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The Life and Work of L. V. Altshuler

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During the Second World War and afterwards, the existence of the Soviet Nuclear Weapons Program provided a small nucleus of scientists free from party interference with their activities, and these scientists, recipients of numerous awards, both national and international, up to and including several Nobel Prizes, are well known in the Western scientific and political literature. This situation is well described by Holloway¹, among other historians².

Lev Altshuler, (9/11/1913-23/12/2003) who was as scientifically accomplished as any of the others, has not been as broadly recognized. This is for a number of reasons. He was not widely traveled, did not speak English, and was rather shy and retiring outside his Russian scientific circles. He was a man of the highest scientific integrity and this led to conflicts with party bureaucrats, and he had no compunctions about aggressively defending his beliefs. In the course of his programmatic activities, he also became the father, as it were, of an entire area of physics; the use of high dynamic pressure to study the properties of materials under extreme conditions.

Lev Vladimirovich Al'tshuler was born in Moscow on 9 November 1913, the son of Anna Esfir' Kershner-Al'tshuler (1881-1968) and Vladimir Altshuler (1882-1965), a lawyer who was one of the active leaders of the Russian revolution. The senior Al'tshuler held a number of high posts under Stalin, but fortunately avoided being a victim of the many purges taking place during that period. Mrs. Altshuler was a homemaker, raising three children and being a center of a "spiritual gravitational anomaly" as described by her children, with intellectual pursuits for an entire extended family. Altshuler had a brother, Sergei (1909-1979), who was a science historian and a sister Olga (1912-1992), a chemist. In the early years, Vladimir Al'tshuler did a number of tasks in support of the revolution. At one point in time, he was given the assignment of delivering a certain sum of money to V. I. Lenin, at that time residing in Zurich. Upon arriving in Zurich, the elder Al'tshuler deposited the funds at a storage facility at the Zurich railway station, and set out to find Lenin. Upon finding him, Al'tshuler suggested that he might join him for a cup of tea. Lenin immediately demanded that Al'tshuler return to the station and recover the money and bring it to him. "Then, we can talk about a cup of tea".

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Figure 1: L. V. Al'tshuler's parents: V. A. Al'tshuler and Anna L. Kershner-Al'tshuler, Moscow, 1945

Lev Al'tshuler was home schooled from age 7-10, and from 10-17 attended state schools. It was here he first met Veniamin Tsukerman, who was to play such an important role in Al'tshuler's life. Tuckerman recalls, "When we were in school, I first saw Lev Al'tshuler engaged in a heated argument with another student. No sooner had I turned away when an inkwell shattered against the wall". I thought to myself, "I like the quickness of reaction. This one is always able to stand up for himself. Now, our friendship can begin."

Al'tshuler graduated with a diploma of "Foreman in Construction". He was ordered to a collective farm in the Volga River Region, with orders to construct pig sties. This effort was a failure because as Altshuler reminisced later. "I couldn't set the fence posts straight". Discouraged, in 1932, he returned to Moscow to look up his friend Tsukerman. Tsukerman invited him to work in the Roentgen laboratory of the "Evening Machine-Building Institute", (This laboratory was eventually moved to the Soviet Academy of Sciences in 1939). Tsukerman had also been able to bring Vitaly Ginzburg into the laboratory in 1931 as a 15 year boy with no prospects. So, Tsukerman brought both Al'tshuler and Ginzburg into his laboratory when neither had viable prospects for further education – not to speak of meaningful employment. Thus began a friendship between these three men, which lasted for half a century.

Al'tshuler's first science teacher at the laboratory was Evgeniy Bakhmetiev, the lab director who was seized and imprisoned in 1935, and perished as a victim of Stalin's purges. He

had originally hired Veniamin Tsukerman as a young engineer to his laboratory in 1930. He exerted a strong influence on Al'tshuler in his earliest years. At this laboratory, Al'tshuler first met Vitaly Ginzburg, the future Nobel Laureate. Al'tshuler entered Moscow State in advanced placement as a junior in 1934 and he graduated in 1936 as a physical metallurgist in the x-ray analysis section of the Physics Department. He remained at the what had become Tsukerman's laboratory after the loss of Bakhmetiev in 1935. The lab was moved to the Academy of Sciences' Institute of Engineering in 1940. The laboratory was then assigned the task of using flash x-ray sources to image bullets and other rapid moving objects. At this time Ginzburg moved over to the Lebedev Institute.

After the German attack on Russia on 22 June 1941, Altshuler was mobilized and was assigned to the Air Force branch of the Red Army as a senior mechanic-lieutenant in the bomber force. In 1942, at the request of the Academy of Sciences, 1000 scientist were recalled from the front and evacuated to Kazan' and Altshuler was assigned to the Academy of Sciences Laboratory headed by his friend Tsukerman. In this facility he first met Yakov Zel'dovich and Yuli Khariton.

