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The extraordinarily beautiful physical principle of thermonuclear charge design
(on the occasion of the 50th anniversary of the test of RDS-37 — the first Soviet two-stage thermonuclear charge)

G A Goncharov

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Contents

Abstract. **On 22 November 1955, the Semipalatinsk test site saw the test of the first domestic two-stage thermonuclear RDS-37 charge. The charge operation was based on the principle of radiation implosion. The kernel of the principle consists in the radiation generated in a primary A-bomb explosion and confined by the radiation-opaque casing propagating throughout the interior casing volume and flowing around the secondary thermonuclear unit. The secondary unit experiences a strong compression under the irradiation, with a resulting nuclear and thermonuclear explosion. The RDS-37 explosion was the strongest of all those ever realized at the Semipalatinsk test site. It produced an indelible impression on the participants in the test. This document-based paper describes the genesis of the ideas underlying the RDS-37 design and reflects the critical moments in its development. The advent of RDS-37 was an outstanding accomplishment of the scientists and engineers of our country.**

1. Impressions of the RDS-37 charge explosion

On 18 October 1955, I, then a young scientist at Andrei D Sakharov's theoretical department, together with a group of participants in the development and computation-theoretical feasibility study of the RDS-37 charge, departed by plane from the town of Sarov for the Semipalatinsk test site. We were to participate in the test of RDS-37, as well as of RDS-27 [the tritium-free modification of the thermonuclear RDS-6s charge tested on 12 August 1953 and otherwise known among developers as a 'sloika' (a 'layer cake')] being lower than RDS-6s in power. The RDS-27 test was accomplished on 6 November 1955. I was among a large group of test participants approximately 30 km away from the explosion epicenter. The charge was dropped from a plane. On that day there were dense clouds, so much so that I could barely see the flash through my dark glasses. The sound effect was also comparatively weak. The test left a disappointment, although the explosive power was close to that which had been calculated.

There came the days in anticipation of the major event, during which I, together with a group of theoretical physicists, took part in the analysis of the RDS-27 test data and preparation of the report about this test.

We were given dark glasses once again. In addition to neutral tinted glass, they contained a set of filters made of developed light-struck film and were completely opaque, so that one could not see the sun through them. We decided to remove superfluous filters from the glasses. This decision proved to be correct and gave us the opportunity to excellently observe the majestic picture of the RDS-37 explosion. Prior to the test we were informed that all participants would be divided into two groups, one of which would be located about 32 km from the explosion epicenter, and the other, including the leaders, at 70 km, in the outskirts of the residential settlement of the test site. I remember being pleased to learn that I would be at the shorter of the two possible distances.

The test was scheduled for November 20. Early in the morning we went to our destination by cars. It was a gentle slope of a hill facing the expected point of the explosion. The sky was rather cloudy, with a strong wind blowing from the side of the expected explosion point. The countdown for the bombing was announced through a loudspeaker. Unexpectedly, there came an announcement of its cancellation. Quite disappointed, we went back to the residential settlement of the test site, but the test's postponement raised our hopes that it would be accomplished in better weather. I recall that November 21 was a lovely cloudless day, and I was upset that the test had not been scheduled for that day. It was carried

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out on November 22. At dawn we anew went to our observation post (termed 'waiting post' in official documents, because the name 'observation post' was used in reference to the point in the outskirts of the residential settlement of the test site where a platform had been constructed). The sky was only slightly cloudy and I noted to myself with satisfaction that the weather had significantly improved in comparison with November 20. An exciting anticipation of the instant of the explosion set in again. I remember the clearly visible inversion exhaust trail of the carrier aircraft which seemed to pass almost above us. There came the last minutes and then seconds preceding the explosion. We put on the dark glasses and stood looking in the direction of the coming explosion, with the ear-flaps of our caps down and our faces partly screened by gloves with separated fingers. When the countdown '0' sounded, the first impression was of almost intolerable heat, as if my head had been placed into an open oven for several seconds. In complete stillness and silence we observed the inexpressible enchanting sight of the rapid expansion of the fireball and the formation of an enormous curling mushroom cloud with a large bright cap. A short time later, a beautiful white cone was formed around the stipe. After about 1.5 minutes, we could see the shock wave approaching. Its motion was clearly seen near the ground surface which was sown with dry stems and partly covered with snow. As the shock wave approached, we lay on the tarpaulin which covered a small area of the hill, most of us with our feet pointing toward the explosion, and anew covered our faces with our gloves. A deafening thunder sounded. Some of us experienced the blows of stones, which the shock had raised from the ground. Upon passage of the shock wave we sprang to our feet crying 'hurrah!', but a few seconds later we were knocked off our feet by a reflected shock wave which arrived quite unexpectedly. I do not remember with certainty, but it seems to me that this was repeated once more.

