Stalin and the Hydrogen Bomb

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In our last issue, in his article entitled 'Stalin and the atomic bomb', Zhores Medvedev shed new light on the beginnings of the nuclear era in the Soviet Union. Now, he turns to the race to build the Soviet Union's thermonuclear or hydrogen bomb. This article also contains much new information. In our next issue, Dr Medvedev will conclude his unique history by examining the crucial role of Gulag labour in the spread of the Soviet nuclear industry.

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The hydrogen bomb: the beginning of the project

The atomic bomb was the artificial creation of man. Plutonium does not exist in nature, and uranium-235 does not accumulate anywhere in the quantities which produce the chain reaction of its almost instant fission. The idea of the hydrogen bomb was based on the physical phenomenon which is most widespread in the universe: nuclear synthesis, the formation of nuclear atoms of the heavier elements at the expense of the fusion of the nuclei of light elements. Almost all the elements of the earth's crust arose in this way. At high temperatures, of the order of hundreds of millions of degrees, the kinetic energy of the atoms of the light elements becomes so high that, colliding with themselves, they are able to 'fuse', forming nuclei of heavier elements. Hundreds of thousands times more energy is released at the nuclear synthesis than at the fission of the heavy atoms. Interest in the problem of nuclear fusion arose in the 1930s, especially after Hans A. Bethe, the German physicist who, in 1934, emigrated to the United States, developed the theory of the production of energy of the stars, including the sun. According to this theory, which was sufficiently well confirmed at the time, the energy of the stars arose in the basic energy of synthesis, which was released in the fusion of four nuclei of hydrogen with the synthesis of one nucleus of helium. This synthesis was produced, however, through several intervening stages. Hydrogen is the main element of the universe, comprising 75 per cent of all matter.

During the explosion of a uranium bomb, or at the epicentre of the explosion of a plutonium bomb, it is generally reckoned that the temperature can reach some millions or some tens of millions of degrees. Many physicists understood that the atomic bomb could serve as the detonator of a more complex bomb of nuclear fusion. However, the necessity for such a bomb seemed completely unreal. If the atomic bomb with an explosive power of 15-20 kilotonnes of TNT was able to destroy a big city and kill hundreds of thousands of people, then to what kind of use could a bomb be put which was thousands of times more powerful, with an explosive equivalent of millions of tonnes of conventional explosives? In what kind of circumstances would it be possible to justify the use of a bomb which would kill people not in hundreds of thousands, but at once in tens of millions?

Nevertheless, amongst a group of American physicists working on the practical development of the atomic bomb in the 'Manhattan Project', there was one, Edward Teller, who was sufficiently authoritative, who already in 1942 had decided to concentrate his efforts precisely on the building of a hydrogen bomb, and began preliminary calculations in order to prove the reality of this project. Edward Teller was born in 1908 in Budapest, but was educated in Germany, and began his research in Munich. In 1935 he went to the United States, where he worked in the laboratory of Robert Oppenheimer at the University of California. Teller's first calculations did show that a temperature of some millions of degrees from a nuclear explosion cannot produce a fusion of the nuclei of ordinary 'light' hydrogen. But this temperature would be sufficiently high to produce a fusion of the nuclei of deuterium, the 'heavy' isotope of hydrogen, with the formation of the 'light' isotope of helium. The thermonuclear reaction in this case can be produced by the very simple formula: $D + D \rightarrow {}_3He + n + 3.27$ Mega electron volts (MeV).

The result of this reaction is that two nuclei of deuterium, fusing, form one nucleus of the light isotope of helium. One neutron and a vast amount of energy are released in the course of this reaction. Easier still would be the fusion of the nucleus of deuterium with the nucleus of tritium – the heavier isotope of hydrogen. In this instance, the nucleus of 'heavy' helium (^4He) is formed, releasing one neutron and five times more energy – 17.3 mega electron volts.

Besides this colossal power, the hydrogen bomb need not be bigger in size than the atomic bomb. Furthermore, the many radioactive products of fission, which contaminate the atmosphere during the explosions of plutonium or uranium bombs, are not formed during this reaction of fusion. What is more, the explosive potential of the hydrogen bomb, which had already become known in the project as the 'super bomb', required much less atomic material to equate with each kilotonne of TNT. It was possible, therefore, to expend less resources in order to destroy a big city with one hydrogen bomb, in comparison with using several atomic bombs for this target.

In September 1945, after the end of the Second World War, most of the physicists who worked at Los Alamos and the other military atomic centres in the United States, began to return to their former universities and laboratories, preferring the 'free' life, the opportunity to publish, travel and teach. Temporary closure threatened Los Alamos. In these conditions, Teller, who was consumed by ideas of the hydrogen bomb, decided to establish new projects at the laboratory in Los Alamos, and to guarantee them with grants from the

Government. With this aim, in April 1946, he organised at Los Alamos a secret seminar on the problems of realising the construction of the hydrogen or thermonuclear bomb. About 40 scientists took part in the seminar, amongst whom was Klaus Fuchs. Fuchs, who had started work on the British atomic project in 1941, had moved to the United States in 1944. In that year, the United States and Great Britain decided to unite their efforts to construct atomic bombs. Britain, at that time, led on research into the uranium bomb, while the United States led research into the plutonium bomb. At Los Alamos, Fuchs was included in Oppenheimer's group. At the end of 1946, the British delegation to the atomic project returned to England, and Fuchs resumed his work at the British atomic centre in Harwell. He also resumed his former links with Soviet intelligence in England. Thanks to this, the Soviet Government found out about the seminar on the hydrogen bomb which had taken place at Los Alamos.

