Physics – Uspekhi **60** (4) 413 – 418 (2017)

CONFERENCES AND SYMPOSIA

PACS numbers: **01.60.+q**, **01.65.+g**, **28.70.+y**

100th ANNIVERSARY OF THE BIRTH OF V L GINZBURG

V L Ginzburg and the Atomic project

V I Ritus

DOI: https://doi.org/10.3367/UFNe.2016.10.038102

Contents

Abstract. This paper is an expanded version of the author's talk presented at a session of the Physical Sciences Division of the Russian Academy of Sciences celebrating the 100th anniversary of V L Ginzburg's birth. Tamm's Special group was organized in June 1948 with the task to clarify the feasibility of constructing a hydrogen bomb. Having verified and confirmed the calculated results by Ya B Zel'dovich's group, the Tamm group proposed an original hydrogen bomb design, which, following A D Sakharov's idea, consisted of an atomic bomb surrounded spherically by nested uranium and heavy water layers: the heavy water, on V L Ginzburg's suggestion, was replaced by higher-calorie solid lithium-6 deuteride. The ionization implosion of deuterium by uranium, both heated by the atomic bomb's explosion, greatly accelerates nuclear reactions in deuterium and uranium and increases the total energy release. Upon their approval by the KB-11 top researchers, the Atomic project leadership, and the government, the proposals were implemented in the RDS-6s bomb, which was successfully tested on 12 August 1953. Lithium-6 deuteride turned out to be a convenient multipurpose nuclear fuel. The paper highlights the recognition by the leaders of the country and of the Atomic project that fundamental science plays a crucial role in promoting scientists' ideas and proposals.

V I Ritus Lebedev Physical Institute,
Russian Academy of Sciences,
Leninskii prosp. 53, 119991 Moscow, Russian Federation
E-mail: ritus@lpi.ru

Received 7 December 2016
Uspekhi Fizicheskikh Nauk **187** (4) 444 – 449 (2017)
DOI: https://doi.org/10.3367/UFNr.2016.10.038102
Translated by G Pontecorvo; edited by A Radzig

Keywords: hydrogen bomb, ionization implosion, lithium-6 deuteride

1. Organization of Tamm's Special group for clarifying the feasibility of constructing a hydrogen bomb

A resolution issued by the USSR Council of Ministers on 10 June 1948 obligated a number of institutions of the USSR Academy of Sciences to carry out scientific research to fulfil tasks assigned by Design Bureau No. 11 (KB-11) (see document No. 121 in Ref. [1]). Concerning the LPI of the USSR AS, the Resolution read:

"The Lebedev Physical Institute of the USSR AS (Cde. Vavilov) is charged with organizing research work on the development of the theory of deuterium burning for fulfilment of tasks assigned by Laboratory No. 2 of the USSR AS (Cdes. Khariton and Zel'dovich), for which a special group composed of theorists is to be organized in a period of 2 weeks under the leadership of Corresponding Member of the USSR AS Tamm and Doctor of physical and mathematical sciences Belenky (deputy group leader) with the participation of Academician Fock.

Cdes. Vannikov, Kurchatov, and Pervukhin are charged with achieving, within a month's time, approval of the program of the aforementioned work and of the time required for its completion.

Within a month's time, Cdes. Vavilov and Khariton are charged to present the plan of experimental investigation of the reactions of tritium and helium-3 with deuterium to the Scientific and Technical Council of the First Main Directorate of the USSR Council of Ministers for approval."

In precisely two weeks, on 25 June 1948, after the Friday seminar of the Theoretical Department, Igor Evgen'evich

Tamm invited Semen Zakharovich Belenky and Andrei Dmitrievich Sakharov to his study. As Andrei Dmitrievich wrote [2]:

"When we all entered the room he closed the door firmly and made a staggering announcement. An order had been issued by the Council of Ministers and the Central Committee of the CPSU to create a research group at LPI of the USSR AS. He was appointed group leader and both of us were group members. The task of the group was to perform theoretical and computational studies aimed at revealing the feasibility of creating a hydrogen bomb; to be more concrete, we were obliged to verify and correct the calculations that were being performed at the Institute of Chemical Physics by Zel'dovich's group.