The brightness of the mushroom's glow declined and nothing could be seen through the glasses. I took them off but was blinded by the remaining glow from the upper part of the mushroom. I had to put on the glasses again, and it was not until several minutes later that I could take off the glasses to observe the further development of the mushroom cloud. The stipe was rapidly expanding, while the cap, which had darkened, was increasing in size and traveling upwards to form a dark cloud. The cloud seemed to gradually occupy almost half of the sky. It moved towards the residential settlement of the test site, and it was not long before its front part found itself above us. We sensed raindrops. As we had no personal dosimeters, and fearing that the rain might be radioactive, we rushed to the cars. The roofs of many of the cars were dented and, in addition, the bus windows were smashed. As was discovered later, the explosion power was in good agreement with expectations, but the shock intensity at the ground turned out to be several times higher than the calculated one. I recall that four of my physicist colleagues and I got into the 'Pobeda' car by which we had come from the residential settlement. A fifth physicist, who did not want to take the bus with the smashed windows, decided to join us. The frightened driver cried out that he would not drive the car for fear a tire would burst due to overload. We could hardly persuade him. It might seem that there was good reason to go at once. But the order to get going came about only forty minutes later. On receiving the command, the column of cars made for the residential settlement. Throughout the drive, moving above the column was a huge, slowly dispersing black cloud, which reached the residential settlement. I remember that several theorists, including me, gathered in an apartment with smashed windows and doors in one of the building in the residential settlement and, excited and filled with emotion, celebrated, as is customary in Russia, the successful RDS-37 charge test.

This test left an indelible imprint on my memory and came to be the most dramatic event of my life, as regards the strength of the impression. I happened to participate later in several atmospheric and many underground nuclear tests which produced a strong impression on me, but the recollections of the explosion of 22 November 1955 nevertheless overwhelm the recollections of other tests. And the reason very likely lies not only with the immense, incomparable scale of the explosion picture which I had occasion to observe from a short distance, but also with feeling of belonging to a historical event — the successful confirmation of the extraordinarily beautiful physical principle of thermonuclear charge design — which gripped me and other participants of the RDS-37 development and test.

2. On the history of the RDS-37 charge development

As Sakharov noted in his *Memoirs*, "*...the test was the culmination of many years of labor, a triumph that had paved the ways to the development of a wide range of devices with diverse high-performance characteristics.... All of us realized the enormous military-technical significance of the test conducted. In essence, it solved the problem of constructing high-performance thermonuclear weapons. We were sure that the tested device would become the prototype for thermonuclear charges of different power, weight, and destination*" [1, pp. 266–267]. Of course, new important inventions were made after RDS-37 creation and impressive progress was achieved in the design of thermonuclear charges. But still, the main starting point, the basis for the further development of thermonuclear weapons and thermonuclear charges for the needs of the national economy, which were also under development in our country, was the RDS-37 charge.

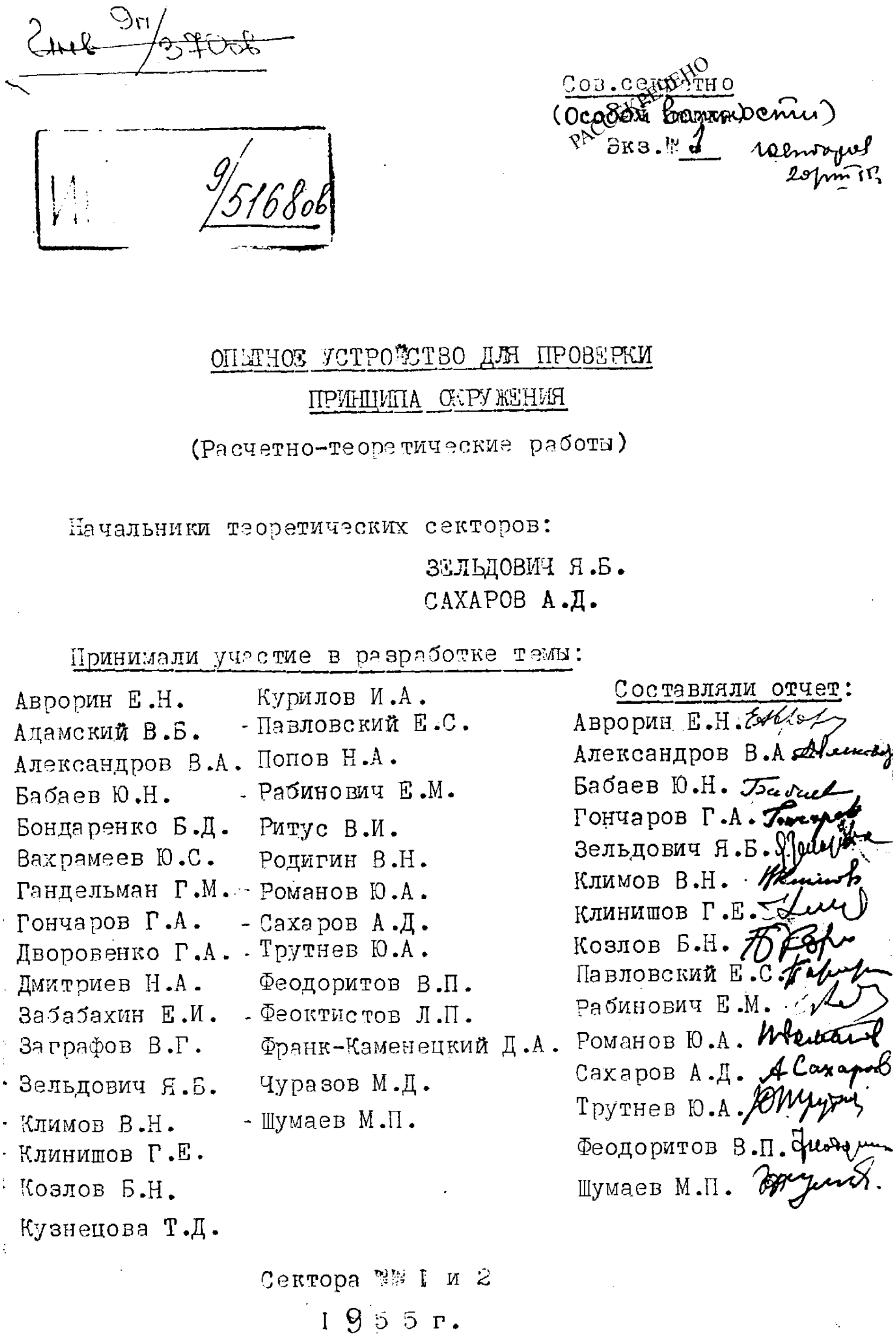
The history of the construction of the first domestic two-stage thermonuclear charge RDS-37 was reflected in Refs [2–8].