It is difficult to reproduce all the details about this, such as the form in which intelligence about American research into the problems of the hydrogen bomb reached the Soviet Union, since in contrast to the almost complete publication of data on this relationship with respect to the atomic bomb, a significant part of the intelligence on research into the hydrogen bomb remains secret. Besides, the actual successes of Soviet intelligence after 1945, when the atomic programme in the United States came fully under military control, were already very modest.

Already from the summer of 1946, Kurchatov and the other leading participants in the Soviet nuclear project knew in a general way about the new direction of research at Los Alamos. The potential opportunity to build a thermonuclear weapon was obvious to the Soviet physicists. However, for its practical development it was necessary first of all to build an atomic bomb, for which at this time there was still no industrial base. It was nevertheless obvious that the hydrogen bomb demanded new materials and new production, of which the main one was to secure significant quantities of deuterium.

It was impossible to prove experimentally the conditions of thermonuclear reactions, which take place at astronomical 'stellar' temperatures, and therefore all the research in this area demanded colossal amounts of calculations. The decision was taken to mobilise all the theoretical resources of almost all the mathematical institutes and departments of the Soviet Academy of Sciences. The co-ordination of this work was entrusted to a talented young physicist, Jakov Borisovich Zeldovich, who headed the theoretical department of the Institute of Chemical Physics. Lev Davidovich Landau, the head of the theoretical department of the Institute of Physical Problems, was also attracted to the work. The director of this Institute, Petr Leonidovich Kapitsa, after the conflict with Beria towards the end of 1945, gave up work on the atomic bomb, and quite openly explained his motives in two detailed letters to Stalin. The dismissal of Kapitsa from work on the atomic bomb from autumn 1945 did not lead, however, to his being released from the directorship of the Institute. The participation of this Institute in the building of the atomic bomb was not of key importance.

The preparatory steps taken in 1946 towards building the hydrogen bomb already could not ignore the scientific potential of Kapitsa's Institute. It was, from the very beginning, very obvious that the construction of the bomb must require liquid or even solid deuterium. The technologies for handling large quantities of liquid gas, using oxygen and helium, had been worked out precisely in the Institute of Physical Problems in the unique apparatuses invented by Kapitsa. Research into the physical properties of gases, condensed by cooling to the temperatures close to absolute zero, brought Kapitsa worldwide acclaim. A change in the leadership of this Institute became inevitable when the Institute's profile was altered from the resolution of the problems of liquid oxygen and helium to the separation of the isotopes of hydrogen, and the isolation of deuterium and its storage in liquid form and in the form of heavy water.

Stalin, Beria and Kapitsa

Kapitsa was recruited to work on the construction of the atomic bomb soon after the appointment of Igor Kurchatov as the overall head of the project in February 1943. Kurchatov did have free reign in mobilising scientists to accomplish a given task, but he prefered to do this by making drafts for the decisions of Sovnarkom, signed by Stalin. This was essential for recruitment into the atomic project under Kurchatov's control of those physicists who, according to their experience, authority and academic position, were, at that time, superior to the young and little known Professor Kurchatov.

Kurchatov's main advantage over his better known colleagues was that he was fully conversant with all the achievements of Britain and the USA in this area as a result of the analysis of the data collected by the intelligence service. During this period, V.M. Molotov and M.G. Pervukhin were in charge of the atomic (or 'uranium') project at the State Committee of Defence (GKO). On 20th March 1943, Kurchatov sent Pervukhin a memorandum 'Concerning the necessity of attracting L.D. Landau and P.L. Kapitsa to the work'. It was proposed that they become consultants to Kurchatov's laboratory 'on questions of the separation of isotopes' (Kapitsa) and 'on the calculations of the development of the explosive process in the uranium bomb' (Landau).[1]

On 20th August 1945, after the explosion of the American atomic bombs over the Japanese cities of Hiroshima and Nagasaki, a Special Committee on atomic energy was established in accordance with a decision of the GKO, signed by Stalin, in order to speed up all the work on building the atomic bomb in the Soviet Union. Beria headed the Committee, which was given extraordinary powers. But the members included only two scientific representatives, Kapitsa and Kurchatov. The other members represented the leadership of the country; the Politburo (Malenkov), the Government (Voznesensky), the NKVD (Avraami Zavenyagin), and the national industrial commissariats which were expected to play the main role in establishing the atomic industry – the ammunition commissariat (Boris Vannikov) and the chemical industry commissariat (Pervukhin). Stalin knew Kapitsa best of all the Soviet academicians. This was not through personal meetings, but through regular letters which Kapitsa sent to

Stalin from the mid-1930s, which touched on a wide range of questions. Kapitsa was the first Soviet scientist who, on 30th April 1945, before the end of the war, was honoured with the title Hero of Socialist Labour.

During the first weeks of very active work of the Special Committee and of the Technical Council which it established, Kapitsa was very energetically engaged in sorting out all the problems. However, during this period there existed a directive of Stalin and Beria to copy completely the American project of the plutonium bomb, almost all the details of which were received by the Soviet Secret Service from Klaus Fuchs and Bruno Pontekorvo, who had worked at Los Alamos. At this time, Kapitsa, in contrast to Kurchatov and his direct collaborators, was not permitted access to the study, analysis and evaluation of the vast quantity of intelligence materials which had been passed through to the NKVD. This caused an inevitable conflict between Kapitsa and Kurchatov, and also with other members of the Special Committee.

