever about the very fact of the existence of intelligence data. It was a secret of the highest national level, since its disclosure, which could put a functioning intelligence network under risk, was apparently unacceptable. My father said that he would never receive an intelligible answer when asking Yu B Khariton why they implemented a less perfect A-bomb design. In the ''Bomb'' series, many people are aware of the intelligence data, which is also ridiculous.

I watched all eight episodes of ''Bomb'' because the newspaper *Troitskii Variant* asked me and some of my colleagues to share our opinions on it (see [25]). I can say that, despite the above and some other inaccuracies, the series, in my opinion, is very impressive and historically correct, including the presentation of the four leaders of the atomic saga (photo 3).

I was very pleased with the image of Yulii Borisovich Khariton, ''a special person,'' as Ya B Zel'dovich called him.

BERIA
Lavrentiy Pavlovich
(1899–1953)

VANNIKOV
Boris Lvovich
(1897–1962)

KURCHATOV
Igor' Vasilyevich
(1903–1960)

KHARITON
Yulii Borisovich
(1904–1996)

Photo 3. Four heads of the Soviet Atomic Project: L P Beria, B L Vannikov, I V Kurchatov, and Yu B Khariton.

The image of Igor Vasilyevich Kurchatov is also quite adequate. Both he and Khariton were very attentive to their colleagues, and this is shown in the film. And the plump, as in life, Boris Lvovich Vannikov really was on very good terms with Kurchatov and Khariton.

It is also a historical fact that Beria treated atomic scientists in a completely different way than the victims in his dungeons. The truth is also that, for Beria, the intimate relationship between a super-valuable and top-secret scientist and a female prisoner, who is executed in the film after Beria finds out about her existence, was unacceptable. In his review of the "Bomb" series, A Yu Semyonov, biophysicist and grandson of N N Semyonov and Yu B Khariton, writes: "When I asked my grandfather about his personal impressions from communicating with Beria, he literally said: 'When I had to talk with him, I clearly understood that this was the most terrible of the people I had ever known or met in my life'" [25]. The "Bomb" series, in my opinion, accurately shows the horror of the Stalin era.

However, the film also shows another historical truth: the enthusiasm and self-sacrifice with which scientists worked on the Atomic Project and their conviction that this work was of utmost importance. I will reproduce a story told by my father, L V Altshuler: "I remember how once in the summer of 1946 I was walking around Moscow with a friend of mine who commanded the artillery of the military corps during the war. It was a clear sunny day. Looking at the pedestrians, my companion ran his hand over his face and suddenly said: 'I look at the Muscovites out for a stroll, and before my eyes they turn into the shadows of people evaporated in the fire of an atomic explosion.' For everyone who understood the reality of the coming atomic era, the rapid creation of Soviet atomic weapons, which was necessary for restoring world balance, had become a 'categorical imperative'" [3, p. 93].

4. FIAN and bombs

It should be said that FIAN, specifically the Atomic Nucleus Laboratory headed by Dmitrii Vladimirovich Skobel'tsyn (photo 4), was involved in the Atomic Project starting in 1944. Of course, all the activities, both at that time and later, in the 'hydrogen' period, were guided by Sergei Ivanovich Vavilov, FIAN director (see photo 4). All top-secret documents and assignments sent to FIAN were submitted to Vavilov and signed by him. In 1946, D V Skobel'tsyn was appointed the director of the newly established Research Institute of Nuclear Physics of Moscow State University.

In 1945, the GKO issued a Decree which ordered FIAN to carry out research agreed upon with Laboratory 2. The decree pertained to studying nuclear reactions for nuclear reactors under development. Ilya Mikhailovich Frank headed this work at FIAN (photo 5). Evgenii Lvovich Feinberg, a member of the Department of Theoretical Physics, also participated in the activities [26] (see photo 5).