Here, first of all we address ourselves to important documentary evidence of RDS-37 construction history — the summary theoretical report on RDS-37 issued in mid-1955. The report is entitled "Test device for verifying the encirclement principle". That was the conventional name given to the radiation implosion principle which underlay the RDS-37 charge operation. The report is signed by its authors, and the names of all the participants in the theoretical development of the subject are indicated on the title page (Fig. 1). The introduction to the report was written by Ya B Zel'dovich and Sakharov and stated the following:

"*The encirclement principle has been elaborated in theoretical departments since 1950. Success first came early in 1954, specifically, a conclusion was drawn about the feasibility in principle of achieving symmetric compression of the hydrogen bomb* (*the 'main device'*) *due to radiative heat exchange* (...).

In devices harnessing the encirclement principle, of vital importance are several processes which have never been experimentally tested or theoretically investigated before.

1. *Radiative heat exchange in a cavity of complex shape.*



Сов.секретно
(Особой важности)
Экз.№ 1

И 9/5168ов

ОПЫТНОЕ УСТРОЙСТВО ДЛЯ ПРОВЕРКИ
ПРИНЦИПА ОКРУЖЕНИЯ
(Расчетно-теоретические работы)

Начальники теоретических секторов:
ЗЕЛЬДОВИЧ Я.Б.
САХАРОВ А.Д.

Принимали участие в разработке темы:

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Зельдович Я.Б.	Чуразов М.Д.	Сахаров А.Д.
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Козлов Б.Н.		Шумаев М.П.
Кузнецова Т.Д.		

Сектора №№ I и 2
1955 г.

Figure 1. Title page of the summary theoretical report on RDS-37 issued in mid-1955. The report is entitled "Prototype device for verifying the encirclement principle"; the page gives the names of the participants in the work and bears the signatures of those of them who drew up the report.
Top secret / Special dossier
Copy № 1
Test device for verifying the encirclement principle
(Computation-theoretical work)
Heads of theoretical departments: Zel'dovich Ya B, Sakharov A D
Participants in the theme elaboration:
1st column: Avrorin E N, Adamskii V B, Aleksandrov V A, Babaev Yu N, Bondarenko B D, Vakhrameev Yu S, Gandel'man G M, Goncharov G A, Dvorovenko G A, Dmitriev N A, Zababakhin E I, Zagrafov V G, Zel'dovich Ya B, Klimov V N, Klinishov G E, Kozlov B N, Kuznetsova T D
2nd column: Kurilov I A, Pavlovskii E S, Popov N A, Rabinovich E M, Ritus V I, Rodigin V N, Romanov Yu A, Sakharov A D, Trutnev Yu A, Feodoritov V P, Feoktistov L P, Frank-Kamenetskii D A, Churazov M D, Shumaev M P
Report compilers:
Avrorin E N, Aleksandrov V A, Babaev Yu N, Goncharov G A, Zel'dovich Ya B, Klimov V N, Klinishov G E, Kozlov B N, Pavlovskii E S, Rabinovich E M, Romanov Yu A, Sakharov A D, Trutnev Yu A, Feodoritov V P, Shumaev M P
Departments Nos 1 and 2
1955

2. (...).
3. *Radiative heat exchange in the explosion products of the primary device.*
4. *Compression of uranium and Li^6D at pressures ranging into the hundreds of millions of atmospheres.*
5. *Diffusion of the neutrons from the primary device* (...).
6. *Apart from these new processes, the very process of atomic-hydrogen explosion* in a *uranium – Li^6D system had not been adequately studied.*

The only experiment and the majority of calculations referred to systems which bear little resemblance to those developed for the encirclement principle as regards layer dimensions, density, and efficiency.

This report sets out the results of calculations for a device proposed for the explosive test to verify the encirclement principle.

