(2) Beginnings of the Soviet H-Bomb Program

Early Soviet theoretical work on thermonuclear ignition was aided by espionage, but many important ideas were conceived and developed independently.

German A. Goncharov

In late 1945 Soviet physicist Yakov Il'ich Frenkel suggested that fission bombs might be used to fuse light nuclei and thus release even greater energies. In a memo addressed to Igor Vasilievich Kurchatov dated 22 September 1945, he pointed out that "it would be in our best interest to utilize the high, billion-degree temperatures developed in the explosion of an atomic bomb in application to synthetic reactions (for example, to produce helium from hydrogen), which are the energy source of stars and which could even further increase the energy released in the explosion of the principal substance (uranium, bismuth, lead)." Despite the error in estimating the temperatures in an atomic explosion and the fallacy of suggesting that bismuth and lead nuclei are fissionable, the thought expressed by Frenkel is significant as the first documented Soviet communication on the topic.

Of course, Frenkel could not have known that the memo's recipient, Kurchatov, already had information about US work progressing along this very line. Such information began to enter the USSR via intelligence channels in 1945. Most of the incoming reports on the problem of liberating nuclear energy from lighter elements—that is, the superbomb problem—were of a cursory nature. But then, in September 1945, Soviet intelligence obtained concrete information that embodied elements of the "classical Super" theory (see the preceding article) and characterized specific features of possible physical plans of a classical Super device. The principal configuration was a combination of a gun-type ^{235}U atomic bomb with a beryllium oxide tamper, an intermediate chamber containing a deuterium–tritium mixture and a cylinder of liquid deuterium. The document characterized the D–T reaction cross sections via an approximate equation, and indicated how much the thermonuclear ignition temperature should be reduced by adding small quantities of T to the D. This document provided the USSR with the first data on the unique properties of T three and a half years before they were openly published. Of particular note is another 1945 intelligence document, in which the superbomb was considered not to be a fusion bomb, but a boosted atomic bomb. The document stated that in this bomb a primary atomic explosion would induce the implosion and detonation of a secondary sphere of plutonium-239. The result would be an increase in the efficiency and energy release of the bomb. The document thus addressed a two-stage atomic bomb construction. However, it was devoid of any clues as to how to implement this concept. Needless to say, the very existence of the intelligence information was known only to an extremely limited circle of people in the USSR.

See the author note on page 44.

The possibility of constructing a superbomb was also announced in the open press in 1945. The *London Times* of 19 October reported the disclosure by physicist Marcus Oliphant, speaking in Birmingham the day before, that it was now possible to produce a bomb one hundred times more powerful than those employed against Japan—that is, a bomb with a TNT equivalent of about two megatons. The press report said that, in Oliphant's opinion, a bomb could be constructed with one thousand times the energy released by existing types.

News of the superbomb capability could not help but unnerve the directors of the Soviet atomic project. On 24 October, the superbomb issue was one of several questions that Yakov P. Terletskii (on orders from Lavrenti P. Beria, the head of the Soviet secret police) was to address to Niels Bohr on his return to Denmark from the US. There were two meetings between Terletskii and Bohr in Copenhagen during a three-day period, 14–16 November 1945. Bohr's responses included the following:

> What does it mean, a superbomb? This is either a bomb of a bigger weight than the one that has already been invented, or a bomb which is made of some new substance. Well, the first is possible, but unreasonable, because, I repeat, the destructive power of the bomb is already very great, and the second—I believe—is unreal.

This reply did little to convince the directors of the Soviet atomic project that the reports of US superbomb efforts could be dismissed. However, it helped to solidify the philosophy that the Soviet intellectual and material resources should be concentrated exclusively on the atomic bomb effort in this period.