At the same time, the Department of Nuclear Physics was formed at FIAN, which included the Laboratory of Cosmic Rays, V I Veksler's laboratory, which was engaged in the design of particle accelerators, and I M Frank's Laboratory, which studied neutron multiplication in a uranium-graphite cube, nuclear dd- and dt-reactions, scattering of fast neutrons on lithium, and the interaction of gamma rays with heavy nuclei. It is for the measurement of the cross sections of these reactions and processes that I M Frank and his colleagues, I Ya Barit, E M Balabanov, L N Katsaurov, V V Nefyodov, I V Shtranikh, and G E Belovitskii, were awarded the Stalin prize on December 31, 1953. Along with them, the Stalin prize was awarded to FIAN theorists I E Tamm, A D Sakharov, V L Ginzburg, S Z Belenky, E S Fradkin, and V I Ritus.

VAVILOV
Sergei Ivanovich
(1891–1951)

SKOBELTSYN
Dmitrii Vladimirovich
(1892–1990)

Photo 4. S I Vavilov, FIAN director (1934–1951), and D V Skobeltsyn, head of the Laboratory of the Atomic Nucleus and later FIAN director (1951–1972) [12, 15, 16].

FRANK
Ilya Mikhailovich
(1908–1990)

FEINBERG
Evgenii Lvovich
(1912–2005)

Photo 5. I M Frank, head of the Laboratory of the Atomic Nucleus at FIAN, and E L Feinberg, a theoretician at the FIAN Theoretical Department.

5. Special team of FIAN's Theoretical Department

In 1945, Klaus Fuchs smuggled into the USSR data not only on atomic weapons but also on ongoing research conducted in the United States that aimed at the creation of charges more powerful than the A-bomb: thermonuclear, or hydrogen, weapons. These American studies were focused on the program of the so-called 'classical Super.'

In 1946, Ya B Zel'dovich (photo 6) and collaborators (S P Dyakov and A S Kompaneets, researchers at the Institute of Chemical Physics of the USSR Academy of Sciences) were ordered to develop a design of a hydrogen bomb that would correspond to intelligence data (see [27–29]). This design was called the 'pipe' (RDS-6t; in the USA, 'Super'). A few years later, studies carried out in the United States showed that this scheme was a dead end, and in 1950 it was abandoned. In the USSR, Zel'dovich's group also encountered serious difficulties in their attempts to implement the 'pipe' scheme.

In that challenging situation, the USSR Council of Ministers issued a decree on June 10, 1948 creating support groups in a number of institutes, including FIAN, which were supposed to fulfill the tasks set by Yu B Khariton and Ya B Zel'dovich to advance the 'pipe' project.

At FIAN, this special group was headed by Igor' Evgenyevich Tamm; Semyon Zakharovich Belenky was appointed his deputy; the group also included Vitaly Lazarevich Ginzburg, Yuri Aleksandrovich Romanov, Andrei Dmitrievich Sakharov, and Efim Samoilovich Fradkin. The decree also instructed Vladimir Aleksandrovich Fock to take part in the activities of the FIAN special group.

A historical picture (photo 7) was taken much later than the events described here: the meeting occurred during the first and only visit of Niels Bohr to the USSR, a year before his death.

I E Tamm participated in the Atomic Project from the very beginning; he made calculations of the shock waves, which were experimentally studied by L V Altshuler (my father). Of course, they knew each other, and I, a teenager, heard at home a lot of good things about Igor' Evgenyevich. Tamm is very vividly remembered by Sakharov. This refers to

ZEL'DOVICH
Yakov Borisovich
(1914–1987)

Photo 6. Ya B Zel'dovich, head the theoretical departments at the Institute of Chemical Physics of the USSR Academy of Sciences (1946–1948) and at Arzamas-16 (1948–1963), one of the leading participants in the Atomic Project.

Photo 7. Niels Bohr (1885–1962) and Igor' Evgenyevich Tamm (1895–1971) in Moscow (May 1961).

about 1950, when three members of the special team (Tamm, Sakharov, and Romanov) were transferred to work at the Sarov-based facility.

"In early April (1950), Igor' Evgenyevich Tamm was instructed to go to the facility. I remember how we met him at the airport. He got off the plane with a backpack over his shoulders, holding skis in his hands (they proved to be useful yet), squinting from the bright April sun. With his arrival, our life — both work and leisure — was greatly revived.