After several days, when Semen Zakharovich recovered from the shock, he melancholically pronounced:

'So our task will be to lick Zel'dovich's ass'."

2. Material transmitted by K Fuchs in 1945 and 1948 and sent to KB-11

At the time, no one knew that already on 28 January 1946 KB-11 had received the material No. 462 (see document No. 11 in Ref. [3]), which included detailed information on the superbomb, the cross section of the reaction $D + D = He^3 + n$, and the ignition scheme of liquid deuterium in a container (tube) by a flux of neutrons from an atomic bomb, which first ignites the 'booster' — the intermediate layer consisting of a deuterium–tritium mixture — and then, upon being amplified, the pure deuterium in the tube.

In the material, it was also said that a certain amount of tritium, essential for the superbomb, had already been obtained at the Clinton Laboratories in the reaction $Li^6 + n = He^4 + H^3$.

This material was transmitted to Soviet intelligence by Klaus Fuchs on 19 September 1945 [4].

Even more detailed information was in material No. 713a and No. 713b (see documents No. 31 in Ref. [3] and No. 342 in Ref. [5]) that arrived at KB-11 on 16 April 1948. It was passed to our intelligence by K Fuchs on 13 March 1948 [4] and stimulated the USSR Council of Ministers to issue the Resolution of 10 June 1948.

Material 713a contained a detailed scheme of a hydrogen bomb indicating all the relevant geometric and physical parameters. Its initializing compartment consisted of an atomic bomb and a 'booster' — a two-litre vessel containing a liquid DT mixture submerged in a reflector of beryllium oxide. The radiation from the atomic bomb heated the BeO reflector and the DT mixture, while the difference in pressures resulting from their ionization led to compression of the hot DT mixture and to its intensive ignition. The total neutron flux from the bomb and the DT booster left the initializing compartment and entered the tube with liquid deuterium and was supposed to provide its nuclear burning.

The material also contained the experimental cross sections of $d + d$, $d + t$, and $d + He^3$ reactions, as well as the Maxwellian mean values $\langle\sigma(v)v\rangle$, obtained with their aid as functionals of the cross sections $\sigma(v)$ and functions of the temperature T. Each mean value multiplied by the product $n_1 n_2$ of the colliding particle concentrations determines the most important quantity

$$\langle\sigma(v)v\rangle n_1 n_2 \,, \tag{1}$$

the rate of the thermonuclear reaction, i.e., the number of reactions occurring within 1 cm^3 of the heated medium per second.

Thus, Ya B Zel'dovich's groups, which were studying thermonuclear detonation of deuterium–tritium plasma at KB-11 (D A Frank-Kamenetsky, G M Gandelman, and N A Dmitriev) and at the Institute of Chemical Physics (ICP) in Moscow (A S Kompaneets and S P D'yakov), had at their disposal material of exclusive importance.

However, this material contained no theoretical justification for the very possibility of nonequilibrium burning of pure deuterium in the tube.

3. Essence of the task assigned to the researchers of Zel'dovich's group

The 1948 schedule of the Theoretical Department of ICP of USSR AS, included the topic "Investigation of the nuclear energy of light elements" aimed at the following:

"Clarification of whether it is possible, in principle, to generate a detonation wave in a light substance: in deuterium and lithium deuteride."

It was proposed to find out whether the propagation of nuclear detonation is compatible with the diffusion of radiation and of neutrons, and whether it is possible to weaken its influence on the detonation.

The extreme difficulty of clarifying the above issues was noted, given the level of knowledge at the time.

It was also proposed to perform calculations for reactions with the participation of tritium and helium-3 (see document No. 160 in Ref. [5]).

Thus, it was quite logical to add the efforts of I E Tamm's group in clarifying these difficult issues. Expansion of the group was also natural: it subsequently included Doctor of physical and mathematical sciences V L Ginzburg and postgraduate student Yu A Romanov.