Figure 2: Senior Mechanic Lieutenant Lev Al'tshuler, his wife Maria Speranskaya and son Boris in 1942, after evacuation to Kazan'

Conditions were drastic at Kazan- initially. Veniamin Tsukerman provided some of his own lodging for Al'tshuler's sister Olga and her family, several of whom were in poor health. He also made sure that Al'tshuler had the very best co-workers- initially; these were K. K. Krupnikov and S. B. Kormer.

The laboratory had responsibility for addressing various issues applying to the ongoing conflict. The first problem Al'tshuler was assigned was to investigate why German antitank projectiles were so effective against Russian tank armor. He and Tsukerman did flash x-ray radiography of artillery shells and found that the German shells used multiple jet effects to achieve maximum damage. For this accomplishment, the two researchers received their first State Award, and a personal commendation from Igor Kurchatov. Eventually, in 1946, Khariton invited them both to join the Soviet atomic project, just getting organized.

Ginzburg, however, was not asked to join the project until 1948, being considered politically suspect. He had been forced to remain in isolation because his wife, Nina Ermakova was repressed in 1944 and charged with anti-Soviet activity. Ginzburg married her in 1946, when she was in exile in Gorky. She had been charged with planning to assassinate Stalin, but when the KGB found her window opened to an interior courtyard the charges were reduced. But she was still sentenced to internal exile after three years in prison- a sentence reduced to nine months. All charges and penalties were dropped after the death of Stalin in 1953. Nevertheless, Ginzburg was asked to join Andrei Sakharov as part of Igor Tamm's group at the Lebedev Institute, which supported Khariton's project at Sarov.

In the spring of 1947, Al'tshuler moved to Sarov, north of Moscow to join the Soviet Atomic Project. This city was associated with the retreat of an 18th century Russian holy man, Saint Serafim Sarovsky. He brought his family with him- his wife, Maria Speranskaya (1916-1977) and two sons, Boris (b. 1939) and Alexander (b.1945) A third son, Michael, was born at Sarov in 1955.

In 1946, Igor Kurchatov had been placed in charge of the Russian Atomic Project, under the surveillance of Lavrenty Beria, head of the KGB. At the Sarov site, the leaders were Yulii Borisovich Khariton, Yakov Zel'dovich, later on, Andrei Sakharov, Igor Tamm (also at the Lebedev Institute in Moscow), and others. In the beginning, Zel'dovich organized the theoretical effort and Tsukerman organized the experimental effort. Of course the goal of the effort was to see how much energy from high explosive detonation was required to compress fissile material to the critical mass required to achieve nuclear fission. Soon US data and details were made available through espionage. This type of information was held very tightly; for example, it was not available to Al'tshuler or Sakharov, but was available at first to Kurchatov and Khariton, and later on, to Zel'dovich.

With the organization just beginning to be formed, it was decided that the Russian program should be focused on duplicating the American results. Since the information on the US A-bomb was considered intelligence, the only scientists aware of this decision were Kurchatov and Khariton. This created certain problems. Al'tshuler argued that a design he could do would be far superior. However, since failure was not an option, it was necessary to go with the successfully tested (by the US) design. However, the Russian team was not allowed to accept

these intelligence retrievals at face value (although they did not know the origin of the material) - they were required to check them very thoroughly. This procedure was puzzling to Altshuler and others, until they understood the reason for it many years later.

In addition to his overall responsibilities cited previously, Tsukerman took charge of an experimental division whose function was to carry out "hydro" shots (nomenclature used by Western weapons researchers), using pulsed x-ray techniques developed with Altshuler previously. His collaborators were Arkady A. Brish, Vera Sofina, Diador Tarasov and Marya Manakova. Other techniques used were explosive flash driven photography directed by Ilya Sh. Model', and electrical contact shock wave diagnostics by K. K. Krupnikov. This work continued later under N. G. Makeev and Y. M. Makarov.

Evgeniy K. Zavoiskii ran a division using electromagnetic methods for measuring the velocity of explosion products and from this to derive the detonation pressure inside the charge. This technique was used extensively at the ICP at Chernolovka in later years, where much high explosive research was carried out, much of it supporting the activity at Sarov.

Al'tshuler had responsibility for equations of state. Here he worked with spherical implosion systems about 20 cm in diameter, immediately producing multimegabar pressures. All development of equation of state techniques was carried out under Al'tshuler's direction. His group included his personal colleagues from Kazan'; Samuil B. Kormer, who with Zel'dovich mastered the measurement of temperature behind shock waves. His other Kazan' co-worker K. K. Krupnikov was joined by Boris Ledyenov, Anna A. Bakanova, M. N. Pavlovskiy, R. F. Trunin, and A. I. Funtikov.