Three of us (I E, Romanov, and I) usually had breakfast and lunch together. Igor' Evgenyevich would recount the news — politics, sports, general interest — that he learned from foreign radio broadcasts (he regularly listened to the BBC in English and Russian, which was quite unusual at that time). We learned from him about the first ascent of Everest in 1953 by Hillary and Tenzing; I recollect this event today, when members of the Soviet expedition, led by Tamm's son

BELENKY
Semyon Zakharovich
(1916–1956)

SAKHAROV
Andrei Dmitrievich
(1921–1989)

GINZBURG
Vitaly Lazarevich
(1916–2009)

Photo 8. S Z Belenky, Tamm's deputy on the FIAN special team, and A D Sakharov and V L Ginzburg, members of the special team.

Zhenya, climbed Everest. Igor' Evgenyevich did not let us turn 'sour'; being himself an enthusiastic and sociable person, he also forced us to pursue our R&R in an active and fun manner. Evening games of chess and their variations were in fashion among us (four players, blindfolded vis-a-vis one's opponent's pieces, etc. I E showed us the Chinese games 'Go' and 'choosing stones'; the latter allows being algorithmized based on the 'golden section,' and we tried to puzzle it out). There were skiing and hiking trips, and — in the summer — swimming trips (in this sport, I was a complete loser, but I E tactfully saved me from unnecessary grief)'' (A D Sakharov, *Memoirs*, [24, part I, Ch. 7 and 8]).

Tamm's deputy on the special team was Semyon Zakharovich Belenky [30] (photo 8). It was he who, after the creation of the special team, as Sakharov recalls, melancholically said: ''So, our task is to kiss Zel'dovich's ass,'' but it turned out differently. Semyon Zakharovich was very ill, so he was not sent to Sarov.

Recalls V I Ritus: ''I met Semyon Zakharovich in 1954 when discussing my work sent to *Zh. Eksp. Teor. Fiz.* (*JETP*), and had closer contact with him in 1955, when I joined the theoretical department. He was a pleasant, witty, wise, and decent man. His premature death in 1956 was a shock to all members of the Theoretical Department.

V L Ginzburg invited Semyon Zakharovich into his group, which also included E S Fradkin. At the beginning of 1953, Belenky, Ginzburg, and Fradkin carried out calculations on mixing in a 'sloika,' taking into account both the initial perturbations during compression and the shock wave that locks the lighter layer. They also took into account the effect of radiation viscosity on mixing'' [19].

Photo 8 shows A D Sakharov and V L Ginzburg in 1948 when the special team was formed at FIAN.

G E Gorelik's book about Sakharov, *Nauka i svoboda* (Science and Freedom) [31], describes in detail the historical events; it was that very time when major newspapers published a devastating article about V L Ginzburg, who ''discredits Soviet science.'' It is known that it was the bomb that saved Soviet physics from a 'Lysenko-type pogrom.'

At the beginning of May 1949, unexpectedly and without any explanation, the All-Union Conference of Physicists, scheduled for May 10 and advertised for a year, was canceled. At the meeting, 'idealistic' quantum mechanics and the theory of relativity were to be lambasted and finally exterminated together with FIAN, the den of idealism in physics.

A few days before the meeting, NKVD officers woke up Vladimir Aleksandrovich Fock at night and delivered him by plane from Leningrad to Moscow. At the Kremlin, high authorities, possibly Stalin himself, ordered him to the blackboard to talk about quantum mechanics and the theory of relativity, and to explain why they are necessary for creating the atomic bomb. After the Kremlin night lecture, Fock came to Tamm's house early in the morning to have a long sleep on a couch. It is also known that a frank conversation occurred between Beria and Kurchatov. Anyway, the meeting was canceled. It was only Stalin who could give such an order, since all such pogrom campaigns were his personal initiative and, obviously, no one would dare object.

Photo 9 shows Yuri Aleksandrovich Romanov, a member of the special team (see [32]; he had very good memories of Sakharov ([33] and in collection [21]), as well as I E Tamm [34]), and Vladimir Aleksandrovich Fock, who needs no introduction (see [35]).