4. Main thermonuclear reactions occurring in a hydrogen bomb

In a hydrogen bomb, the nuclear energy of deuterium — a heavy isotope of hydrogen — is utilized. When the deuterium is heated by the explosion of the atomic bomb up to temperatures of the order of 10 keV (1 eV is equal to 1.16×10^4 K times the Boltzmann constant $k = 1.38 \times 10^{-16}$ erg deg^{-1}), thermonuclear reactions originate between deuterons, i.e., nuclei of deuterium:

$$d + d = p + t + 4\ \text{MeV}\,, \tag{2}$$

$$d + d = n + He^3 + 3.3\ \text{MeV}\,, \tag{3}$$

with energy (4 MeV and 3.3 MeV) released in the form of the kinetic energy of the reaction products. As a result, the energy released when 1 kg of deuterium is burnt turns out to be equal to the energy released when 1.3 kg of plutonium or U^{235} is burnt. The tritium nuclei — tritons (t) — produced in these reactions and the nuclei of helium He^3 participate in the thermonuclear reactions

$$t + d = n + He^4 + 17.6\ \text{MeV}\,, \tag{4}$$

$$He^3 + d = p + He^4 + 18.34\ \text{MeV}\,, \tag{5}$$

in which the energy release is noticeably higher. This is explained by the very strong coupling between the nucleons

(2p + 2n) in the He^4 nucleus, the dominant helium isotope. Taking into account secondary reactions reveals that the total energy release when 1 kg of deuterium is burnt increases by a factor of four.

From a theoretical point of view, reactions (4), (5) are interesting because the effective cross section of the first one exhibits a resonance behavior at energies of the colliding particles of the order of 100 keV, which is due to excitation of the compound He^5 nucleus to an energy level exceeding the mass of $n + He^4$ by 17.7 MeV, while the cross section of the second reaction behaves in a similar manner at an energy of the colliding particles of the order of 260 MeV owing to excitation of the compound Li^5 nucleus to an energy level exceeding the mass of $p + He^4$ by 18.6 MeV. Since the widths of the resonance levels of the He^5 and Li^5 nuclei are large, the cross sections of reactions (4), (5) also increase significantly in the region of low energies (~ 10 keV) of the colliding particles. As a result, the cross section of the dt reaction is more than 100 times higher than that of the dd reaction. The enhancement of the He^3d reaction cross section is weaker owing to the stronger Coulomb repulsion of the deuteron from the doubly charged He^3.

Reactions (4), (5) exhibiting common properties, as in the case of reactions (2), (3), is due to the *mirror symmetry* of the participating nuclei, i.e., the symmetry with respect to exchanging $n \rightleftarrows p$ in them. Since nuclear forces exhibit isotopic invariance, the difference in masses between mirror nuclei is mainly due to the Coulomb energy of repulsion between protons and to the difference in masses between the neutron and the proton. The level structures of mirror nuclei, such as $He^5 \rightleftarrows Li^5$ or $Li^7 \rightleftarrows Be^7$, are similar to each other.

One can quite agree with Fermi, whose opinion was that this is good physics. Truly, this was said concerning the atomic bomb and, as noted by Sakharov, did not rule out an attempt to escape from the moral aspect of the issue, for he actually said: "In any case, this is good physics" [2].

5. Rate of a thermonuclear reaction and the ideas put forward by Sakharov and Ginzburg

From the very beginning, the researchers in I E Tamm's group did not concentrate on verifying the results obtained by Zel'dovich's group, but advanced over a broad front of issues.

Thus, in his first report S1, Sakharov dealt with derivation of a formula for the thermonuclear reaction rate, i.e., the number of reactions taking place per second in 1 cm^3 of a mixture of reacting particles heated to the temperature T. This rate is given by formula (1), presented above, where the angular brackets stand for averaging of the quantity within the brackets over the thermal, i.e., Maxwellian, distribution of relative velocities of the colliding particles:

$$\langle \sigma(v) v \rangle = \int d^3 v \left(\frac{\mu}{2\pi T} \right)^{3/2} \exp\left(-\frac{\mu v^2}{2T} \right) \sigma(v) v \,, \tag{6}$$

where $\mu = m_1 m_2/(m_1 + m_2)$ is the reduced mass of these particles.