Kirin I. Shchelkin directed the division of full-scale field test prototypes, assisted by his deputy Viktor I. Zhuchikhin. Shchelkin himself was the discoverer of "Spinning Detonation", striking evidence of detonation instability in gas phase detonations. (The same effect in solids was observed at Livermore by A. Kusubov of the USA in 1967) The prototypes were exact copies, 1.5 to 2.0 meters in diameter, of the fission device designs, but U238 ($\rho=19$ g/cc) was substituted for U235/Pu 239. For alpha phase plutonium, a U238 alloy of the appropriate (reduced) density was fabricated at the Solid Alloy Plant in Moscow and used in the prototypes.

Following the direction of Yuli Khariton, the Soviet replica of Fat Man was constructed, fielded and tested successfully on August 29, 1949. After this successful test, Khariton promised Al'tshuler that after his team carefully analyzed the data from this test, he would be able to design the second test device. This device using his design was fielded and tested on September 24, 1951. This device, "Joe 2", was half the size and weight of the initial test, called in the West "Joe 1", and had twice the yield of Joe 1; 38 kilotons to 22 kilotons.

Khariton was a different kind of leader than is usually encountered in such massive activities. He felt that not only should science serve defense, the converse should be true. He phrased this approach in programmatically styled verbiage "We must know ten times more than we need (to know) today". This policy in place at Sarov enabled Al'tshuler to begin his fundamental research in dynamic high pressure in addition to his programmatic responsibilities. The primary weapons program personnel were often prominent scientists, unlike the situation in

the West after 1950. The same situation held for the second Soviet nuclear weapons laboratory started under E. A. Zababakhin, with E. A. Avrorin, Vadim Simonenko and B. K. Vodalaga having major responsibilities there. This second laboratory was not started until several years later, so that in the earliest years, Khariton was the director of the Sarov facility, with responsibilities quite similar to those of J. Robert Oppenheimer, a fact that Khariton himself pointed out years later on the occasion of his visit to Los Alamos. He was much honored by his countrymen, and received a full state funeral after his death. One of us (VEF) has generously supplied photographs of this occasion, shown in Figures 25-2 to 29-2 of Appendix 2.

It should also be noted that Al'tshuler's friend and sponsor Veniamin Tsukerman was completely blind. He told the time by means of a mechanical dial where he could "feel" the time. He learned speed typewriting with two hands. His wife, Ziniada Azarkh, prepared his lectures. He memorized them and was able to exhibit his x-ray shadowgraphs with the help of indentations placed on the film. This deception was so effective that at a seminar in 1944 attended by Ioffe, Tamm, Landau, Zeldovich, Semenov, Vavilov, Obreinov and Shalnikov at the time his work was being evaluated for a state prize no one was aware that anything was amiss. After the presentation, Landau and Shalnikov came to complement him on his talk. Shalnikov commented that Tsukerman's eyesight must have improved since their days together in Kazan. Sadly, Tsukerman had to confide in his friends, admitting the reality of the situation. His life story has been the subject of a separate biography, as will be mentioned later. Years later, after the end of WWII, he was involved in smuggling streptomycin from the Mayo Clinic, going outside official channels, in order to save his daughter Irina's life who had tubercular meningitis. This medication also saved the life of many Russian children. Irina became deaf as a result of the large amounts of medication she required to save her life. Tsukerman then became a leader in developing techniques to help deaf people. Years later, Tsukerman dictated his memoirs to Arzakh describing these events; they were published in Russia at the time of the two archives used as the background for this article, and give a description of some of these events from Zuckerman's perspective. They are now available in an English translation³.

In the period 1945-1966, Altshuler and his colleagues were considerably ahead of their American counterparts in achieving ultra high pressures in dynamic high pressure experiments. This disparity was not evident until the first publication of his work. In fact, his first publications⁴ followed those of US investigators⁵, indicating that not only had the initial US publications allowed Altshuler to request permission to publish his own work, but also let him show the achievements of the Soviet scientific team. He published a comprehensive review of his work in 1965⁶, and this paper quickly became required reading for those entering this field in Russia- and in the West.

Confronted by this pressure disparity, in 1959, J. M. Walsh, a leading Los Alamos investigator, wrote directly to Altshuler with 16 questions. Altshuler answered 15- the question left unanswered was "How do you achieve such high pressures?" The question was, in fact, answered several years later, but eventually became understood by US investigators.

The Soviet scientists had to invent much of their efforts "from scratch". Fortunately, Tsukerman was an experimental genius with an incredible talent for improvisation. Differences

were sometimes found between the theoretical calculations and experimental results. These differences were always ironed out after intense and often combative arguments.