Kapitsa, in his work, proceeded from the premise that it was necessary from the beginning to resolve many problems, for example, in separating isotopes of uranium, as scientific ones. Kurchatov, Beria and others, however, knew that these problems had already been solved, and the task consisted in checking and defining more precisely the reports which had been received from the United States.

From October 1945, Kapitsa, through the secret dispatch office of the Kremlin, sent Stalin a letter which was cautiously critical of Beria, suggesting his ‘release from all appointments by the SNK, except my work in the Academy of Sciences’.[2] This letter had no consequences, and Kapitsa continued to be invited to meetings of the Special Committee. On the 25th November, Kapitsa sent Stalin a very detailed letter, undoubtedly having thought through the minutiae of Stalin’s psychology, which Kapitsa understood without seeing the man. He addressed Stalin as an equal, as the leader of science to the leader of the State. Stalin had never received such a letter from anyone. Kapitsa made it obvious that he thought the other State leaders were second-rate figures, simply required to carry out tasks, that they did not understand the real problem of the atomic bomb. Especially Beria. ‘. . . he has a conductor’s baton in his hands . . . but the conductor must not only wave the baton, he must also understand the score. With Beria this is a weakness . . . Beria . . . needs to work, to mark with a pencil the resolutions whilst sitting in the chairman’s armchair – this does not mean to lead is a problem. . . Nothing happens for me with Beria. His attitude to scientists goes completely against the grain with me’.[3]

Having evaluated sufficiently critically the work on the atomic bomb of the Special Committee and the Technical Council, Kapitsa set out in this letter a list of undoubtedly useful characteristics and recommendations for Stalin. Nobody else could have pointed Stalin towards a course of action with such directness. Kapitsa had already announced without a hint that he wanted to leave all the atomic committees and councils. ‘. . . I cannot be a blind performer, since I have already risen above that position’.

Two weeks later, Kapitsa was formally released from work on the atomic bomb. Kapitsa's letter to Stalin has been commented on repeatedly. Legends grew up around it. According to one, Beria was so pleased at the departure of the obstinate Kapitsa from the atomic departments that he arrived at the Institute of Physical Problems and 'even brought with him a magnificent gift for Kapitsa – a richly inlaid double-barrelled hunting rifle'.[4]

According to another legend, Beria asked Stalin to sanction Kapitsa's arrest, but was unsuccessful. Both legends are extremely improbable. Beria was a very malicious and vain man. Knowing Kapitsa's opinion of him, Beria was hardly likely to curry his favour with a unique gift. Alternatively, Beria also understood that Kapitsa's arrest would not serve his own interests. All the work of the Soviet intelligence service on the atomic bomb was based on voluntary collaboration with several American and British scientists, and was a result of their extremely positive attitude towards the Soviet Union and Stalin personally. The arrest of Kapitsa, who had huge moral and scientific authority amongst physicists throughout the world, could discredit the Soviet leadership and undermine the effectiveness of the intelligence work. Besides, Stalin knew very well that Beria was not an angel, and that the criticism in Kapitsa's letter was completely objective.

The departure of Kapitsa from the atomic project was, apparently, a relief for Kurchatov. It was now easier for him to fulfil the role of 'top genius', resolving quickly many complex problems of atomic physics without equations and calculations, and even without experiments. They left Kapitsa alone. At the beginning of 1946 he continued regularly to write letters to Stalin. On 4th April 1946, Stalin, for the first time in many years, replied straightaway to some of Kapitsa's letters.

> 'Comrade Kapitsa!
> I have received all your letters. There is much that is instructive in them – I am thinking somehow to meet with you to discuss them.
> Concerning L. Gumilevsky's book *Russian Engineers*, it is very interesting, and will be published before long.
>
> J. Stalin'[5]

Lev Gumilevsky's book, the manuscript of which Kapitsa had sent to Stalin, was published in 1947. It was one of a popular series of books called 'Let us restore Russian priority', about various areas of science and technology.

It seems that Kapitsa's risky resignation from the military atomic projects had had no adverse consequences for him. Then, unexpectedly, on 17th August 1946, Stalin signed a decision of the Council of Ministers relieving Kapitsa of all state and scientific posts. Anatoly Petrovich Aleksandrov, a collaborator of Kurchatov and corresponding member of the Academy of Sciences of the USSR, was appointed director of the Institute of Physical Problems, founded by Kapitsa. This decision was endorsed on 20th September 1946 by the Presidium of the Soviet Academy of Sciences. Kapitsa fell into disfavour. The town cottage, in which Kapitsa's family lived, was situated in the grounds of the Institute. This was now a top security location, and Kapitsa's family had to abandon their house in Moscow and move to the academic summer dacha on Nikolina Hill in a picturesque district near Moscow. Kapitsa's disgrace continued for almost nine years, and came to an end only after all the basic problems in constructing the thermonuclear weapons had been resolved. Kapitsa was able to return to his traditional research, and he was soon awarded the Nobel Prize for his discoveries.

The hydrogen bomb:
the project's mistakes and the mobilisation of scientists

In plutonium and uranium bombs the transition of the charge to 'critical mass' which starts off the explosive chain reaction of the fission of atomic nuclei, is achieved not by the accumulation of the mass of plutonium or uranium-235, but by the increase in their density by colossal compression at several hundreds of thousands of atmospheres. Such compression strongly condenses metal, moving its atoms closer together and establishing critical mass by a lower level of charge. This super-pressure guarantees, by the implosion of the usual explosive substances, that a great number of charges are directed inwards by the synchronised electrical detonators by the explosives, which are positioned spherically at equal distances from the plutonium or uranium 'beads' which, in the case of plutonium, are about the size of a big apple. From the outer pressure of the focused blast waves such beads are reduced in size almost twofold, and the source of the neutrons-detonator fuse, located at the centre of the bead, starts the chain reaction of the atomic explosion. The first atomic bombs drew in not more than 7-10 per cent of the plutonium or uranium. The remaining mass evaporated in the explosion. The various modifications which followed successfully increased the co-efficient of fission of plutonium or uranium, which, correspondingly, increased the power of the explosion.