Since the cross section $\sigma(v)$ contains the exponential Gamow factor, viz.

$$\sigma(v) \sim \exp\left(-\frac{2\pi e_1 e_2}{\hbar v} \right), \tag{7}$$

which reduces the cross section significantly at small velocities of colliding charges e_1, e_2 of the same sign and the Maxwellian distribution drops exponentially at large velocities, integral (6) is essentially calculated by the saddle-point technique and reduces to an exponential function with its exponent determined by the cubic root of the inverse temperature:

$$\langle \sigma(v) v \rangle \sim \exp\left[-3 \left(\frac{\pi^2 e_1^2 e_2^2 \mu}{2\hbar^2 T} \right)^{1/3} \right]. \tag{8}$$

Clearly, the rates of reactions between nuclei of minimum charge and minimum mass are the highest. Since increasing the rate (1) of a thermonuclear reaction by increasing the temperature to values required for the detonation of pure deuterium gave rise to problems, Sakharov proposed, in his second report S2, to increase it by a drastic increase in the product $n_1 n_2$ of the concentrations of reacting particles (see document No. 52 in Ref. [3]). Even before report S2 was completed, Sakharov's proposal was presented in detail by I E Tamm in his report of 8 December 1948 (see document No. 49 in Ref. [3]).

This proposal — the '1st idea' — consisted in exploiting alternating spherical layers of uranium U^{238} and of thermonuclear fuel, which Sakharov chose to be heavy water D_2O. Sakharov showed that, when such a system — a 'sloika, or layer cake' — is heated by the explosion products of an atomic bomb, ionization implosion of the light thermonuclear fuel layers arises due to the heavy uranium layers. It substantially increases the intensity of thermonuclear burning, while the neutron flux from the reaction $d + d = He^3 + n$ and from the secondary reaction $t + d = n + He^4$ leads to intensive fission of uranium U^{238}.

In his reports G1 and G2, Ginzburg, unlike Sakharov, dealt with the issue of deuterium detonation (see document Nos 47 and 48 in Ref. [3]). In the first of these, "a discussion is presented of the solution obtained by the group at the Institute of Chemical Physics. It turns out that the detonation of liquid deuterium is certain not to take place, if the electron temperature in the nuclear reaction zone is much lower than the nuclear temperature. Therefore, the detonation of deuterium, if it can occur at all, must take place at an electron temperature comparable to the nuclear temperature."

In the report G2, "a detailed analysis is presented of the nature of the possible detonation regime. It turns out that in deuterium only a quasiequilibrium regime can exist where the electrons are, to a good approximation, in equilibrium with the radiation and at the same time the electron temperature is close to the nuclear one. The nuclear reaction zone in the case of this regime has a width that amounts to several tens of meters."

In the concluding part of this report, Ginzburg discusses Sakharov's interesting and quite promising proposal to reduce the width of the nuclear reaction zone by applying the 'compression of deuterium' arising when a shock wave propagates in a layered system — the 'sloika', in which layers of deuterium alternate with layers of uranium. In this case, liquid deuterium can be substituted by heavy water or liquid deuterated methane. He writes that one can also discuss the 'burning' of mixtures containing Li^6 (so as to make use of the heat released from the reaction $Li^6 + n = t + He^4 + 4.8$ MeV), U^{235}, Pu^{239}, etc.

Lithium is not referred to by chance here. 'Fission' reactions of lithium isotopes caused by protons and neu-

trons, namely

$$p + Li^7 = 2He^4\,, \qquad n + Li^6 = t + He^4\,,$$

are mentioned by Ginzburg in his popular booklet "The atomic nucleus and its energy" [6], published in 1946.

The first of these reactions is the well-known nuclear fission by *protons*, first realized under laboratory conditions by J D Cockroft and E T S Walton in 1932.