At the same time, research on thermonuclear weapons was going on. Sakharov has written about “the Three Ideas” in his memoirs. The first idea was the “sloika” (alternate layers of fusion and fission fuels- also called “layer cake”) and the second idea was Vitaly Ginzburg’s 1948 suggestion of the use of Li^6D as the thermonuclear fuel. These ideas were combined in the Soviet test of the first deliverable hydrogen bomb on August 12, 1953. Al’tshuler was asked to provide EOS data for the device detonated in this event, but he demurred, arguing that the conditions for fusion were so extreme that they could not be realized in the laboratory. “You must rely on your best theoretical equations of state”, he advised.

The Soviet team was aware of radiation transport as a mechanism for compression of the thermonuclear charge from an idea first proposed by Fuchs and John von Neumann at Los Alamos in about 1945, which eventually became part of a classified 1946 Los Alamos report. Actually, this figure had been provided by Klaus Fuchs for that report, as Fuchs was the report secretary. At first, there was some uncertainty as to that authorship of that drawing as none of the report authors could recall having inserted it. Los Alamos personnel eventually found that that Fuchs was responsible for it. By the time the issue arose, Fuchs was not available for comment. He had told his Russian contacts when he delivered this information that the concept was one he and von Neumann had worked out at Los Alamos. The Fuchs-von Neumann configuration in the report was one for which radiation compression would have been the only credible method of achieving fusion. Radiation compression was what Sakharov called “the third idea”. So, in the Soviet Union, radiation compression was an option that was always around in the early years. It was called by the Russians the “Fuchs-Neumann” approach.

The Russian thermonuclear effort for some time consisted of trying to improve the “sloika” scheme, an idea of Sakharov tested in a deliverable version on August 12, 1953. At the same time, there was a study of a “stick deuterium burn”, which involved setting off a thermonuclear detonation wave which would propagate along a cylinder of thermonuclear fuel, called in the US the “Runaway Super” a version of a concept attributed to Edward Teller. Attempts were made to precompress this fuel by, among other things, using shock hydrodynamic means, a technique proposed by Ulam in the US, but found to be unworkable. Zel’dovich eventually realized that the energy provided by shock compression raised the fuel temperature and pressure to very high levels but did not provide the compression required for fusion. In the US, Alder, interestingly enough, described this point in some detail⁷, showing why this would not work. Also there were concerns with the stability of propagating detonation fronts; if we were to initiate a thermonuclear detonation front in an uncompressed thermonuclear fuel, could it propagate indefinitely? Zeldovich was aware of the role detonation stability played in conventional explosives where a one-dimensional detonation cannot propagate indefinitely. Finally after discussions with D. A. Frank-Kamenetskiy, who understood atomic opacity issues, a key part of the radiation transport calculations, and with others, this “third idea” was addressed in early 1955 by a review panel. This panel consisted of Igor Tamm, Chairman; Vitaly Ginzburg, Yakov Zel’dovich, Mstislav Keldysh, Mikhail Leontovich, Andrei Sakharov and Isaak Khalatnikov- three future Nobel Laureates and a president of the Soviet Academy of Sciences. The panel decided in favor of the idea, even though they realized that if the idea didn’t work,

there would be repercussions. As to Vitaly Ginzburg, he agreed to serve on the panel, because he knew he would be reunited with his friends Al'tshuler and Tsukerman. It should be noted that although Frank-Kamenetskiy came up with several interesting approaches for implementing the third idea, they were not deemed to be practical. The original Fuchs-von Neumann geometry was decided upon. Nevertheless, it was Frank-Kamenetskiy's knowledge of molecular and atomic opacities that played a key role in the deliberations of the panel.

Figure 3: Vitaly Ginzburg, Lev Al'tshuler and Veniamin Zuckerman in front of the Zuckerman cottage, Sarov 1955, after the panel evaluation of the "Third Idea" cited by Sakharov.

After the favorable review of the idea by the panel Sakharov proceeded forward with the third idea using the Fuchs von-Neumann configuration, and immediately commenced work with Yakov Zel'dovich. A device using this idea was successfully tested on November 23, 1955. This brought the Soviets into rough parity with the US.

During this time, encouraged by Yuli Khariton, Al'tshuler was proceeding with series of his own dynamic high pressure experiments. The data and experimental procedures to design, field and test nuclear devices had been established. He now branched out to expand knowledge

of materials at very high pressures and temperatures, and enhance the technological and scientific base of the Soviet program.