Nonetheless, Kurchatov recruited Yuli B. Khariton with orders to collaborate with I. I. Gurevich, Yakov B. Zel'dovich and Isaak Ya. Pomeranchuk in looking at the possibility of energy release from lighter elements. Their findings were summarized in a report, "Utilization of the Nuclear Energy of the Light Elements," which was read by Zel'dovich at a meeting of the Technical Council of the Special Committee on 17 December 1945. The approach advocated was based on the idea of triggering a nuclear detonation in a deuterium cylinder by achieving nonequilibrium combustion. In 1991 this report was reproduced

A PORTION OF THE TOWN OF SAROV in the 1930s or 1940s. The building in the background contained the theoretical divisions of KB-11 from 1948 to 1956. KB-11 evolved into the present-day All-Russian Scientific-Research Institute for Experimental Physics (VNIIÉF). (All photos courtesy of RFYaTs–VNIIÉF.)

in full in *Uspekhi Fizicheskii Nauk*.[1] Based on Zel'dovich's presentation, a resolution was passed concerning only measurements of the reaction cross sections of light nuclei, but without any directives as to the organization and pursuit of analytical and theoretical studies or practical work on the superbomb. All the same, in June 1946 a team of theoreticians at the Institute of Chemical Physics of the Academy of Sciences of the USSR, including A. S. Kompaneets and S. P. D'yakov and under the direction of Zel'dovich, embarked on a theoretical investigation of the feasibility of releasing nuclear energy from light elements as part of the research program on the problems of nuclear combustion and explosion. Concurrently with the work of this group, informative intelligence reports about US superbomb activities continued to enter the USSR during 1946–47. They were augmented with new revelations in the open press, including a 1947 article by Edward Teller.[2]

Information from Fuchs

In London on 28 September 1947, Klaus Fuchs, a German-born British physicist who had worked on the Manhattan Project, met with the Soviet intelligence agent Aleksandr S. Feklisov. Feklisov asked Fuchs ten questions, the first concerning the superbomb. From the report of this meeting, we know that Fuchs orally communicated the reality of ongoing theoretical superbomb studies in the US under the direction of Teller and Enrico Fermi at the University of Chicago. Fuchs described certain structural characteristics of the superbomb and its operating principles and mentioned the use of T and D. He verbally conveyed that, around the beginning of 1946, Fermi and Teller had proved, in effect, the workability of such a superbomb. However, Feklisov was not a physicist and in his report could only very roughly reproduce the structural details of the superbomb and its operation. Fuchs did not know if practical efforts had begun in the US on the construction of a superbomb or what their results were.

In October 1947 an intelligence report arrived in the USSR that related US attempts to set off a chain reaction in a D–T–Li medium. It indicated that Teller intended to implement such a reaction to create a thermonuclear bomb that would carry his name. This communiqué was the first, and very likely the only, intelligence report of that time to mention lithium as a thermonuclear fuel component (note that the isotopic composition of the Li was not indicated). In the early information received in 1945 and 1947, Li, specifically ^{6}Li, was mentioned only as a means of boosting T production in nuclear reactors. Not to be dismissed is the possibility that the report echoed Teller's proposal to use ^{6}LiD in the Alarm Clock.

On 3 November 1947, the research results of the Zel'dovich group were heard for the first time at a meeting of the Scientific–Technical Council of the First Central Administration. A report by D'yakov, Zel'dovich and Kompaneets, "Utilization of the Subatomic Energy of the Light Elements," was presented. The report pinned the greatest

IGOR VASILIEVICH KURCHATOV led the Soviet nuclear program.

hopes on nonequilibrium combustion and on achieving a detonation-type reaction accompanied by propagation of a shock wave through the main body of thermonuclear fuel. The possibility of detonation in an unbounded medium of D and ^{7}LiD had been investigated (^{6}LiD was excluded because, according to the authors' data, the cross section of the ^{6}Li + D reaction is smaller than that of ^{7}Li + D). Diffusion of radiation and neutrons was ignored. The cross sections of secondary reactions (D + T and so on) were regarded as unknowns and were varied. The report concluded that detonation of pure D was feasible if the cross sections of secondary reactions were sufficiently large. Detonation in ^{7}LiD was thought to be possible if the cross sections of the ^{7}Li + D reaction were six times larger than those obtained experimentally. A resolution of the Scientific–Technical Council acknowledged the importance of this work and the need to continue developing the nuclear physics and, in the event of positive results, to work on practical objectives. The Council of Ministers adopted a resolution in February 1948, placing Zel'dovich officially in charge of operations at project "KB-11." Working within KB-11, Zel'dovich continued to coordinate the work of the theoreticians at the Institute of Chemical Physics (in Moscow) on the utilization of nuclear energy from light elements.