According to calculations, the proposed system is reliable. Its power is estimated to lie in a range of 600 – 1400 thousand tons.

Testing this system, accompanied by measurements of the explosion power (...) *would permit checking the validity of calculations of all new processes and the conception as a whole and making in the immediate future a series of efficient high-power hydrogen bombs of different sizes.*

It should be emphasized that the proposed system is the first one subjected to a comprehensive computation. In its design, efforts were mounted not to introduce additional new aspects, apart from to the inevitable ones listed above (...).

In view of the aforementioned reasons, the proposed system is not optimal.

Some of the ways of making improvement are clear even now (...).

The majority of minor improvements, which may be only made at the expense of the time fixed, are negligible in the face of the radical step, which is the realization of the encirclement principle itself and the verification of the calculations of new physical processes accompanying the explosion of the prototype device.

The development of the encirclement principle is an impressive example of creative team work. Some generated ideas (*a lot of ideas were needed, and some of them were put forward independently by several authors*). *Others demonstrated their abilities in designing calculation procedures and analyzing contributions from various physical processes.*

Everyone in the long list of the project participants given on the title page has played a significant role.

In the early stage of the work (*1952*) *the participation of V A Davidenko in discussions was very valuable.*

In the development of so complex a system, of special importance are mathematical computations; *in several cases, calculations involving partial differential equations radically improved our knowledge about the operation of one component or another, or the role of the after-effects of one change or another in the system. Most of these calculations were performed at the Division of Applied Mathematics* (*DAM*) *of the Institute of Mathematics, the USSR Academy of Sciences, and were coordinated by M V Keldysh and A N Tikhonov.*

1. *Calculations of the compression of the main device were performed at the DAM in the department headed by K A Semendyaev. Several calculations were carried out at KB-11 in the department headed by I A Adamskaya. Individual calculations were made in the department headed by A A Samarskii.*
2. *Calculations of heat transfer* (...) *under complex geometrical conditions* (...) *were carried out at the DAM, I M Gel'fand's department. Individual calculations were made at KB-11 in the department headed by A A Bunatyan.*
3. *The efficiency calculations of the primary device and its radiation yield were made at the DAM in A A Samarskii's department.*
4. *The heat penetration into the enclosure was calculated at the DAM in A A Samarskii's department.*
5. *Calculations of the explosion efficiency of the main device were performed at the DAM in A A Samarskii's department. Several calculations were made by I M Khalatnikov's group.*
6. *The Li^6D equation of state was calculated by I M Khalatnikov's group.*

Many calculations were performed on the 'Strela' computer at DAM. Solutions were worked out for highly complicated problems involving elaboration of computational techniques, programming, and organization.

The development of the prototype device has required a great deal of design-oriented, experimental, and technological efforts carried out under the direction of Yu B Khariton, the Chief Designer of KB-11 (*At that time, Yu B Khariton was also the scientific supervisor of KB-11 — Auth.*).

Design-oriented work was carried out with the active participation of D A Fishman, N A Terletskii, B A Yur'ev, V F Grechishnikov, G I Matveev, N V Bronnikov, P I Koblov, S G Kocharyants, V G Alekseev, P P Dodonov, I V Bogoslovskii, and A I Yanov.

E A Feoktistova and B A Terletskaya took part in the development (...) of the primary unit.

A D Zakharenkov, N A Kazachenko, V S Kustov, A G Ivanov, D M Tarasov, and B V Litvinov participated in gas-dynamic experiments.

V A Davidenko, B D Stsiborskii, A A Malinkin, and G P Antropov are taking part in experiments on neutron passage through the device simulator, which have got under way."

In mid-1955, the materials of the computation-theoretical feasibility study of the RDS-37 charge were reviewed by a commission chaired by I E Tamm and including V L Ginzburg, Zel'dovich, Keldysh, M A Leontovich, Sakharov, and Khalatnikov. The commission report stated that KB-11 and the DAM had carried out a rather large work on investigating the new physical principles underlying the design of hydrogen bombs with atomic implosion, and that the next major step in hydrogen weapon development would be testing the prototype device proposed by KB-11 at the No. 2 test site. The commission confirmed that it was expedient to perform this test in 1955 [4, p. 1103].

The results of the RDS-37 charge test successfully performed on November 22, 1955 were a triumph of theoretical thought and testified to the strong qualifications of Soviet scientists and engineers. The Soviet Government highly appreciated the services rendered to the country by the RDS-37 charge creators. Many participants in the RDS-37 development and testing received government awards in 1956. Zel'dovich, who has held the honorary title of a Hero of Socialist Labor, was decorated with the third medal for Hammer and Sickle. Sakharov, who has also held the honorary title of a Hero of Socialist Labor, was decorated with his second Medal for Hammer and Sickle. F P Golovashko, the pilot-in-command of the aircraft which delivered and dropped RDS-37, was conferred the honorary title of

Hero of the Soviet Union. The titles of Hero of Socialist Labor were conferred on Keldysh, E A Negin, and N I Pavlov. Zel'dovich, I V Kurchatov, Sakharov, and Yu B Khariton were awarded the Lenin Prize. More than 2400 people were decorated with orders and medals of the USSR.