In 1946, V L Ginzburg is mentioned in a letter sent by Academician A N Shchukin to G M Malenkov concerning the registration of explosions of atomic bombs applying radar techniques (see document No. 78 in Ref. [5]). Discussions of these issues with Yu B Kobzarev and Yu B Khariton led Shchukin to the conclusion that radiogoniometers, instead of radars, operating at long waves were required for registering explosions at large distances, and he noted that the "first tentative calculations concerning this issue were performed by Doctor of physical and mathematical sciences Cde. Ginzburg. Investigation of this issue should be assigned to the Physical Institute of the USSR Academy of Sciences."

6. Thermonuclear reactions in a 'sloika' with lithium and its caloricity

Lithium deuteride is mentioned as a solid thermonuclear fuel in the schedule of activities of the Institute of Chemical Physics. Its chemical properties are similar to the properties of ordinary lithium hydride LiH, which is known (see, for instance, Ref. [7]) to be used for transporting hydrogen without balloons; 1 kg of LiH reacting with water yields 2.8 m^3 of H_2.

It is difficult to understand why Sakharov proposed to utilize heavy water D_2O or liquid heavy ethane C_2D_6, instead of solid LiD, in the 'sloika'. It is possible that he did not see the ICP schedule of activities or did not want to borrow anything, knowing that Ginzburg contacted the ICP group.

In his third report, "Use of Li^6D in the sloika" V L Ginzburg gave a detailed exposition of his idea (his '2nd idea' according to the terminology introduced by Sakharov) concerning the use of the new thermonuclear fuel (see document No. 59 in Ref. [3]). 'New', because the dominant isotope Li^7 in the lithium deuteride LiD is completely replaced by the Li^6 isotope, whose abundance amounts to 7.3%. Owing to the large neutron flux and the large cross section of the reaction

$$Li^6 + n = He^4 + t + 4.6\ \text{MeV} \tag{9}$$

that grows as $1/v$ when $v \to 0$ with a resonance at $E_n = 0.27$ MeV, this reaction serves as an essential *exothermic source of tritium*.

Besides this reaction, the following thermonuclear reactions will also occur in the 'sloika':

$$Li^6 + d = n + Be^7 + 3.3\ \text{MeV}\,, \tag{10}$$

$$Li^6 + d = p + Li^7 + 5.0\ \text{MeV}\,, \tag{11}$$

$$Li^6 + d = n + He^3 + He^4 + 1.7\ \text{MeV}\,, \tag{12}$$

$$Li^6 + d = 2He^4 + 22.2\ \text{MeV}\,. \tag{13}$$

Owing to incomplete purification of Li^6D from the dominant isotopes Li^7 and H, the following thermonuclear reactions will also proceed:

$$Li^7 + d = n + Be^8 + 15.03\ \text{MeV}\,, \tag{14}$$

$$Li^7 + d = n + 2He^4 + 15.15\ \text{MeV}\,, \tag{15}$$

$$Li^7 + d = He^4 + He^5 + 14.3\ \text{MeV}\,, \tag{16}$$

$$Li^7 + p = 2He^4 + 17.3\ \text{MeV}\,, \tag{17}$$

$$Li^6 + p = He^4 + He^3 + 3.9\ \text{MeV}\,, \tag{18}$$

as well as the reaction

$$Li^7 + n = Li^8 + \gamma + 1.98\ \text{MeV} \tag{19}$$

with the subsequent β-decay $Li^8 \to Be^8 + e^- + \tilde{\nu}_e$ and the decay $Be^8 = 2He^4 + 0.05$ MeV.

Notice the large energy releases in these reactions. However, their rates are noticeably lower than those of dd- and dt-reactions owing to the triple charge of lithium and larger reduced mass of the colliding particles [see Eqn (8)].