The explosion of the hydrogen bomb through fusion of the nuclei of deuterium at temperatures of millions of degrees which were provided by the atomic explosion also demanded super-high pressure. According to Teller's original theory, the pressure at several hundreds of thousands of atmospheres, which was able to provide the implosion of the usual explosive materials, would also be sufficient to start off the chain reaction of the thermonuclear synthesis. To prove this it was necessary to do a fantastically large number of calculations, and the absence at this time of fast computers made working out the theory of the hydrogen bomb extremely slow. This difficulty delayed the theoretical work in the Soviet Union as well. The Soviet Union lagged significantly behind the United States in computers, which were then known in the USSR as 'electronic calculating machines'.

But this disadvantage was largely overcome by enlisting a significantly large number of mathematicians in the calculations. Each one was given this or that task, often not representative of the general picture, or even of the general goal for which his calculations would be used. The admission of students to all the physics-mathematical faculties of the universities was stepped up sharply. By 1950, the Soviet Union led the world in the number of mathematicians it had.

The problems of the atomic bomb were resolved basically by physicists from the scientific school of Academician Abram Fedorovich Joffe, who founded the Leningrad Physicotechnical Institute. They were mainly experimental physicists, not theoreticians. But theoretical physics and mathematics were very necessary for the initial research into the hydrogen bomb. This direction was represented by the Moscow schools; Igor Tamm, head of the theoretical department of the physics institute of the Academy of Sciences (FIAN); Lev Landau, head of the theoretical department of the Institute of Physical Problems (IFP); Yakov Zeldovich, youngest of the theoreticians and head of the theoretical department of the Institute of Chemical Physics (IKF).

At this time, the best mathematicians worked in the Institute of Applied Mathematics of the Soviet Academy of Sciences, the head of which was Academician Mistislav Vsevolodovich Keldysh. Several leading mathematical schools were based at the Universities of Moscow and Leningrad, and, up to the war, also at Kharkov. In 1946 and 1947 these scientific centres, and a not inconsiderable number of others, established by orders of the Soviet Council of Ministers which were signed by Stalin, were brought into the project to build a thermonuclear weapon, and placed under a regime of strict secrecy. The general co-ordination of all these efforts fell on Kurchatov's shoulders. However, during this period, and especially in 1948 and 1949, Kurchatov was so heavily involved in building an industrial reactor and in the production of plutonium for the first atomic bomb in the atomic cities established in Chelyabinsk and Sverdlovsk regions, that the centre of all the work on the hydrogen bomb was transferred to a secret atomic centre in Gorky region, on the border with Mordovia, known as KB-11. By 1948, despite the large number of calculations which had been made, and the theoretical investigations, there was still no work going on in the Soviet Union on the actual construction of the hydrogen bomb. As we now know, nor was there any in the United States. However, Soviet intelligence had no 'sources' in Teller's group, and could not spy on the project to build the hydrogen bomb in the United States.

The theoretical model of the 'super' bomb suggested that after the beginning of the thermonuclear reaction in one of the ends of the cylinder containing liquid deuterium, the energy released in the nuclear synthesis would spread along the cylinder to detonate the thermonuclear reaction in the entire mass of deuterium. The explosion, although it took only part of a microsecond, was produced in two stages. But the calculations did not successfully prove that the thermonuclear reaction started in the deuterium would spread automatically, and would not 'go out' for some reason. New, more complex computers with dedicated special programmes were ordered so as to speed up the calculations at Los Alamos which were essential to Teller's work. It was necessary to wait for the appearance of the new supercomputers in order to obtain the answers to many questions. The American system did not permit Teller, compulsorily by order of the government, to enlist mathematicians from various universities.

In the Soviet Union it was rather easier to mobilise scientists for this or any other task of importance to the state. Stalin's signature was tantamount to law for the Academy of Sciences. In the middle of 1948, Zeldovich, just like Teller, could not prove that the thermonuclear reaction in liquid deuterium placed in any 'tube' would spontaneously react. New approaches and new ideas were needed. This also necessitated new people. Kurchatov decided to include Tamm in the group working on ideas for the hydrogen bomb. He was, at this time, the most authoritative theoretical physicist in the Soviet Union. One of Tamm's young collaborators, Andrei Dmitrievich Sakharov, who was then 27 years old, described this event in his memoirs:

> 'In the last days of June 1948, Igor Evgenevich Tamm surreptitiously asked me and another of his students, Semen Zakharovich Belenky, to stay behind after a seminar . . . When everyone had gone out, he closed the door firmly and told us some stunning news. A research group had been established at the FIAN on the order of the Council of Ministers and the Central Committee of the Communist Party of the Soviet Union. He had been appointed head of the group, and we were both to be members. The group's task was theoretical and computational work, with the aim of elucidating the possibility of building a hydrogen bomb'.[6]

The third participant in the group was Tamm's student, Vitali Lazarevich Ginsburg. Soon, several young physicists also joined the new theoretical collective. There were no refusals to participate in the research. At that time, young scientists were usually very hard-up, and lived in poor conditions. Inclusion in an atomic project provided access to top secret work, and to be taken on always meant new high salary scales, a new status, and the provision of good flats in Moscow. The recipients of these 'elite' flats did not know then that, from 1943, practically all of them were bugged by the NKVD.[7]

On Beria's orders, the analysis of the atomic scientists' bugged conversations was assigned to department 'C' of the NKVD, which was headed by General Pavel Sudoplatov. The main problems for the state security organs in monitoring these flats were Lev Landau's countless conversations, each of which, to the end of his days, he never suspected was recorded on tape. He not infrequently called the state structure in the Soviet Union 'fascism', and regretted that he himself had been reduced to the level of a 'scientific slave'.[8] But no kind of 'leak' of secret information was found.