Efim Samoilovich Fradkin, a member of the special team, was fighting at the front line, where he was seriously wounded. He came to FIAN immediately after demobilization, in military uniform (see photo 9). Writes A D Sakharov: ''in our entire company, Fradkin was the only one who achieved that level of a highly-professional 'cutting-edge' theoretical physicist that we all dreamed of'' [24, part I, Ch. 5].

6. Physics of the 'sloika' (RDS-6s)

Recalls Sakharov:

''For two months, I diligently studied the reports of the Zel'dovich group, while also improving my then very meager knowledge of gas dynamics and astrophysics (the latter was needed, since the physics of stars and the physics of a thermonuclear explosion have much in common). At that time, we all studied gas dynamics in the corresponding volume of the remarkable multi-volume monograph by Landau and Lifshitz. I pondered these subjects continuously.

ROMANOV
Yurii Aleksandrovich
(1926–2010)

FOCK
Vladimir Aleksandrovich
(1898–1974)

FRADKIN
Efim Samoilovich
(1924–1999)

Photo 9. Members of FIAN's special team: Yu A Romanov, V A Fock, and E S Fradkin, participants in the Atomic Project.

After two months, I made a sharp turn in my work: namely, I proposed an alternative design for a thermonuclear charge; it was completely different from that considered by the Zel'dovich group in what regards the physical processes occurring during the explosion and even the main source of energy release. Below, I call this proposal 'Idea 1.'

Soon, Vitaly Lazarevich Ginzburg significantly enhanced my proposal by putting forward 'Idea 2'" [24, part 1, Ch. 6].

A schematic drawing of the Sakharov–Ginzburg 'sloika' was made at my request on the basis of numerous open descriptions (I have published it in [36, p. 14] and [37, p. 454]). The numerical parameters (dimensions, etc.) of the elements indicated in the figure remain secret, not subject to disclosure, and, according to the Treaty on the Non-Proliferation of Nuclear Weapons, will forever remain so.

The 'sloika' is an 'ordinary' atomic bomb, supplemented by alternating 'light' layers of thermonuclear fuel and 'heavy' layers of uranium-238 ('Idea 1' — the 'layered cake' — was proposed by A D Sakharov). V L Ginzburg's 'Idea 2' was to use as a thermonuclear fuel not heavy water or liquid heavy ethane (as Sakharov originally proposed), but solid lithium-6 deuteride. It should be said that the use of solid lithium deuteride as a fuel was proposed earlier in 1946 by the group of Ya B Zel'dovich, A S Kompaneets, and S P Dyakov at the Institute of Chemical Physics, and Ginzburg's proposal was to enrich lithium deuteride with the ^{6}Li isotope, which, unlike the main isotope ^{7}Li, is actively fissioned by neutrons, forming helium and tritium. The cross section for thermonuclear fusion reactions involving tritium is approximately two orders of magnitude larger than that for reactions involving deuterium. Consequently, the energy release of a hydrogen bomb with tritium as a thermonuclear fuel will also be higher. However, obtaining tritium is an extremely expensive process, and, most importantly, tritium is unstable, so long-term storage of thermonuclear charges with tritium is impossible. V L Ginzburg's proposal enabled obtaining tritium in reactions involving ^{6}Li directly at the moment of the explosion. It was for this proposal that Ginzburg was awarded the Stalin Prize of the 1st degree and elected a corresponding member of the USSR Academy of Sciences [20].

The physical foundations of the 'sloika' are described in sufficient detail in V I Ritus's articles [17–20].

The primary fusion reactions of deuterium nuclei in light layers are:

$$\mathrm{D} + \mathrm{D} = \mathrm{p} + \mathrm{T} + 4\ \mathrm{MeV}\,,$$

$$\mathrm{D} + \mathrm{D} = \mathrm{n} + {}^3\mathrm{He} + 3.3\ \mathrm{MeV}\,.$$

The tritium nuclei (T) and helium nuclei (^{3}He) formed in these reactions, in turn, are involved in secondary thermonuclear reactions:

$$\mathrm{T} + \mathrm{D} = \mathrm{n} + {}^4\mathrm{He} + 17.6\ \mathrm{MeV}\,,$$

$$^3\mathrm{He} + \mathrm{D} = \mathrm{p} + {}^4\mathrm{He} + 18.34\ \mathrm{MeV}\,,$$

which feature a noticeably greater energy release. The cross section of the DT reaction exceeds that of the DD reaction by more than 100 times.