3. On the origin of the ideas underlying the RDS-37 charge design and the role of Klaus Fuchs

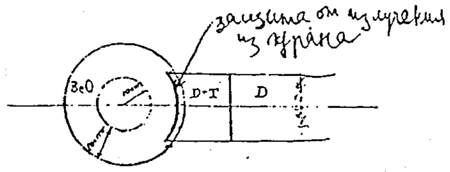
When creating the atomic bomb, the Soviet Union was responding to the challenge of the United States of America. However, as early as 1945, it became clear from intelligence reports delivered to the USSR that in the future our country would probably face with another challenge from the USA — the development and advent of a still more formidable version of nuclear weapons — the hydrogen bomb. Intelligence reports arrived from different sources, but the most important information about the work on the hydrogen bomb problem pursued in the USA was imparted to the USSR by the German-born scientist Klaus Fuchs via intelligence channels in 1945 and 1948. The available intelligence reports, including Fuchs's materials, triggered in our country decisive organizational measures. As early as October 22, 1945, a decision was reached at a meeting of the Technical Council within the Special Committee, which charged Kurchatov, A I Alikhanov, and Khariton to consider the issue of setting up the work to design a superbomb on the principle outlined in intelligence materials [8, p. 66; 18, p. 25]. In 1948, Fuchs passed along new information on atomic bombs and the hydrogen bomb problem to the USSR, with the effect that on June 10, 1948 the USSR Council of Ministers adopted special directions as discussed below. Central to the Government's regulations of June 1948, as is now evident, was setting up at the Physics Institute of the USSR Academy of Sciences (FIAN) a problem-oriented theoretical group under the direction of I E Tamm. It was precisely Fuchs's information that resulted in the recruitment of Tamm's group whose work had a profound effect on the solution to the problem of developing a hydrogen bomb in the USSR. The prominent role of the information on a hydrogen bomb, which Fuchs passed to our country, consisted primarily in this. The specific content of Fuchs's information was also of considerable importance in our work. However, prior to discovering the conception of designing a high-efficiency two-stage hydrogen bomb, which was independently discovered by Soviet scientists, they had to come a long and arduous way in theoretical and experimental research.

What data on the hydrogen bomb problem did K Fuchs convey to the USSR? Declassified archival documents suggest that his information related to the American hydrogen bomb project 'classical Super" i.e., the 'Tube' (1945), and to the two-stage 'Tube' initiator whose operation hinged on the radiation implosion [1] principle (1948) proposed by Fuchs in 1946. It is pertinent to note that Fuchs's information concerned not only atomic bombs and

[1] "*Fuchs told the FBI* (in 1950, after his conviction in England for passing atomic secrets to the USSR. — *Auth.*) *that it had been his idea to ignite the superbomb by implosion, but that "he did not furnish information concerning the ignition of the superbomb by the implosion process*" [10, p. 311]. Fuchs claimed his authorship because this idea was termed J von Neumann's proposal in a question he was asked by the FBI [11, p. 28]. The available documents allow the conclusion that the idea of radiation implosion originated in 1946 (see below).

«Все проекты в отношении возбуждения в сверхбомбе, представленные до сих пор, весьма неопределенны. Один из них, заслуживающий наибольшего предпочтения, состоит в следующем: в центре находится бомба с "25" (около 100 кг "25") пушечного типа. Она окружена заполнителем из BeO, хорошо отражающим нейтроны и пропускающим излучение. Часть поверхности из BeO покрывается металлическим ураном в качестве предохранителя от действия излучения. За этим предохранителем находится смесь D + T, подогреваемая нейтронами, исходящими из бомбы.*

*Если применяется магнитное поле, то смесь D + T может иметь кольцеобразную (т.е. тороидальную — Авт.) форму. При этом имеет значение лишь поперечная теплопроводность. За смесью T + D находится чистый D**.*



Верно: (подпись) */Горелик/*
Материал обработал: (подпись) */Терлецкий/*
28 января 1946 г.»

* Условное обозначение урана-235.
** В длинном цилиндрическом сосуде в жидком состоянии.

Figure 2. "*So far, all schemes for initiation of the super are rather vague. The one in highest favor is as follows: At the center is a '25' gadget* (about 100 kg of '25'), shot together by a gun. It is surrounded by a BeO tamper which has good neutron reflection properties and is transparent for radiation. Part of the surface of the BeO is covered with Tuballoy** as a shield against radiation and behind this shield is a D + T mixture, which is heated by the neutrons escaping from the gadget.*

If a magnetic field is used, the D + T mixture might be of the form of an annular (*i.e., toroidal — Auth.*) *ring, so that only the transverse heat conductivity matters. Beyond the D + T mixture is pure D***.*
Correct: (signature) /Gorelik/
Processed by: (signature) /Terletskii/
January 28, 1946."

Notes: * '25' conventionally denoted uranium-235;
** 'Tu' or Tuballoy was a code word for uranium in the documents of the period;
*** Liquid D in a long cylindrical vessel — *Auth.*

the hydrogen bomb, but matters of the atomic industry as well. Fuchs's materials were always properly appreciated by Kurchatov and other supervisors of the Soviet atomic project. We now turn to Fuchs's materials relating to the hydrogen bomb problem.