The American challenge

The new, fast-acting computers which arrived at Los Alamos in the middle of 1949 immediately accelerated the work of the American enthusiasts of the hydrogen bomb. However, deep disappointment awaited Teller and his collaborators. Their model of the superbomb, which they had already begun to call 'classic', turned out to be mistaken. Their calculations showed that the spontaneous reaction in deuterium took place not at pressures of hundreds of thousands, but at tens of millions of atmospheres. The implosion achieved with the help of the usual focused explosions could not guarantee such pressures. Teller had reached a dead end. According to the calculations, it was possible to reduce the necessary pressure if the deuterium was mixed with tritium, a heavier isotope of hydrogen. But tritium, in contrast to deuterium, is not found in nature. This radioactive isotope has a half-life of about twelve years. It is possible to produce it in special reactors, but this process is too expensive and slow. Zeldovich's group, which was behind Teller in going down this path, also met a dead end. It also discovered that only a very big quantity of tritium in combination with deuterium could guarantee a self-supporting thermonuclear reaction. But the tritium bomb was too expensive and impractical.

These failures gave rise to favourable conditions for ceasing the hydrogen bomb project and limiting nuclear weapons according to the explosive potential of atomic bombs. The United States still had the atomic monopoly, and by the summer of 1949 had acquired an arsenal of 300 atomic bombs, which, according to the military's projections, was enough to destroy around 100 Soviet cities and industrial centres, and to remove 30 to 40 per cent of all the economic infrastructure of the Soviet Union. But, according to the American strategists, this atomic arsenal was insufficient to deliver a decisive defeat to the Soviet Union in case of war. The American government decided to increase the atomic arsenal to 1000 bombs by 1953.

The successful testing of the first Soviet atomic bombs, which only became known in the United States in the middle of September 1949, presented the American Government with a choice. On the one hand, it was possible to end the race in atomic weapons and begin negotiations with the Soviet Union. On the other hand, it was possible, on the contrary, to speed up the building of a new super weapon – the hydrogen bomb. The international situation favoured a peaceful course. The Berlin crisis had ended in May 1949 in favour of the West. Stalin abandoned the blockade of West Berlin without achieving his objectives. The civil war in China had also ended. The proclamation on 1st October 1949 of the People's Republic of China was a strategic defeat for the United States in Asia. But the conflict had nevertheless ended, and war had ended as well. New initiatives to build stability, not arms races, were needed.

Several committees and commissions were established in the United States to work out a new strategy. The result of this work was that the opinion prevailed that the appearance of nuclear weapons in the Soviet Union and the victory of the communists in China constituted a threat to the United States. On 31st January 1950, President Truman publicly announced that he had directed the Atomic Energy Commission 'to work on all forms of atomic weapons, including the so-called hydrogen or super bomb'.[9] The next day, the front pages of the American newspapers, on the whole, commented favourably on Truman's decision.

Having taken this decision and, moreover, announced it publicly, Truman was certain that scientific research in this area would be successful. Truman's decision meant that all the work would be directed towards practical realisation, and the project to build the hydrogen bomb would receive essential financial and organisational support.

Truman's decision was a triumph and a tragedy for Teller. Without him there wouldn't have been even an idea of the superbomb at this time. No one else thought it was necessary. The whole project was the product of one man's megalomania. Now Teller had won acceptance for his plan. But his tragedy was that he had no proof of the very possibility of building a superbomb. Several months after Truman's announcement, the supercomputer's calculations showed that not only the pressure, but also the temperature in the atomic bomb was insufficient for the chain reaction of the synthesis in deuterium to start. Only tritium, an isotope of hydrogen with two neutrons in the nucleus, which made these nuclei less stable, was suitable for the beginning of the reaction. But, according to calculations made at Los Alamos, to obtain one kilogram of tritium was equivalent to 70 kilograms of plutonium in terms of energy and finance, which was enough to produce ten to twelve ordinary atomic bombs. What's more, one kilogram of tritium still didn't guarantee the beginning of a chain reaction in a cylinder with deuterium.

Edward Teller was in despair, according to historians of the American nuclear programme. The most expensive new military programme in American history was started on his initiative, but at the same time all the ideas on which it was based turned out to be false. For 14 months after Truman's announcement, alternative solutions were sought in the laboratory at Los Alamos and several other atomic centres, but the necessary idea was not discovered. The only consolation for Teller and his colleagues was that, if the Soviet Union was following the same path, on the basis of intelligence information about the projects discussed at the seminar in Los Alamos in 1946 (Klaus Fuchs, a participant at this seminar, had been arrested in England in January 1950), then the Soviet scientists were also expending vast efforts uselessly. However, Teller was mistaken in this assumption. In the Soviet Union, after Truman's announcement of 31st January 1950, the hydrogen bomb projects were also stepped up from the possibilities of theoretical research to practical realisation. But all the work went not in the direction of Teller's ideas, since Zeldovich, having checked them, ceased work on this model earlier than Teller himself. Already, from the end of 1949, all the efforts of the Soviet physicists working on the hydrogen bomb project were concentrated on realising the Sakharov-Ginsburg model of the hydrogen bomb.