Call attention to mirror symmetry of reactions (10), (11). However, unlike the stable Li^7, Be^7 undergoes *K*-capture with a half-life of 53 days and transforms into Li^7. Since 10% of decays proceed via the excited level of lithium-7, i.e.

$$Be^7 + e^- = \begin{cases} Li^7 + \nu_e\,, & 90\%\,, \\ Li^{7*} + \nu_e = Li^7 + \gamma + \nu_e\,, & 10\%\,, \end{cases}$$

with subsequent emission of a γ-quantum of energy 478 keV, registration of the Be^7 yield over 1–2 months permits the intensity of reaction (10) to be estimated during an explosion.

Reactions (9), (18), proceeding via mirror-symmetric compound nuclei Li^7 and Be^7 with similar energy level structures, are also mirror symmetric. Thus, the Li^{7*} level of energy 478 keV corresponds to the Be^{7*} level of energy 434 keV.

In subsequent reports presented by Ginzburg, the dependence of the caloricity of the 'sloika' upon the thickness of the layers was investigated.

The caloricity and the zone width in the Li^6DU system without compression is calculated with account of the correct cross section of the dt reaction, and similar calculations are performed for the D_2OU system. The shock wave zone is of the order of 20 cm in both cases. The difference in the total caloricity amounts to a factor of four.

Such calculations are performed with account of the tt reaction (which turned out not to be substantial), of the possible role of layer mixing, and of neutron diffusion. Estimates are made of the influence of the layer thickness on the slowing down of the dt reaction.

In 1948–1949, Tamm's group prepared 24 reports: Belenky — 4, Ginzburg — 6, Romanov — 5, Sakharov — 7, Tamm — 2 (see document No. 97 in Ref. [3]).

7. I E Tamm on steps to be taken when realizing Sakharov's and Ginzburg's ideas

On 9 April 1949, I E Tamm transmitted S I Vavilov his proposals "On the use of light elements as nuclear explosive substances" (see Appendix to document No. 67 in Ref. [3]). In these proposals, he informed him of A D Sakharov's ideas to make a bomb of alternating layers of ordinary uranium and heavy water and of V L Ginzburg's ideas to add the light lithium isotope to deuterium, and briefly presented their physical content. Propagation of the detonation wave in the

'sloika' leads to extremely strong compression of the deuterium-containing substance by the layers of uranium, which results in significant acceleration of the nuclear reaction in deuterium, while the fast neutrons produced in the reaction fission uranium, thus substantially enhancing the total energy release.

The absorption of slow neutrons by lithium-6 results in the production of tritium and in secondary thermonuclear reactions, which increases the total energy liberation.

Igor Evgen'evich further presented estimates of the energy release from the 'sloika' depending on its size and weight and stressed the low cost of the materials required when compared to plutonium.

In conclusion, Igor Evgen'evich listed the necessary steps to be taken "so as to be able to acknowledge with certainty that the new hydrogen bomb can actually be realized or, contrariwise, that it cannot be used for practical purposes." Such steps included:

— extension of the theoretical studies under way in the LPI group, bringing in other theorists;

— performing experimental studies of the nuclear reactions taking place in the 'sloika' and, in particular, obtaining a certain amount of tritium;

— experimental investigation of the stability of the layers of explosive materials during the explosion;

— performing complicated mathematical calculations taking advantage of a special bureau;

— performing possible experiments during the very first explosions of atomic bombs.

Igor Evgen'evich's physical intuition amazes, as does his belief in the ideas and calculated results of his colleagues; it was evident from the program for many years ahead that it was thought over comprehensively and presented clearly. The point is that this was done at a time when most of the group reports had not yet been written, and the group had no access to any experimental data on the dt-reaction cross section (access was established on 5 May 1949; see the facsimile of document No. 71 in Ref. [3]). The journal *Physical Review* of 15 April 1949 with the article by E Bretscher and A P French, where the dt-reaction cross section was reported [8], was to arrive at LPI later.

On 11 April 1949, S I Vavilov presented these proposals to L P Beria, who the next day ordered B L Vannikov together with M G Pervukhin, A P Zavenyagin, and Yu B Khariton to consider them and to present their proposals.