If the lithium-6 deuteride proposed by Ginzburg is used, due to the large flux of secondary neutrons and the large cross section of the

$$^6\mathrm{Li} + \mathrm{n} = {}^4\mathrm{He} + \mathrm{T} + 4.6\ \mathrm{MeV}$$

reaction, it becomes a significant exothermic additional source of tritium. Being a source of such energetically advantageous tritium, lithium-6 deuteride became the main thermonuclear fuel in all hydrogen bombs. Its industrial production was quickly launched at plant no. 817 ('Mayak').

Sakharov's idea, in turn, to alternate layers of thermonuclear fuel with layers of heavy uranium-238 yielded a double advantage:

(1) first, during the passage of a shock wave in such a layered system, when uranium-238 atoms and lithium-6

deuteride molecules are completely ionized under the extreme conditions of an explosion, given the conditions of thermodynamic equilibrium of an electron gas in heavy and light layers, ionization compression of light layers by heavy ones occurs. As a result, the density of thermonuclear fuel increases by an order of magnitude, which facilitates fusion reactions; this phenomenon of increasing the density of thermonuclear fuel was called by Sakharov's colleagues 'sakharization';

(2) second, under the effect of high-energy, 14-MeV secondary neutrons, the nuclei of uranium-238 begin to fission with the release of 'atomic energy.'

As a result, only 15–20% of the 'sloika' is a hydrogen bomb, and the rest of the energy released in its explosion originates from fission reactions of heavy elements in the central core and in the layers of uranium-238.

A D Sakharov was fond of saying: ''An unrealized idea is not yet an idea'' (the same dictum in children's language sounds like ''it is so easy to build a house: we will draw it and live in the drawn house''). The wonderful ideas and schemes outlined above were separated from a workable design of the RDS-6s by 'a huge distance,' the passing of which required five years of intense creative work, including the development of fundamentally new computational methods.

Various calculations were carried out at the Institute for Physical Problems (IFP) (L D Landau, N N Meiman, and I M Khalatnikov [11]), the Department of Applied Mathematics of the Mathematical Institute of the USSR Academy of Sciences (OPM MIAN) (A N Tikhonov and A A Samarsky), and other [academic] institutes. They were, of course, carried out at FIAN by the special team's members remaining there (V L Ginzburg, S Z Belen'kii, and E S Fradkin), who determined the quantities necessary for calculating the explosion process: thermal conductivity and the equation of state of uranium at temperatures of 100 million degrees, the characteristics of mixing, viscosity, and diffusion, etc.

The 'sloika' (RDS-6s) was exploded on August 12, 1953; its capacity was 400 kilotons of TNT equivalent (TE). This figure in itself says little to the uninitiated. It is instructive to compare it with some visual parameters of a thermonuclear explosion a third as powerful, 140 TE kilotons (project 'Chagan': the first Soviet industrial thermonuclear explosion carried out on January 15, 1965 in Kazakhstan). The explosive device, which had the shape of a container 86 cm in diameter and 3 m in length, was placed in the floodplain of the Chagan River in a borehole at a depth of 178 m. The explosion threw out 10.3 million tons of soil to a height of 950 m to form a funnel with a diameter of 430 m and a depth of 100 m.

7. After the 'sloika'

In 1954, I E Tamm returned to Moscow, while A D Sakharov, V I Ritus, and Yu A Romanov remained at the facility. The subsequent events related to the Atomic Project mainly developed apart from FIAN; however, not entirely. A few months after testing the 'sloika,' in early 1954, the facility's theorists determined that its power could not be increased. Then, as a result of collective brainstorming, 'Idea 3' (in Sakharov's classification) arose: it consisted in compressing lithium-6 deuteride with the radiation of a fuse, an atomic bomb.