The Americans worked to build a hydrogen bomb which was thousands of times more powerful than the usual atomic bomb. The Sakharov-Ginsburg model of the hydrogen bomb had several limitations. The calculations showed its full feasibility. The process of the atomic fission of plutonium and the atomic fusion of deuterium take place not in two stages, but simultaneously. The hydrogen component of the bomb cannot be increased beyond a certain limit, which restricts the power of the explosion. This power could be only 20 to 40 times greater than the usual plutonium bomb and this was, of course, a disappointment. The price of the destructive potential of this variant of the hydrogen bomb wasn't lower than the atomic bomb of improved construction. After testing, therefore, this bomb did not undergo further research and into mass production. But its successful testing in August 1953 nevertheless had great moral and political effect.

Sakharov's hydrogen bomb

Edward Teller, as the theoretical discoverer of the hydrogen bomb, significantly overestimated his own scientific potential. He was not a physicist of wide vision with experience of work in several areas. But he had a talent for lobbying politicians. He was, besides, the most extreme reactionary and fanatical anti-communist. Teller discredited himself amongst American physicists by his testimonies and accusations against Robert Oppenheimer, the former head of the Manhattan project, the 'father' of the atomic bomb, in a special 'political' court where Oppenheimer was charged with disloyalty. As a result of the hearing, which attracted worldwide publicity, Oppenheimer opposed the building of the hydrogen bomb. Teller managed to convince the American administration that the Soviet physicists, even if they managed to build the atomic bomb, although not soon, they would never be able to build the hydrogen bomb. He was convinced that the physical principles of the thermonuclear weapon were so complex, and the mathematical calculations which were essential for its construction were so vast in number, that they could be accomplished only in the United States. Reports which were sent to Truman by other experts and commissions also asserted that it was extremely unlikely that the Soviet Union would be able to build a thermonuclear weapon. They were not so sceptical about the abilities of Soviet physicists, but were united in their view that the Soviet Union did not possess the industrial and raw material base which was essential for building an atomic industry. According to American experts, the main factor limiting Soviet opportunities was the absence of uranium and a uranium industry. The absence of computers was also mentioned.

Teller's inflated opinion of himself had no real basis. Very many Soviet physicists, even young ones, were much more talented and had a broader scientific outlook. Igor Tamm, the leading Soviet theoretical physicist, had wider experience of research than Teller, embracing not only nuclear physics but also thermodynamics, quantum mechanics, physical optics and other fields. Lev Landau also significantly outshone Teller.

The young Yakov Zeldovich had a deeper mathematical mind and broader outlook than Teller. Precisely because he did not have sophisticated computers he became convinced of the hopelessness of the 'classical' model of the hydrogen bomb earlier than Teller. According to Sakharov, Tamm, already in 1948 when his department was included in research on the problem, was extremely sceptical about Teller's model, and oriented his group towards experiments to find new solutions.

Sakharov and Ginsburg very quickly, towards the end of 1948, worked out a new idea of the hydrogen bomb which was immediately recognised as well-founded and practicable. In this model, which has never been revealed in detail, and continues to remain classified, the problem of pressure was solved by the distribution of the deuterium not in a cylinder, but in layers in the actual plutonium charge (hence the codename 'layer cake' in discussions of the model amongst physicists). The atomic explosion guaranteed both the temperature and the pressure for the beginning of the thermonuclear reaction. In place of tritium, which was too expensive and had to be artificially produced, Ginsburg suggested using the light isotope of lithium, which is a natural element. Lithium, the lightest of the hard elements of the earth's core, was fully accessible. Notwithstanding the need to separate lithium-6 from the other isotopes, the production of lithium-6 was thousands of times cheaper than the production of tritium. The separation of lithium-6, which comprises 7.4% of natural lithium, was somewhat easier than the separation of deuterium from natural hydrogen. Besides, it was possible to use lithium not in a mixture, but in conjunction with deuterium – as lithium deuteride. The nucleus of lithium-6, swallowing up one neutron at the atomic explosion, disintegrates into the nucleus of tritium and the nucleus of helium-4. This releases more energy than the merging of two nuclei of deuterium and tritium. The formula for the reaction is:

$$^{6}\text{Li} + \text{n} \rightarrow {}^{3}\text{H} + {}^{4}\text{He} + 4.6\ \text{MeV}$$

The tritium formed in the reaction in turn gives rise to the reaction with deuterium.

The disadvantage of this model is that the mass of material for the thermonuclear explosion must be proportional to the mass of plutonium in the charge. The light and heavy elements are distributed in layers. It is impossible therefore to increase the dimensions of the charge only at the expense of the deuterium. The advantage is that the dimensions of such a bomb are not great and it is possible to test the bomb, and not intermediate and more complex and large systems. This project was approved by the Special Committee on atomic energy already in 1949. At the same time it was decided to set up a special department for Tamm's group at the secret facility in Gorky region, which was led by Yuli Khariton. When Tamm and Sakharov flew for the first time to this atomic centre in the summer of 1949, the final preparations to test the first Soviet atomic plutonium bomb were being made. After the successful testing of this bomb on 29th August 1949, all the main participants in the work were preparing for their first leave in several years. After the main members of the Special Committee and the Technical Council returned from leave at a special Black Sea resort which was also part of the atomic administration system (physicists swam in the sea escorted by bodyguards), important decisions about the fate of the hydrogen bomb were taken. It was proposed that 'Establishment KB-11' should be significantly expanded. It was given a new name, 'Arzamas-16'. It was proposed that military variants of the atomic bomb would be built and produced there. Research into two variants of the hydrogen bomb was also planned. One was the

Sakharov model, and the other a modified Teller model on which Zeldovich had already worked at the establishment for more than two years. From 1950, Tamm's entire group had to travel to Arzamas-16 for permanent work. The development of Arzamas-16 was linked with extensive new constructions in the secret atomic city. Comfortable cottages were designed for the new scientific members of the establishment. The young scientists were expected to work here for many years. In atomic establishments no one was able to resign and to leave by their own decision.