Figure 2 shows an excerpt of Fuchs's message of September 1945 about the classical 'Super' [9, p. 900]. Shown in Fig. 3 is the schematic diagram of the hydrogen bomb from his message conveyed to the USSR via Soviet intelligence officer A S Feklisov in London in March 1948 (borrowed from Ref. [12]). Fuchs's material of 1948 contained a detailed description of the bomb design with a two-stage igniting block and of the processes proceeding in its explosion.

"*The detonator* (the primary unit — *Auth.*) *is a fission bomb of the gun type. The active material is 71 kg of 40% pure* U_{235}.... *The tamper is BeO. The fission gadget has an efficiency of 5%* (*calculated*). *The tamper, which is transparent to the radiation from the fission bomb, is surrounded by an opaque shell which retains the radiation in the tamper and also shields the booster* (part of the 'tube' in which deuterium is added with 4% tritium — *Auth.*) *and main* (deuterium — *Auth.*) *charge against radiation.... The*

BELOW: In March 1948, Klaus Fuchs, meeting with his Soviet control in a London pub, passed along an advanced design for the Super. *Courtesy Joseph Albright and Marcia Kunstel.*

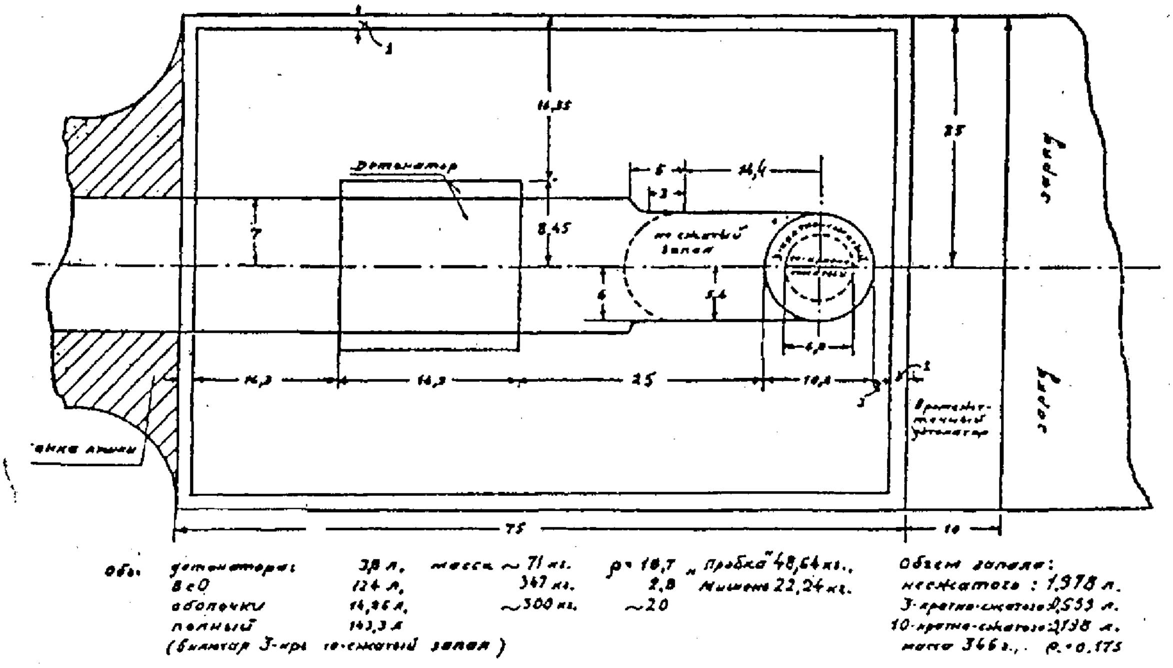


Figure 3.

energy production, energy release into tamper and temperature in tamper are shown in figure (not published — *Auth.*). *Based on crude calculations, which require refinement. The unit of time is a 'shake'* — 10^{-8} *second. The primer* (primary for the 'tube' initiation, it is actually secondary — *Auth.*) *contains 346 g of liquid D – T in 50 : 50 mixture, situated in the tamper. It is first compressed by the projectile to 3-fold density* (using high explosive — *Auth.*). *This precompression may not be necessary. As the tamper and primer are heated by the radiation, the primer is further compressed, possibly to 10-fold density.* (*Radiative transport equalizes the temperatures in primer and tamper, and gives therefore rise to a pressure differential.*) *The compression opens the 'gap' for the ignition of the primer. The primer is likely to have a very high efficiency* (*80%*) *of energy release*" [7, p. 907].

The Russian translation of Fuchs's materials of 1948 — materials No. 713a (about the superbomb), and No. 713b (about atomic bombs) — was rushed to L P Beria. On April 23, 1948, Lavrenty Beria instructed B L Vannikov and Kurchatov to carefully analyze the materials and produce within 2 – 3 days their assessment with proposals as regards organizing necessary research and work in view of the new information contained in the materials. Beria also instructed them to familiarize Khariton with the materials and obtain his assessment and practical proposals concerning the work of KB-11 [8, p. 906; 13, sheet 324].