Again, we have to recall that the Lebedev Physical Institute was named after Petr Nikolayevich Lebedev (see Refs [38, 39]), who, in 1899, observed for the first time this very radiation pressure, which in his experiments was negligible. Lebedev, of course, could not imagine that this radiation can be used to compress a metal ball with a diameter of, for example, 10 cm to a diameter of about 4 cm (a 10- to 20-fold decrease in volume). He can be considered a co-author of 'Idea 3' with great reserve. True, the described fantastic compression of lithium-6 deuteride is nevertheless not directly caused by radiation pressure but by the ablation phenomenon: the X-ray radiation of an atomic-bomb fuse reflected from the inner surface of the casing heats in an ideally uniform way thermonuclear fuel, which is compressed by the recoil pressure of the instantly evaporating surface layer.[1] Laser-driven fusion 'operates' in the same way; the development of this mechanism, as is well known, is also closely connected with FIAN.

This abrupt change by the theorists in the direction of the studies, which were scheduled by the government, caused concern among high authorities. To test 'Idea 3,' in early June 1955, an authoritative commission arrived at the facility. Headed by I E Tamm, it included V L Ginzburg and other members: from Moscow — M V Keldysh, M A Leontovich, and I M Khalatnikov, and from the facility — Ya B Zel'dovich and A D Sakharov. For Vitaly Lazarevich, this was the first and only visit to the facility and a wonderful chance to see his old friends from the early 1930s: L V Altshuler and V A Tsukerman (see photo 10 and details [40]).

V A Tsuckerman is the prototype of blind atomic physicist Naum Lifshitz, the protagonist of the ''Bomb'' series. Of course, the film does not reflect the uniqueness of Veniamin Aronovich Tsukerman's personality. Tsukerman as early as during WWII filmed how a bullet fired from a barrel exits it. In 1946, Yu B Khariton invited Altshuler and Tsukerman to join the Atomic Project.

8. Back to the FIAN of 1948

A D Sakharov recalls that, in the fall of 1948, ''instead of our 14-meter room in the 'corridor' house,'' he was provided with an apartment. ''Ya B Zel'dovich joked that, in my getting an apartment, this was the first time fusion energy was used for peaceful purposes'' [24, part I, Ch. 6].

Says M S Rabinovich (Sakharov's friend at FIAN's graduate school):

''The theoretical department at FIAN began working on the atomic problem. I was not involved in these activities and watched everything from the side. Andrei was drawn into this orbit. He no longer told me a word about his work, but he talked a lot about life.

Once he told me: 'Such a situation occurs. I am often invited to the Kremlin, to a meeting. It usually lasts until four in the morning, then all the participants go to their cars, but I don't have a car, and no one knows that I don't have a car; I don't tell anyone about this. And one needs to get from the Kremlin to Oktyabrskoe pole [district] — and the distance is twelve or even fifteen kilometers.' So, if he failed to find a taxi, he went home on foot'' [21, p. 521–522].

L V Pariyskaya (mathematician and programmer, a researcher at the Department of Theoretical Physics of FIAN in 1943–1974, worked with A D Sakharov on the special team; see photo 11):

[1] I am grateful to R Z Sagdeev for explaining the physics of this phenomenon — *author's note*.

Photo 10. V L Ginzburg, L V Altshuler, and V A Tsukerman (Sarov, June 1955).

Photo 11. At the 1000th meeting of V L Ginzburg's seminar (FIAN, March 2 1983). First row (right to left): A G Molchanov (1930–2009), Ya B Zel'dovich, L V Pariiskaya (1904–1988), V I Ritus, L M Ozernoi, B L Altshuler, and L A Panyushkina [42].

"In general, soon everything in our department changed. Our serene life was over, there were no more funny stories [told] on the sofa. The young people were evicted to some kind of cubbyhole behind a glass partition in the corridor. Our superiors were anxiously conferring in undertones, now on the sofa, now at the blackboard. I didn't know what was going on with us: they didn't tell me, and I didn't ask. Rumors swirled around the institute that some mysterious general had appeared in our place. (General? Why a general? The war is over, and a general is here.) They brought me some kind of long questionnaire that I had to fill out.