On 13 March 1948, an event took place that played an exceptional role in the subsequent course of the Soviet thermonuclear bomb program. On that day, Fuchs and Feklisov met a second time in London, and the British scientist handed over materials of paramount importance. Included in the documents was new theoretical information pertinent to the superbomb. It contained a detailed description of the classical Super project with the new initiation system developed since the 1945 project—the two-stage configuration operating on the radiation implosion principle. (See the preceding article.) A gun-type ^{235}U bomb with a beryllium oxide tamper was used as the primary atomic bomb. The secondary unit of the initiator was a liquid D–T mixture with a high concentration of T. A heavy jacket of opaque radiation-impervious material confined radiation within the cylindrical chamber containing the primary and secondary units. This initiator was joined to a long cylinder containing liquid D for most of its length but with a liquid D–T mixture (with a small concentration of T) in its first section.

The documents described the operating principle of the initiator and contained several graphs characterizing its performance. The document presented experimental and theoretical data essentially substantiating the project's workability. The experimental data included the D–T and ^{3}He–D reaction cross sections. Theoretical estimates confirmed the ignitability of the D–T mixture in the initiator, but, as in the theoretical document of 1945, did not theoretically confirm that nuclear combustion could ignite and propagate in the main body of thermonuclear fuel. The ignition of the D–T mixture in the initial section of the cylinder and the propagation of nuclear combustion through the main body of D during normal operation of the superbomb's binary initiating chamber were taken for granted. The information was probably consistent, by and large, with information set forth in the Fuchs–von Neumann patent of 1946. In addition the documents conveyed improved atomic bomb designs.

On 20 April 1948 the directorate of the Ministry of State Security forwarded a Russian translation of these materials to Stalin, Molotov and Beria. The Soviet political leaders viewed the new intelligence as direct evidence of potential major advances by the US in atomic and superbomb development, and they called for drastic measures to push through feasibility studies on the construction of similar bombs in the USSR and to impart official status to these operations.

ALEKSANDR S. FEKLISOV, the Soviet intelligence courier who worked with Klaus Fuchs in the UK from 1947 to 1949. In early 1948 Fuchs gave him documents that described the classical Super program in detail.

On 23 April, Beria ordered Boris L. Vannikov, Kurchatov and Khariton to analyze the materials and submit proposals for setting up the investigations and operations needed to pursue the systems described. The recommendations presented by these three on 5 May formed the basis of resolutions adopted by the Council of Ministers of the USSR on 10 June 1948.

One of these resolutions, "Supplement to the Plan of Operations of KB-11," mandated KB-11 to verify theoretically and experimentally data on the feasibility of implementing every conceivable type of advanced-configuration atomic bomb and a hydrogen bomb. The hydrogen bomb was assigned the code name RDS-6. The resolution commissioned KB-11 to investigate the theory of initiation and combustion of D and D–T mixtures. It called for the participation of the Physics Institute of the Academy of Sciences of the USSR (FIAN) and set a target date of 1 June 1949. The resolution mandated the creation of a special group within KB-11 to work on the development of RDS-6.

A second resolution defined several measures aimed at ensuring execution of the first resolution. In the part concerning feasibility studies of hydrogen bomb construction, the second resolution mandated the Physics Institute (led by Sergei I. Vavilov) to "organize research efforts on the development of a theory of deuterium combustion in accordance with the specifications of Laboratory No. 2 (Yu. B. Khariton and Ya. B. Zel'dovich) and, to that end, in 48 hours to create within the Institute a special theoretical group under the direction of . . . I. E. Tamm." Among its numerous directives, the resolution called for improvements in the living conditions of project participants and, in particular, the provision of a separate room for one member of the Tamm group: Andrei Dmitrievich Sakharov. On the day these two resolutions were adopted, new intelligence materials were sent by direct order from Beria to Khariton at KB-11 for use in the project. Permission to work with intelligence documents of 1948 was granted to Zel'dovich. Of the theoretical physicists of KB-11, only Zel'dovich and D. A. Frank-Kamenetskii were granted permission to work with early intelligence documents (of 1945) on the atomic bombs and the superbomb.

ANDREI DMITRIEVICH SAKHAROV in 1948 conceived of a bomb design with alternating layers of uranium-238 and deuterium, analogous to a proposal made by Edward Teller. It formed the basis of the first thermonuclear weapon tested in the Soviet Union.