The equations governing shock wave are given in Courant and Friedrichs⁸. They are:

$$(1) \quad v = v_0 \left(1 - \frac{U_p}{U_s} \right) \quad \text{conservation of mass}$$

$$(2) \quad p = p_0 + \rho_0 U_s U_p \quad \text{conservation of momentum}$$

$$(3) \quad \Delta E = \frac{1}{2} (p + p_0) (v_0 - v) \quad \text{conservation of energy}$$

p = pressure, Megabar (1 Mbar = 10^{12} dynes/cm²; = 10^{11} Pascal, 100GPa)

ρ = density, gm/cc

v = specific volume, cc/gm

E = specific internal energy (Mbar-cc/gm = 10^{12} ergs/gm)

U_p = particle velocity, cm/ μ sec

U_s = Shock velocity, cm/ μ sec

The set of p , v and E are not a complete thermodynamic set. It is necessary to apply an equation of state (EOS) theory to obtain the complete EOS at the shock Hugoniot point. A way of getting around this is to observe the state of the shocked material upon release, since the release process is isentropic. That means the entropy at release is the same as the entropy of the shocked state. So, in the shocked state, this procedure gives p , v and S , a complete thermodynamic set. This procedure was exploited extensively in Russia from the early years on, and extended it into the plasma region. No equivalent body of published work exists in the West.

Altshuler, Bakanova and Dudoladov discovered irregularities in the shock wave data on rare earth and alkali earth metals, indicating electronic shell effects⁹. E. B. Royce in the US made similar observations. His work was rejected initially by Physical Review Letters with the reviewer, Harry Drickamer stating that "...the paper would be of interest only to high explosive buffs." On the other hand, the cited Russian work was published immediately by JETP Letters. Royce's work was available in the same time frame¹⁰ but was not published in the open literature until 1973¹¹, although references to it were published in the proceedings of a 1967 conference¹².

Kormer, having mastered the techniques for making direct determination of temperature behind a shock front, was able to show, with Zeldovich, that the conductivity observed in

shocked ionic crystals was due to excitation of electrons from donor states associated with dislocations created by the shock front. Thus, conduction electrons were being excited across an energy gap much smaller than the intrinsic gap.

Altshuler and colleagues described these and other accomplishments of the Russian program in detail in a lengthy recent review¹³. The full list of references based on Altshuler's pioneering work must be two- or three hundred. For the most part, each publication represented a major experimental effort.

At first, his work applying shock wave techniques to a broad scope of physics problems took a long time to be recognized in the West. After Walsh's first letter and response, Los Alamos concentrated on routine EOS measurements. That scientific staff remained more or less static until about 1980. However, in 1960, Berni Alder realized, even before the publication of Reference 5, that the techniques described by Al'tshuler had immense potential for application to physics issues, and immediately started to recruit personnel for the Livermore Laboratory to pursue this area.

Figure 4: Professor Berni J. Alder, University of California.

The situation at Livermore evolved as follows. In 1952, when Livermore was founded, Roy Goranson was brought from Los Alamos to take over EOS research. At that time, J. M. Walsh took over the Los Alamos work. Tragically, Goranson took his own life in 1953. In 1956, Alder brought Russell Christian to Livermore from Los Alamos to complete Ph. D. studies with the expectations that he would remain to take over EOS activities, but after obtaining the degree, he left Livermore to join Mission Research Co. Alder agreed with the Lab Director to find someone to take this responsibility, and in 1961, Russell Duff came from Los Alamos to Livermore to take over the work. At about this time, Walsh left Los Alamos, and R. W. McQueen became the leader of the LASL effort. Historically, the US effort began to shift toward the use of two stage gas guns, pioneered by William Isbell and others, and some rather

sophisticated techniques introduced at Livermore, while Los Alamos concentrated until 1980 on more routine EOS while the Russian group extended their work to ever higher pressures and temperatures. Note was taken by Al'tshuler of some exceptional work by C. E. Ragan of Los Alamos who carried out experiments as a part of some nuclear explosive tests¹⁴. These experiments brought US investigators very close to the highest pressures attained by the Soviets. It should be noted, however, that although the Soviets continually reported somewhat higher pressures than Western investigators could reach, the accuracy of these results was never specified, and to field a large series of such experiments would have been very costly for US investigators. Their methods were pretty well understood by Western investigators.

A report on the developing Livermore work with a review and basic tutorial was given in a set of lectures at the Enrico Fermi School in 1969¹⁵. The tutorial aspect was emphasized because of the significant numbers of students attending.

Los Alamos experienced an increase in scientific effort from 1979-1998. During this same period of time, the Russian program became even more intensive and sophisticated. A good review of the Russian work up to the 2005 with comparison to US efforts was recently published¹⁶. As to the present time, all labs including the Russian ones are mostly inactive in the EOS field.

Altshuler had his own set of difficulties at Sarov. In the later years of Stalin, attempts were made to bring physics into consistency with Marxist principles. Relativity was denounced as "Bourgeois romanticism"; quantum mechanics as "cosmopolitan fancies". Altshuler recalls the Nobel Laureate Igor Tamm losing his temper after having read some Party reports denouncing some of the aspects of modern physics.