Arzamas-16

After two missions to Arzamas-16 in 1949, Tamm's group moved there for permanent residence in 1950 to carry out not only theoretical research, but also to make decisions about actual construction. Complex new production facilities were needed – a special reactor for the production of tritium, and a unit to separate the light isotope of lithium from natural lithium. The technology for the production of deuterium had already been worked out at IFP under the leadership of Anatoly Aleksandrov. But it was essential to construct a special facility for the large quantities of deuterium which were required. Many other problems arose, since the materials required to build the hydrogen bomb differed from those installed in the atomic devices.

The decision to dispatch Tamm's group to Arzamas-16 was formalised as a decision of the Council of Ministers and signed by Stalin. But despite such authoritative endorsement, the security organs would not permit access to such a secret establishment to the most important member of the group, Vitaly Ginsburg, who had been appointed by Tamm to the theoretical department as one of the co-authors of the entire project on 'layers'. Ginsburg was older and more experienced than Sakharov. He was a member of the Communist Party, in contrast to the non-party member Sakharov. However, Ginsburg's wife, Nina, was in political exile at this time. In 1945, when she was a student at Moscow University, she was arrested together with a group of other students, and charged with 'counter-revolutionary activity'. After nine months in prison she was sent into exile. She was only able to return to Moscow in 1953, after Stalin's death. Therefore, Ginsburg was designated 'unreliable'. This saved him from the glory of becoming, together with Sakharov, the 'father' of the first Soviet hydrogen bomb, but in general it worked to his advantage. He continued working very successfully at FIAN. In 1956 he was elected a Full Member of the Academy of Sciences of the Soviet Union. On their visits to Moscow, Tamm and Sakharov continued to consult with Ginsburg, and sometimes entrusted certain calculations to him. Now, 84 years old, Ginsburg continues working, and recently published two books, one of which was his scientific autobiography.[10]

Sakharov and Tamm's other team members flew to Arzamas-16 in March 1950. Tamm flew in in April with a rucksack and skis, hoping, apparently, to go walking in the surrounding woods. However, on the first such sojourn, according to Sakharov, they did not even reach the nearest woods as 'we heard shouting from behind: "Stop, don't move"!'

> 'We turned round and saw a group of soldiers pointing their Kalashnikov assault rifles directly at us . . . They took us to a building beside which a lorry was waiting, ordered us to sit down on the floor, and tied our legs. Opposite, on a little bench, sat a group of four soldiers with Kalashnikovs. One of them said: "If you try to run away or move your legs – we'll shoot without warning"'.[11]

Such a strict regime at Arzamas-16 is explained by the fact that several prison camps comprised a large part of all the structures of the town. Thus, the town, as Sakharov writes in his memoirs, published in 1990, 'represented some kind of symbiosis of the leading scientific research establishments, experimental facilities and a big camp . . . The prisoners built the factories, the test sites, the roads and the living accommodation for the research staff. They themselves lived in barracks and went to work escorted by German Shepherd dogs . . . Every morning, long grey columns of people in quilted jackets, accompanied by German Shepherds, passed our curtained windows'.[12]

As Sakharov realised soon after beginning his work, the prisoners who were sent to Arzamas-16, even if they had received not very long sentences, had practically no chance of freedom.

> '. . . The authorities had one problem – where to put the people who were released who knew the location of the facility, which was considered a great secret . . . The authorities solved this problem by a simple, pitiless and completely illegal means – those who were released were exiled forever to Magadan, where they couldn't tell anyone about anything. There were two or three such deportations, one of them in the summer of 1950'.[13]

Such exiles to Magadan also took place from Chelyabinsk. Sakharov found out completely by chance about the deportation of prisoners to the Magadan region three months after this arrival at the facility. The prisoner-artist Shiryaeva, whom Sakharov often met together with Zeldovich, found herself part of this deportation. Shiryaeva, who had been sent to the camp for taking an 'anti-Soviet' conversations, was detailed to paint the ceilings and walls of the houses of the top brass and in the town's club, and the sociable Yakov Zeldovich quickly befriended her.

> '. . . Once, it was already summer, Zeldovich disturbed me during the night . . . Ya. B. was very worried. He asked me to lend him some money. Fortunately, I had just been paid my monthly salary, and gave him everything . . . After several days I discovered that Shiryaeva had completed her term of imprisonment and she, together with others in the same position, had been sent away from the establishment "into permanent exile" to Magadan . . . Several months later, Shiryaeva gave birth. Ya. B. said that in the house where she gave birth, the floor was covered with ice to a depth of several centimetres'.

Born in Magadan, a little girl, Shura, Zeldovich's daughter, survived. Twenty years later, in 1970, Sakharov met her together with her father in Kiev. Two of the main theoreticians, on whose creative enthusiasm depended the fate of the thermonuclear weapon in the Soviet Union, and therefore the country's foreign policy, in the summer of 1950, could not resolve what seems a rather simpler task – how to save a pregnant woman and friend from complete illegality and possible death.