Sakharov was increasingly often summoned to somewhere. A secretary, out of breath, would come running:

'Sakharov, to the director!'

'Sakharov to the phone, quickly, quickly!!'

Some unprepossessing-looking person would come and report:

'Limo for Sakharov has arrived!'

I felt that some kind of powerful whirlpool was engulfing Sakharov and our department along with him. ⟨...⟩

There were few of us: Igor' Evgenyevich, Vitaly Lazarevich, Sakharov, several young physicists, and us — two calculators sitting in a separate room. We were provided with new 'Mercedes' German adding machines. The devices were very good; the were convenient for operation but were rather noisy. Sakharov immediately announced that he would deal only with me and asked the others not to bother me. ⟨...⟩

Sakharov worked with the same frenzy. It often seemed to me that he was mortally tired: either he was working night hours as well, or he was not sleeping well. One day he came late. I went straight to him to show the results obtained. But he looked at me with such devastated eyes that I could not but ask: 'What's wrong with you?' He paused. And suddenly he squeezed his head with both hands and whispered: 'You don't understand!! This is horror, horror! What am I doing!?' — and continued almost whispering, 'You know, it's a kind of internal hysterics. I am not able to do anything... .'

I immediately told him: 'Go home right now and get to bed. Now!' He thought a little, agreed. and left. He came the next day and said to me triumphantly: 'You know, I slept for 13 hours in a row...' " ([41], see also [21, pp. 472–474]).

A D Sakharov (written 34 years after the creation of FIAN's special team):

"I could not help but realize what terrible, inhuman things we were doing. But the war had just ended; it was also an inhuman thing. I was not a soldier in that war, but I felt like a soldier in this scientific and technical one. (Kurchatov sometimes would say that we are soldiers — and this was not just rhetoric.) Over time, we learned or inferred by ourselves such concepts as strategic equilibrium, mutual thermonuclear deterrence, etc." [24, part I, Ch. 6].

Indeed, mutual thermonuclear deterrence prevented a major war for decades. However, opposing sides piled up nuclear weapons very rapidly. Moreover, the missiles themselves (both stationary and based on submarine missile carriers) changed qualitatively. New advanced carriers reduced the flight time, and the multiple warheads, MIRVs, turned each missile into a super-deadly weapon capable of erasing several large cities from the earth. And this 'balance of fear' was growing increasingly unstable. In modern times, a number of episodes when the Soviet or American early warning systems failed were declassified, and it was only through luck that the world was saved from thermonuclear suicide.

Sakharov was one of the few, perhaps the only one in the USSR, who understood this situation. Hence, the main message of his article, "Reflections on Progress, Peaceful Existence and Intellectual Freedom," published in 1968 was: "Every rational being, once on the edge of the abyss, first tries to move away from this edge, and only then thinks about satisfying all other needs. For humanity, to move away from the edge of the abyss means to overcome disunity" [43, p. 11].

As can be seen from the now declassified documents of the Politburo of the Central Committee of the CPSU and the KGB of the USSR, the very voluminous pamphlet "Reflections..." by Sakharov was carefully studied by L I Brezhnev and on his behalf by other Politburo members. It significantly shaped most important aspects (unfortunately, not very consistent) of the USSR's foreign policy over the following decades. Details about this can be found in my book dedicated to the 100th anniversary of Andrei Dmitrievich Sakharov [44].

Photo 12. A D Sakharov (photo by Yu Rost).

9. Instead of a conclusion

Two memorial plaques to I E Tamm and A D Sakharov on the facade of FIAN's main building epitomize the inseparable connection among FIAN, these great scientists, and the Soviet Atomic Project. However, FIAN is famous not only for this. ''Only physics is quintessence and everything else is nothing...'' — these are words from ''Dubinushka,'' the immortal anthem of physics students composed by B M Bolotovsky, who worked at FIAN for 70 years and passed away in May 2021 [45]. There are many other aspects of FIAN's remarkable history, but they are beyond the scope of this report.

I am grateful to V I Ritus for his numerous comments. I used his recollections and published memoirs [17–20, 46–50] about colleagues in the Atomic Project in preparing the report and editing the text of this article.

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