In their conclusion signed on May 5, 1948, Vannikov and Kurchatov noted:

"*As regards the material No. 713a, the basic ideas about the role of tritium in the transfer of explosion from a uranium-235 primer to deuterium, about the necessity of careful selection of uranium primer power, and about the role of particles and photons in the transfer of the explosion to deuterium are new.*

These materials are valuable in that they will be helpful to Cde. Zel'dovich in his work on the superbomb, performed under the operations plans approved by the First Main Directorate.

More effort should be put into research in that area and a start should be made on the work on the practical design."

Vannikov and Kurchatov proposed to set up a group in KB-11 for the design study of a deuterium superbomb and set before it the task of developing its conceptual design by January 1, 1949.

A crucial point in Vannikov and Kurchatov's conclusion was the proposal that the Physics Institute of the USSR Academy of Sciences should take part "*in the study of nuclear reactions involving deuterium and tritium and in tackling the most topical theoretical aspects of the superbomb problem*" [8, p. 906; 13, sheets 338 – 348].

On the same day, Khariton produced his conclusion about Fuchs's materials. It said:

"*The new materials Nos 713a and 713b contain a portion of highly significant, previously unknown information which may foster solutions to several practical problems.*

Material No. 713a pertains to the superbomb, wherein the working substance is deuterium, and the primer is forty-percent uranium-235.

Material No. 713b is concerned with the analysis of numerous design versions of the bombs on the basis of plutonium, uranium-235, and their combinations.

Material No. 713a contains a description of the main parts of the superbomb and a rough sketch which gives an insight into the dimensions of several significant elements. The entire initiation system was outlined: *40% uranium-235 first, then the mixture of deuterium with 50% tritium, then deuterium mixture with 4% tritium, and lastly deuterium.*

There are several physically significant remarks, so far not quite clear, concerning the initiation mechanism, for instance, about the radiation-transparent tamper and its opaque shell, about the existence of the optimal power of the uranium primer and its composition (40% uranium-235), about the reaction transfer from the primer with 50% deuterium to the booster detonator with 4% tritium by way of neutrons....

Comparison between old and the latest materials creates an impression that long-term exploratory theoretical and experimental work has found safe ground for the basics of design....''

While on the subject of additional tasks of KB-11 in view of the new received materials, Khariton noted that ''*it would be expedient to get down to a conceptual design of the superbomb.... To design the superbomb requires setting up a design group*'' [8, p. 906; 13, sheets 326 – 333].

One can see from Khariton's conclusion that the gist of the physical idea and scheme of radiation implosion from Fuchs's material No. 713a were not understood at that time. This lack of understanding persisted until 1954. This was promoted by the extreme restrictions on the circle of people given access to material No. 713a. Of Zel'dovich's group members, only he himself had access to this material. D A Frank-Kamenetskii had no access to material No. 713a, although he had access to other intelligence materials that were sent to KB-11 and kept in Khariton's safe (until 1956) [14, sheets 247 – 253].

When in March 1949 Khariton addressed Beria asking him to familiarize Tamm and A S Kompaneets with the experimental data on DT reaction cross sections from Fuchs's document, M G Pervukhin and P Ya Meshik stated their viewpoint for Beria: ''*Cdes. Tamm and Kompaneets must be denied access to materials of Bureau No. 2* (materials arriving via intelligence channels — *Auth.*), *so as not to familiarize extra people with them...*'' [4, p. 1100; 15, sheets 214, 215]. In that instance, Tamm and Kompaneets received only excerpts with cross section data from the material. As regards Sakharov, during his first stay in KB-11 in June 1949 he wrote a plan for work on the hydrogen bomb problem. The section relating to the 'tube' contained the following item: ''*Ignition of the* (cylindrical — *Auth.*) *charge* (of deuterium — *Auth.*) *by gun-type explosion or additional charge with trioxane* (tritium — *Auth.*)'' [4, p. 1100]. This is an indication of the fact that at that time Sakharov was already familiar with the approaches to the 'tube' ignition problem outlined in Fuchs's materials of 1945 and 1948. No other documentary evidence is known, which might shed light on this question.

It is pertinent to note that in the United States, where the idea of radiation implosion appeared, the enormous potential of this idea remained unrealized for several years as well. It was not until 1951 that Edward Teller realized, when elaborating upon S Ulam's proposal, that the two-stage scheme harnessing the radiation implosion principle, which was initially proposed as a means for igniting the 'classical super' (the 'tube'), may underlie the design of a full-scale thermonuclear charge. This confirms the objective complexity of the problem [4, pp. 1096, 1097].

The proposals submitted by Vannikov, Kurchatov, and Khariton underlay the Resolutions adopted on June 10, 1948 by the USSR Council of Ministers: No. 1989-773ts/sd ''Supplement to the plan of the works for KB-11'' [16, pp. 494, 495] and No. 1990-774ts/sd ''On additional assignments in the context of the special research plan for 1948'' [16, pp. 495 – 498]. Resolution No. 1990-774ts/sd bound S I Vavilov, the director of FIAN, to set up a problem-oriented theoretical group under Tamm's supervision to carry out research on the theory of deuterium combustion. Tamm's group at FIAN was comprised of S Z Belen'kii and Sakharov; brought in later were Ginzburg and Yu A Romanov. A closed seminar under S L Sobolev's supervision was organized at Laboratory No. 2.