Al'tshuler's run-in with the Party came during a visit of party officials to Sarov in 1950. When they asked Sakharov what he thought of Mendelian genetics, he responded that the theory seemed scientifically correct. There was a nervous flutter among his questioners, but no one dared to object to his statement. Al'tshuler was another matter. He went further in his statements, criticizing Lysenko, an agronomist in great favor with Stalin, but who was responsible for vast agricultural failures in the Soviet Union, Al'tshuler was immediately scheduled to be banished from the project- perhaps to the camps, until Sakharov interceded in his behalf with events eventually escalating to a late night call from Lavrenty Beria. After some prodding from Kurchatov, Beria took all these incidents directly to Stalin, who was in a rare magnanimous mood. He advised Beria to "Let the physicists go on about their business. We can always execute them later."

After these incidents, Al'tshuler spoke out on various human rights issues, including the Hungarian revolt in 1957, the Arab-Israel conflict of 1957 and the Czech Spring in 1968. Of course, after Stalin's death in 1953, conditions eased considerably and mass amnesties were declared. In any case, Lev Al'tshuler departed Sarov in 1969, by coincidence, on the same train as Andrei Sakharov. At this time, Al'tshuler was proposed for the Soviet Academy for the final time. Although he had strong support, Communist officials intervened and prevented his election. At this point, Al'tshuler joined one of us (VEF) and was supported during the rest of his active scientific life.

Figure 5: Lev Al'tshuler on his last day in Sarov, October 16, 1969 Note the historic monastery towers of Saint Seraphim Sarovsky in background. Andrei Sakharov departed Sarov the same day.

It should be noted that even today, in Russia, Lev Al'tshuler is considered to have been one of the very great ones. After a short time, after leaving Sarov, Al'tshuler joined the Academy of Sciences Institute of High Energy Densities and remained active there until his very last years. He remained close to Sakharov and Elena Bonner, spending much time with them over the years, and met them on their return from exile-see Figure 6.

Figure 6: L. V. Al'tshuler, Elena (Lusia) Bonner, and Andrei Sakharov, on their return from internal exile

An amusing story is told about Sakharov and Al'tshuler's initial meetings after his return to Moscow from internal exile. Sakharov told Al'tshuler that they could discuss highly classified nuclear matters, since they had been both cleared for such information at the highest levels. However, Sakharov pointed out that they really could not have such discussions after all, since "The people tapping our telephones and listening through the wall are not cleared."

Boris Al'tshuler received the Ph.D. in physics at Sarov, with his mentor Sakharov "opposing" his thesis. This is a Russian custom where one individual is chosen to be in charge of critical questions during the Ph. D. exam. When Al'tshuler left Sarov, Boris had to take a job cleaning the streets. Upon his return from internal exile, Sakharov brought Boris Al'tshuler to the Lebedev Institute as a member of its theoretical section, where he remains today.

Later on, in 1985, Al'tshuler greeted a frequent visitor to his house, who came to obtain handouts of food. Seeing a portrait of Sakharov over Al'tshuler's bed, he pointed to it and said- "There is Sakharov, who sold out to the Bolsheviks." At that moment, Al'tshuler's beloved dog, named "Sharik" leaped out from under the bed and bit the man on the leg. Al'tshuler loved to tell

this version of the story but his son Boris surmised that that the dog was awakened by the ensuing argument, and sensing his master's anger, bit the object of his master's invective.

The first encounter Altshuler had with Westerners was in 1974 in Moscow, when Berni Alder requested a meeting. Altshuler arrived, but after about 10 minutes, armed guards arrived and whisked him away. In the hopes of having more successful meetings with Al'tshuler, Alder asked Academician L. F. Vereshchagin to invite US delegates to an upcoming meeting in Moscow scheduled for June, 1975. This happened, and here, a number of Western scientists were able to meet and discuss physics topics with Al'tshuler, Kormer, Gandelman and others. In the Appendix, Figures 17-2 and 18-2 are shown of that meeting. Photos are also available of all the participants¹⁷. Shown in Figures 19-2 and 20-2 are Al'tshuler, Kormer, Gandelman, and V. E. Fortov.

The citation Al'tshuler valued the most was the one delivered at the Enrico Fermi School in Varenna, Italy in 1969, by Edward Teller citing Al'tshuler as "...one who has done the most in opening this new field." (High dynamic pressures; see Ref. 14, p1) In Russia there is no controversy about Edward Teller in the physics community-he is considered to be one of the great physicists of history.

Finally, Lev Al'tshuler received the American Physical Society Shock Wave Award in 1991. This presentation is shown in Figure 7. This was appropriate since Altshuler was the world leader in the field for his entire active life.