In June 1948 a special team at the Physics Institute, consisting of Igor Evgenievich Tamm, Semyon Zakharovich Belen'kii and Sakharov, began working on the problem of the nuclear combustion of D. The team was soon joined by Vitaly Lazarevich Ginzburg and Yuri A. Romanov. The resolution of the Council of Ministers contained no provision for this group to work with intelligence data (nor did the members of Zel'dovich's Moscow group, Kompaneets and D'yakov, have such authorization). The mission of the Tamm group was to determine how to verify and refine the calculations of the Zel'dovich group on the nuclear detonation of D.

Sloika

While analyzing the results of the Zel'dovich group calculations, in September and October 1948, Sakharov thought of an alternative solution and began to explore the possibility of building a combined bomb, mixing D and ^{238}U together. He arrived, independently of Teller, at the notion of a heterogeneous scheme with alternating layers of D and ^{238}U—that is, a scheme analogous to the Alarm Clock. Sakharov's scheme was called *Sloika*. ("Layer Cake" is the usual translation but a *sloika* is more accurately a kind of cheap pastry.) It was based on the principle of ionization compression of thermonuclear fuel, and Sakharov's colleagues dubbed this process "Sakharization" [honoring the scientist, but also creating a pun on Sakharov's name with the suggestion of "caramelization," from the Russian word for sugar, *sakhar*[3]]. Note that Sakharov's proposal was predated by a 17 July article by Watson Davis, "Superbomb Is Possible."[4] This article presented general considerations pertaining to the feasibility of constructing a D bomb. One section, under the heading "Combined Bomb," begins with a profound remark:

> Because in one of the two D–D reactions a neutron is produced, it may prove practical to make a sort of combined deuterium–plutonium bomb, using the neutrons of the D–D reactions to fission plutonium.
>
> For this reason, any competent chemist could tell you that the material of the superbomb might be a solid consisting of a chemical combination of plutonium and deuterium.

Of course, the idea of a heterogeneous structure did not appear in the article.

On 2 December, Ginzburg issued his second report on the work of the Tamm group, "Investigation of the Deuterium Detonation Problem II." As in the first report, the main topic was the feasibility of nuclear detonation in an unbounded medium of liquid D. Addressing systems worthy of practical consideration, Ginzburg estimated the effectiveness of a structure consisting of an atomic bomb surrounded by a layer of D encased in an outer shell. He noted that one might successfully replace the liquid D with heavy water. He also submitted the following important remark: "Another possibility to consider is the 'burning' of mixtures containing lithium-6 (with a view toward utilizing the heat of reaction $^6Li + n \rightarrow T + {}^4He + 4.8$ MeV), ^{235}U, ^{239}Pu, etc." Ginzburg had thus thought of using ^6LiD as a thermonuclear fuel, but it is important to observe that he was originally thinking in terms of increasing the heat release directly at the expense of neutron capture by ^6Li rather than boosting the production of T.

On 20 January 1949, Sakharov issued the first report describing his Layer Cake scheme: "Stationary Detonation Wave in the Heterogeneous System Uranium-238 + Heavy Water." The report systematically presented the Layer Cake concept and methods for calculating a stationary detonation wave in a Layer Cake of unbounded volume consisting of plane layers. Taking into account secondary reactions involving T, Sakharov equated their cross sections with that of the D + D reaction in one of its channels. He stressed that the D + T and T + T reactions had not been studied experimentally, and all assessments of their cross sections were conjectural. He emphasized that a stationary detonation wave had to be investigated before the initiation problem could be solved. The simplest initiation scheme, which had to be analyzed mathematically, was to place an atomic bomb in the center of a large (essentially infinite) spherical "layer cake." Other initiation schemes were also conceived, some perhaps needing less Pu. Sakharov characterized one such scheme as the "utilization of an additional plutonium charge for precompression of the 'layer cake.'" This was actually the basic idea of the two-stage thermonuclear bomb configuration. Five years passed before Sakharov returned to this crucial idea. (See the following article.)

On 2 March 1949, Ginzburg published a report, "Utilization of ^{6}LiD in the Layer Cake." In assessing the efficacy of using ^{6}LiD in the Layer Cake, he had already taken into account the formation of T from ^{6}Li, along with the phenomenon of ^{238}U fission by 14 MeV neutrons. It is amazing that Ginzburg proposed the use of ^{6}LiD without knowing the true cross sections of the D + T reaction; he assumed in his reports, as did Sakharov, that they were equal to the D + D cross section in one of its channels.