Although Zeldovich, like Teller before him, understood the impossibility of the first variant of the 'two-stage' hydrogen bomb, the theoretical work continued on the variants of this model. The task was to find a mechanism for compressing deuterium and tritium, or deuterium and lithium, which would guarantee not hundreds of thousands, but millions of atmospheres. The idea arose that it was possible to guarantee such pressure by the use at one moment of very powerful laser beams. In the United States, Stanislav Ulam, a talented physicist who had emigrated from Poland, put the idea to Teller. The first American hydrogen bomb was thus called the 'Ulam-Teller' model. This model achieved the very high pressure necessary for tritium and deuterium not by explosive waves of chemical explosive materials, but by the characteristic 'implosion' of reflected radiation of the atomic explosion. This model required a large quantity of tritium, and new reactors were built for its production. Although there was still no bomb, the preparation of a special structure for testing proceeded at great haste. At Los Alamos, Saturdays as free days were revoked (in the Soviet Union Saturday was then still an ordinary working day). The test was scheduled for 1st November 1952 on a small atoll in the southern part of the Pacific Ocean. The test was a success. The atoll was completely destroyed, and the crater from the explosion which was covered with water was more than a mile in diameter. Measurements showed that the force of the explosion was equivalent to ten megatons of TNT. This exceeded the power of the atomic bomb dropped on Hiroshima by a thousand times.

The results of this explosion, which were announced by the American Government, produced real shock and criticism elsewhere in the world. It was obvious that such a fantastically powerful bomb could not be used against military targets. It could not be a weapon of war. It was a weapon of genocide and political blackmail.

Sakharov's hydrogen bomb, which was more modest in terms of explosive power, was prepared for testing without especial haste. Stalin, having received a report about the testing of the American hydrogen bomb in the middle of November, interpreted this as confirmation of his conviction that the United States was seriously preparing for war with the Soviet Union. In November 1952, Dwight Eisenhower won the election for President of the United States. Teller's extreme haste and that of the other founders of the American hydrogen bomb led to the testing of incomplete constructions of more than 60 tonnes in weight several days before the elections. This was linked directly to Truman's departure from the White House, which created uncertainty. Eisenhower could stop the testing. As an experienced general he might doubt the expediency of such an excessively powerful weapon.

At the beginning of 1953, it was reported to Stalin that work on the Soviet hydrogen bomb, twenty times more powerful than the atomic bomb, was close to completion.[14] However, Stalin was not to live to see the testing of this bomb. This was carried out on 12th August 1953. This Soviet test was known as 'Joe-4' according to the American classification, in honour of 'Uncle Joe', as Stalin was known in the United States during the war.

Epilogue

After the successful testing of the first Soviet hydrogen bomb, all the main participants received long rest leave. On their return from the south, in accordance with a secret decision of the Presidium of the Supreme Soviet of the Soviet Union, almost all the key participants in the project received generous rewards. I.E. Tamm, A.D. Sakharov, A.A. Aleksandrov, Ya. B. Zeldovich, L.D. Landau and the head of Arzamas-16, General P.M. Zernov, were all made Heroes of Socialist Labour. The young scientists were speedily elected to the Academy of Sciences. Kurchatov and Khariton received the title of Hero of Socialist Labour for the third time. At the same time, these scientists also received a special enhanced Stalin prize – five hundred thousand roubles each. And not forgetting Vitaly Ginsburg, who was awarded the Order of Lenin.

After the building and testing of the first Soviet atomic bomb, in 1949, many staff of the security services and heads of prison camps attached to the atomic establishments received the title of Hero of Socialist Labour. In 1953, in connection with Beria's arrest, fewer were honoured. General Lieutenant Pavel Meshik, Beria's appointee, who was responsible for the security regime and secrecy of all the atomic establishments, both scientific and industrial, and one of the organisers of the deportations into 'permanent exile' in Magadan of the prisoners who had finished their sentences in the camp, was arrested and shot, together with Beria. The deported 'special exiles' began returning to the central regions after 1955. More than 20,000 people returned from Magadan region alone. But they were still not allowed to settle in the big cities or close to the border.

After the testing of the Sakharov 'layerbomb', the efforts of Sakharov himself, Zeldovich and many others were united in order to build a more powerful two-stage hydrogen bomb, similar to the one the Americans were testing. This task was accomplished very quickly. The bomb was tested only two years later, on 22nd November 1955. But this does not mean that it was impossible to explode it earlier. It was simply decided to prepare the bomb straightaway, but not the 'device'. The bomb was tested by being dropped from a plane, and not on the ground. This necessitated a very big modification of the atomic testing range in Semipalatinsk region and the resettlement of tens of thousands of inhabitants of the regions adjoining the range. A new Arctic testing range at Novaya Zemlya was equipped in order to test subsequent hydrogen bombs which were even more powerful.

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OBITUARY

We have learnt, with sadness, of the death of Fred Silberman.

He was always a good friend to the Bertrand Russell Peace Foundation and to The Spokesman and a courteous and candid critic when he didn't entirely agree with us.

Many of us best remember Freddy for his commitment to the Institute for Workers' Control and the shrewd and good humoured advice he always gave to fellow campaigners. His pioneering work as a trade union research officer, first with the TGWU and later with TASS, meant that he was able to draw on valuable first hand experience and a range of contacts which he never stinted to share to help further industrial democracy.