8. Governmental approval of I E Tamm's proposals; concentration of his group's efforts on the development of RDS-6s

Owing to Yu B Khariton, perhaps, on 21 April 1949, I V Kurchatov and M G Meshcheryakov handed in their proposals concerning work on the superpowerful atomic weapons (see document No. 68 in Ref. [2]). They coincided with I E Tamm's proposals on the necessity of measuring the cross sections of the reactions $H^2(d,n)He^3$, $H^2(d,p)H^3$, $H^3(d,n)He^4$, and the interaction cross sections of neutrons with uranium; the laboratories where such work could be done were indicated; the Ukrainian Physical Technical Institute in Kharkov was designated for the construction of a 2-MeV generator, while Base No. 10 (presently the Mayak Production Association)was recommended for the production of tritium by the irradiation of lithium in a uranium-graphite pile.

The proposals also include the following item: "For greater concentration of all theoretical studies and calculations to link the work of groups led by Cdes. Tamm, Sakharov, and Ginzburg with the work of KB-11."

After discussion of Sakharov's proposal at the Scientific ans Technical Council of Laboratory No. 2, Yu B Khariton and Ya B Zel'dovich acknowledged this proposal to be extremely important and interesting and agreed that the LPI group should concentrate its efforts on developing Sakharov's proposal, while work related to the 'tube' should be continued by Kompaneets and D'yakov under the guidance of Zel'dovich.

The leadership of the First Main Department took all the proposals of scientists into account and together with them prepared two draft resolutions for the USSR Council of Ministers: "On work aimed at the creation of a hydrogen bomb" and "On organization of the production of tritium". Beria sent them to Stalin, who approved them the same day — on 26 February 1950.

The first of these resolutions, titled "On work for the creation of RDS-6", assigned tasks to a number of institutions and laboratories of the USSR AS for designing the products RDS-6S and RDS-6T (the code names of the 'sloika' and 'tube', respectively). Thus, for example, according to the resolution, "Cdes. Tamm I E, Sakharov A D, Belenky S Z, Romanov Yu A, Bogoliubov N N, Pomeranchuk I Ya, Klimov V N, Shirkov D V are bound to be detached for 1.5–2 years for work at KB-11", and also, LPI director S I Vavilov was obligated to "charge Cde. Ginzburg V L with performing theoretical work at LPI in accordance with tasks assigned by KB-11."

9. Transfer of the Tamm–Sakharov group to KB-11 and the organization of Ginzburg's group at LPI of the USSR AS

As a result, in March 1950, Sakharov, Romanov, and, somewhat later, Tamm started continuous work at KB-11. S Z Belenky remained in Moscow, apparently for health reasons.

I became acquainted with Semen Zakharovich in 1954 during a discussion of my work to be sent to the journal *JETP*, and then more closely in 1955, when I became a member of the theoretical department. He was an agreeable, clever, wise, and decent person. His untimely death in 1956 was a shock for all our colleagues of the theoretical department.

V L Ginzburg included Semen Zakharovich, as well as E S Fradkin, in his group. Numerical calculations were performed, as previously, by L V Pariiskaya and F I Strizhevskaya, and to provide good guidance for them Vitaly Lazarevich invited mathematician Yu A Gol'fand. At the beginning of 1953, Belenky, Ginzburg, and Fradkin performed calculations of the mixing processes in the 'sloika', taking into account both initial perturbations due to compression and the shock wave slamming the light layer. They also took into account the influence of radiation viscosity on the mixing.

Yury Abramovich Gol'fand, however, became interested in problems of theoretical physics and began neglecting the responsibilities assigned to him by Ginzburg. This led to a serious conflict between them, which did not terminate even when Yu A Gol'fand and E P Likhtman did outstanding work on extension of the Poincaré group by bispinor

generators. This was the first work on supersymmetry that related fermions and bosons. In 1989, its authors received the I E Tamm Prize of the USSR AS.