Figure 7: John W. Shaner of Los Alamos presents the 1992 Shock Wave Award of the American Physical Society to Lev. V. Al'tshuler

As to Altshuler's basic motivation he recalls a conversation with a colleague when on a bright and sunny day, surrounded by people, both were feeling a strong sense of vulnerability after Hiroshima. His friend told him "These people-I cannot but help seeing them evaporating in the fire of an atomic blast-leaving those horrid human shadows in their place". At that time, "overtaking and surpassing" America in this area became Russia's basic priority.

But Altshuler also had concerns much later. When he first saw the lines of prisoners marching past twice daily, he recalled Mikhail Lermontov's line "the country of lords and slaves" to which his heroine Tatiana Vasil'evna rebuked the hero "You don't love Russia". What does it mean to love Russia? Al'tshuler recalled Pontius Pilate's unanswered question "What is truth?" Altshuler felt that there were only ambiguous answers to such questions. As to his isolation, Al'tshuler quoted Dante, it was a situation in which one could only "Lasciate ogni speranza".

The question of why the US, and the West in general has lagged behind Russia in certain areas; shock waves, pulsed power, turbulence and oceanography is complicated and has been dealt with elsewhere¹⁸. Altshuler had his own opinions about this, which he was circumspect about stating. He respected much of what was done by US investigators. Among close associates and friend he was more outspoken. He expressed these views at Paderborn in 1989 through a Thomas Fermi theoretician, Dr. Galina Shpatakovskaya, a fluent English speaker. He was very impressed by the work of Brown and McQueen of Los Alamos¹⁹, which enabled him to correlate his iron results with others in the field, clearing up some controversy in the matter. One of us (RNK) was aware of this controversy from a previous Gordon Conference²⁰.

He was also interested in a previous (1979) Livermore paper by Hawke²¹ in which hydrogen became metallic at 2 Mbar and 400 deg. K, because it was based on the work of Sakharov and Pavlovskii, who pioneered these techniques. (See plate 30-2) This Livermore experiment was analyzed in detail by Max Fowler²² of Los Alamos the long-time US leader in high magnetic field physics, who independently verified the procedures and results obtained. The Pioneer Saturn flyby also verified Hawke's work in that it showed, with the discovery of a Saturnian magnetic field, the existence of metallic conducting hydrogen in Saturn's planetary core, providing the basis for a geomagnetic dynamo. Previous thinking was that Saturn would have no magnetic field, based on the general belief that hydrogen remained an insulator up to at least 10 Mbar.

Another problem was a perception by static high pressure researchers in the US that shock wave work was something for "high explosive buffs", as stated by Harry Drickamer, long the dean of US High Pressure scientists. Drickamer was burly, forceful and intimidating- a notable presence. In lengthy discussions, he argued that first-rate work in high pressure was carried out at universities, and shock wave specialists were generally doing unexceptional work as government contractors. However, at Paderborn, one of us (RNK) introduced him to Lev Al'tshuler. He listened to his talk and those of other Russian investigators and his attitude began to change. Drickamer hated to lose arguments, and so he jokingly conceded the point as far as the Russians were concerned, but he would withhold judgment on the US investigators. As time passed, however, Drickamer was seen actively and enthusiastically participating in discussions where shock wave work of US investigator was being presented at US high pressure meetings.

There is a tremendous amount of archival material becoming available on Al'tshuler and his colleagues, in the Russian language and not readily available. Many of the earlier publications from the US side were not authored by scientists and were undertaken with a set of preconceived notions. In a communication to one of us (RNK), Yuli Khariton addressed several of these articles pointing out that they were simply wrong²³. He pointed out that "...many of the American newspapers and reporters are tendentious when presenting the history of the Soviet nuclear weapons development. Probably, having not enough information, the publications of some American specialists are guilty of this too".

Now, these issues await someone-Russian or American- to put all the pieces together from information becoming available. Hopefully, this brief biography can provide a beginning.

Acknowledgements

The insights on decisions made at Sarova in the early years were provided by Boris Al'tshuler, who, as a young physicist who was living with his parents in a closed city, was aware of the issues developing over time both with the Soviet program in general, and with his father personally, who was involved in these matters at the highest level.

The authors would also like to acknowledge with sincere gratitude, his assistance in providing us with volumes of documentation on his father's life. In particular, we wish to thank him for allowing us to quote from Lev Al'tshuler's 1994 memoir "The Lost World of Yuli Khariton" and his own 1994 tribute to Nobel Laureate Vitaly Ginzburg, presented to him on his 90th birthday "Three Friends: Lev V. Al'tshuler, Vitaly Ginzburg and Veniamin A. Tsukerman". By this time, both Al'tshuler and Tsukerman were deceased, and the memoir was presented by Boris Al'tshuler. These documents are still not readily available in the West.