On 17 March, Khariton, having learned of the results achieved by the Tamm group, submitted to Beria a request that Tamm and Kompaneets be granted access to intelligence data on the cross sections of the D + T reaction. M. G. Pervukhin and P. Ya. Mesik looked over this request on orders from Beria, and they responded that "it is not reasonable to pass intelligence materials to I. E. Tamm and A. S. Kompaneets [because that would] familiarize 'extra' people with these documents." They did, however, write that the experimental data on the cross sections were to be sent to Tamm and Kompaneets without citing the source. The two Russian scientists were sent the data on 27 April. Ironically, that virtually coincided with the open publication of similar data in the 15 April issue of the American journal *Physical Review*.[5] It is essential to note that the General Advisory Committee to the US Atomic Energy Commission, under the direction of J. Robert Oppenheimer, had already in October 1947 recommended the declassification of all the nuclear properties of T.

After familiarizing himself with the D + T data, Ginzburg reexamined his estimates of the efficacy of using ^{6}LiD in the Layer Cake, and on 23 August 1949 he published the upgraded results in a report, "Detonation Wave in the System ^{6}LiD–Uranium." He wrote that the experimental values of the D + T reaction cross sections were many tens of times greater than those of the D + D reaction. In this light the advantages of the Layer Cake using ^{6}LiD became far more impressive, and certainly it would be the only system worth considering in practice. One can imagine Ginzburg's creative satisfaction when his efforts were rewarded with such a grand prize.

Decisions

What decisions were made regarding the Layer Cake proposal and other possibilities at this time? As early as 16 November 1948, Tamm had sent a letter to Vavilov, the director of the Physics Institute, officially reporting that his group had discovered a possible new technique for using D as an explosive, based on a special combination of D or heavy water with natural U.

Vavilov in turn officially informed Beria of Sakharov's Layer Cake proposal on 11 April 1949. On 8 May, Khariton sent Vannikov a summary of the proposal. In this and other, earlier documents, Khariton vigorously espoused the Layer Cake project, noting that "the basic idea of the proposal is extremely ingenious and physically transparent."

A series of conferences were held on 4–9 June at KB-11, with the participation of Vannikov, for the purpose of reviewing the status of work on atomic bombs and the hydrogen bomb RDS-6. On orders from Beria, Sakharov attended the KB-11 RDS-6 conference and became familiar with the work of KB-11, including the building of RDS-1, the first atomic bomb readied for testing in the USSR. This was Sakharov's first trip to the city of Sarov. His familiarization with the physical scheme of RDS-1, a replica of the US implosion-based Fat Man bomb, encouraged the Tamm group to redirect the main thrust of their research to the development of a spherical layered system compressed by a chemical explosive.

The scientific research plan adopted at the conference for work on RDS-6 in the period 1949–50 dictated a program of work on both the Layer Cake and the "Tube" (the name for the Soviet analog of the classical Super). The part of the plan pertaining to the Tube contained a section on the "initiation of a cylindrical deuterium charge by an explosion in a gun configuration or by an auxiliary charge containing tritium." This suggests that, at the conference, Sakharov was already acquainted with the ideas and initiation schemes for the Tube from the intelligence data of 1945 and 1948. By mid-1949, however, Sakharov's scientific interests in regard to the hydrogen bomb were completely devoted to the search for ways to implement the Layer Cake concept.

About three months after the conference, on 29 August 1949, RDS-1 was detonated at a test site in Kazakhstan. (See the article by Herbert Friedman, Luther B. Lockhart and Irving H. Blifford on page 38 for a fresh account of how US scientists detected and analyzed the fallout from this test, which they named Joe-1.)

VITALY LAZAREVICH GINZBURG proposed the use of ^{6}LiD as a thermonuclear fuel in late 1948. He learned the full value of his idea only after secret D + T reaction cross sections were released to him.

A decision made in the remainder of 1949 was an order signed on 2 December by P. M. Zernov, the leader of KB-11: A team of theoretical physicists was to be recruited to be added to a special group of KB-11 that had been working on the problems of developing RDS-6 since February 1949. Thus, the theoretical section of KB-11 became directly involved in work on the Tube.

Several recommendations for the organization of future work on the RDS-6 had been formulated at the June conference, but Beria refrained from making any new administrative decisions until 31 January 1950. On that day, President Truman announced the directive to continue US work on the superbomb.

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