10. Completion of work on the first hydrogen bomb RDS-6s and its successful test

The work of the Tamm–Sakharov group at KB-11 on the first hydrogen bomb is described in my review [9]. This work was completed by a successful test of the 'sloika' on 12 August 1953. Its energy release — 400 kilotons of trinitrotoluene equivalent (TNT) — turned out to be noticeably greater than the magnitudes calculated by Landau's group — 250 kt — and by Tikhonov's group — 220 kt — owing to the actual dt-reaction cross section being larger than the value used in calculations and to tritium being used not only in the first light layer, as implied in calculations, but also in the second light layer. This was a magnificent success of Tamm's group. Igor Evgen'evich and Andrei Dmitrievich became Full Members of the USSR Academy of Sciences and Heroes of Socialist Labor, and they received large Stalin prizes, dachas, and cars.

Vitaly Lazarevich became a Corresponding Member of the USSR Academy of Sciences; for the proposal to use lithium-6 in the product RDS-6c, he was awarded a Stalin prize of first degree that amounted to 100 thousand roubles.

At the same time, the Tamm–Sakharov group continued their hard work, but led by Sakharov alone. After the test of the 'sloika', Igor Evgen'evich returned to LPI, having received V A Malyshev's permission to consider his mission to KB-11 completed.

11. 'Third idea', its realization in the RDS-37 bomb, and the result of its successful test

Besides the above, at the beginning of 1954, a 'third idea' — compressing the thermonuclear fuel by radiation from an atomic bomb — arose and its development began. V A Davidenko, who used to visit the theorists, very emphatically proposed to deal with this idea. It was 'hovering in the air' after rumours started gradually arriving about the impressive energy release from the American bomb 'Mike', exploded on 1 November 1952 in the Enewetak Atoll. The idea became realistic in the construction of the hydrogen bomb RDS-37 that consisted of a 'sloika' compressed by the radiation of an atomic bomb, both situated inside a common casing (see document No. 120 in Ref. [10]).

In July 1955, V L Ginzburg became a member of the expert commission that examined the physical principles of atomic compressing and calculations of the RDS-37 experimental device. On the basis of presented calculated results this commission, consisting of I E Tamm (chairman), M V Keldysh, M A Leontovich, A D Sakharov, V L Ginzburg, Ya B Zel'dovich, and I M Khalatnikov, came to the conclusion that in an explosion of RDS-37 about half of all the energy would be released directly in thermonuclear reactions and the other half in fission of uranium 238 by fast neutrons. Together with I V Kurchatov, the expert commission "unanimously approved the idea of the RDS-37 product with atomic squeezing, as well as the work done on this product" (see documents Nos 160 and 170 in Ref. [10]).

Upon completion of computational–theoretical work related to RDS-37, a report was issued that consisted of several parts with dates between 18 June and 8 July 1955 (see document No. 163 in Ref. [10]). The title page contained a list of all the members of Zel'dovich's and Sakharov's departments who took part in relevant work. In the report, physical processes taking place in the system are presented, an estimate is given of the expected power yield (0.6–1.4 Mt of TNT), and the important role is noted of the numerical calculations performed by the mathematical groups of KB-11 and of a number of institutions of the USSR Academy of Sciences, and of the significant work performed by the engineering departments of KB-11.

The test of RDS-37 took place on 22 November 1955; the energy release of the bomb amounted to 1.7 megatons of TNT (see document Nos 184 and 188 in Ref. [10]). Tritium was not utilized in RDS-37: it was generated in reactions (2), (9) mainly owing to the employment of lithium-6 deuteride, proposed by V L Ginzburg. This thermonuclear fuel started to be exploited as the *main* fuel in all hydrogen bombs together with plutonium — the initiator of its radiative compressing and heating.

In March of 1955, an essentially new step was taken in the use of Li^6D — I proposed *double compressing* of the main thermonuclear charge by *radiation* not only from the atomic bomb but also from a *small thermonuclear charge* (see document No. 140 in Ref. [10]). The subsequent inclusion of two sources of radiation enhanced, prolonged, and symmetrized squeezing of the main charge. It's a pity I did not give this proposal the code name 'Munchausen'. But that is another story.

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