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²² Fowler, C. M., et al. "Nearly Isentropic Compression of Materials by Large Magnetic Fields: a Survey", Proceedings of the International Symposium on Intense Dynamic Loading, and its Effects, Sichuan University Press, Chengdu, China, June 9-12, ,1992, pp 17-28.

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Appendix

The following are archival photographs just released from the Russian Files, showing many of the principals during their careers and afterwards.

Figure 1-2: Irina V. Tsukerman, Vladimir A. Al'tshuler and his grandson, Boris L. Al'tshuler. In later years, Lev Al'tshuler joked that his son Boris was pointing the way to the "New Russia". Boris Al'tshuler was an activist in support of human and children's rights.

Figure 2-2: Lev Al'tshuler(youngest), sister Olga, and brother Sergei with governess, and grandfather Alexander Al'tshuler in Maikop, October 1916. Later on, Ilya Al'tshuler (son of Boris) visited Maikop and found individuals who remembered the family.

Figure 3-2: Sergei Al'tshuler, sister Irina and Lev Al'tshuler, Maikop, Russia ~ 1917

Figure 4.2: Lev Al'tshuler after being inducted into the Red Army, 1941

Figure 5-2: Lev Al'tshuler peeling potatoes, army, early 1942

Figure 6.2: Lev Al'tshuler at the front, early 1942

Figure 7.2: Zinaida Arzakh, V. Tsukerman, Lev Al'tshuler, Alexander Avdeenko, Maria Speranskaya, on 23 September, 1943, last day at Kazan', returning to Moscow after the Germans had been driven far back from Moscow. Avdeenko was the mechanical genius who constructed most of the shots.

Figure 8-2: Konstantin K. Krupnikov attaches explosive charges. Sarov, 1949.

Figure 9-2: After detonation of explosive charge, Sarov, 1949

Figure 10-2: Veniamin Tsukerman, daughter Irina and Izrael Galynker, Moscow, 1956. Galynker had been sent to the Gulag in 1948 for unauthorized contacts with the West, helping to obtain antibiotics to cure Irina's tubercular meningitis.

Figure 11-2: Veniamin Tsukerman, Izrael' Galynker and Lev Al'tshuler, Baltic Sea, 1958.
Galynker had been released from the camps only two years before.

Figure 12.2: Tsukerman, Lev Al'tshuler, Yuli Khariton. Sarov, 1960

Figure 13-2 Lev Al'tshuler with his beloved dog Sharik, Moscow, May 25, 1985

Figure 14-2: Boris Al'tshuler, Andrei Sakharov, Elena Bonner and D. Drell in the Sakharov kitchen, Moscow, 1987

Figure 15-2: Lev Al'tshuler receives the 1991 Shock Wave Award

Figure 16-2: Back row, L. V. Al'tshuler, V. Rumer and V. Tsukerman; Front row, Maria (Speranskaya) Al'tshuler, Anna Bakanova and Zinaida Arzakh. Sarov, 1960

Files of Academician L. F. Vereshchagin

Fig 17-2: June, 1975 AIRAPT Conference, Moscow State University, Moscow, USSR. Second row, Minomura, Keeler, Ruoff; third row, A. S. Kusubov; fifth row, Lev Al'tshuler.

Files of Academician L.F. Vereshchagin

Fig 18-2: June, 1975 AIRAPT Conference, Moscow State University, Moscow, USSR. First row, Osugi, Pugh; second row, Ruoff, S. B. Kormer; third row, U. Franck (partly hidden); Elsbeth Franck; far right, sixth row, A. I. Pavlovskiy

Figure 19-2: V. E. Fortov, L. V. Al'tshuler and G. M. Gandelman, Moscow, June 1975

Figure 20-2: R. N. Keeler and S. B. Kormer, Moscow, June 1975

Fig. 21-2: Moscow, 1993, R. N. Keeler, Robert Harter, Lev Al'tshuler and Patrick Renehan

Figure 22-2: Otto Diehl and L. V. Al'tshuler. Paderborn. 1989

Figure 23-2: V. A. Novikov, B. K. Vodolaga, L. V. Al'tshuler and R. N. Keeler, Kiev, 1987

Figure 24-2: L. V. Al'tshuler, R. N. Keeler and J. W. Shaner, Los Alamos, Kiev, 1987

25-2: Honor Guard for funeral of Yuli Khariton, 23 December 1996

26-2: Funeral procession for Yuli Khariton

27-2: At the casket of Yuli Khariton

Figure 28-2: Yuli Khariton at the viewing

Figure 29-2: VIP Assembly at Khariton funeral

Figure 30-2: A. I. Pavlovskii, who with Andrei Sakharov, developed the systems used by Hawke in his metallic hydrogen experiments.