Prior to the formation of Tamm's group, the theoretical aspects of the superbomb (specifically, a deuterium 'tube') were considered by only one group which worked at the Institute of Chemical Physics of the USSR Academy of Sciences under Zel'dovich's supervision (consisting of Kompaneets and S P D'yakov). The group commenced its work on the 'tube' problem in mid-1946. In February 1948, Zel'dovich was moved to work in KB-11 [16, pp. 481 – 484], but continued to supervise the above group as well. The report by I I Gurevich, Zel'dovich, I Ya Pomeranchuk, and Khariton ''Utilization of the nuclear energy of the light elements'' [17; 18, pp. 53 – 59] was presented at the December 1945 session of the Special Committee's Technical Council and came to be the launching investigation into the 'tube' problem in our country.

Setting up a new group in 1948, which included top-notch scientists to work on the hydrogen bomb problem, was a major objective factor which had a strong bearing on the progress of this work. The work of Tamm's group led to the advancement of new ideas which allowed steering an original course, distinct from that adopted in the United States, toward the goal. The members of Tamm's group did not restrict themselves to verification and improvement of the 'tube' calculations performed by Zel'dovich's group. As early as in autumn 1948, Sakharov conceived the idea of a new hydrogen bomb configuration — the 'sloika' (a Layer Cake) of alternating layers of uranium and thermonuclear fuel which was supposed to be heavy water or heavy ethane. In late 1948 — early 1949, Ginzburg made a significant improvement: he proposed the use of substantially more efficient lithium-6 deuteride for a thermonuclear fuel in the Layer Cake [4, pp. 1099 – 1100].

Early in December 1948, a seminar was held in Laboratory No. 2 of the USSR Academy of Sciences, which heard the reports by Kompaneets and D'yakov on the 'tube', and by Tamm on the Layer Cake [8, pp. 90, 91]. One of the idealized problems considered in the former paper was the explosion problem of a finite preheated mass of deuterium. An inference was drawn that the explosion in this formulation is possible only for an unrealistically large deuterium mass. In this case, the conclusion was accompanied by the remark that the deuterium mass might be reduced by adding heavy elements to it:

''*Another method consists in an increase in pressure* (*up to* $10^{11} - 10^{12}$ *atm*). *Such a pressure may be produced by atomic explosives; their use for initiating the process without propagation is inexpedient. Initiation by way of a converging detonation wave produced by conventional explosives is impossible to achieve*.''

The idea of employing atomic explosives to strongly increase the pressure and, hence, the deuterium density was elaborated even in the first report by Sakharov on his proposed Layer Cake, issued in January 1949 [4, p. 1100; 8, p. 89]. Concerning the problem of ignition of the Layer Cake explosion, Sakharov noted that the simplest triggering configuration to be mathematically considered first of all involves placing an atomic bomb at the center of a large (practically infinite) spherical Layer Cake. Also conceivable are other ignition schemes, probably more advantageous in terms of the minimal amount of plutonium required. Among these schemes, Sakharov named "*the use of an additional plutonium charge to precompress the Layer Cake*". This was actually the idea of a two-stage thermonuclear charge design in which the Layer Cake would fulfill the function of the secondary unit! But it was not until 5 years later (early in 1954) that Sakharov reverted to this idea. In the spring of 1954, when both Zel'dovich and Sakharov saw the possibility of compressing the Layer Cake type thermonuclear unit by the radiation of a primary atomic bomb, they started translating it into a real structural design together with the teams of theorists, mathematicians, designers, and other specialists of KB-11 and other organizations enlisted. This was preceded by the development and successful testing of the first domestic thermonuclear RDS-6s charge — a spherical Layer Cake compressed by detonating a conventional explosive.

The RDS-6s charge was developed in accordance with Resolution of the USSR Council of Ministers No. 827-303ts/sd "About Work on the Construction of RDS-6" [19], which was approved by I V Stalin on February 26, 1950. The resolution was adopted in response to the public statement made by the President of the United States Harry Truman about speeding up work on the hydrogen bomb. To develop RDS-6s, a group (later a department and a sector) under Tamm's supervision was set up in KB-11, which also included several members of his Moscow group, transferred to KB-11.

The RDS-6s development was of fundamental importance in the history of thermonuclear weapons creation in our country. Industrial production of lithium-6 deuteride was organized. In this aspect, our country outstripped the USA. During the work on the Layer Cake, its detailed computation-theoretical model was constructed to provide a quantitative description of the basic physical processes during compression and explosion. The accuracy of this model was borne out by the RDS-6s ground test. Since the Layer Cake became the prototype of the thermonuclear unit in the two-stage thermonuclear RDS-37 bomb, this model permitted the computation-theoretical substantiation of RDS-37 to be significantly speeded up.

The commencement of work on the encirclement principle is dated 1950 in a theoretical report on RDS-37. That year, a start was made in KB-11 on the consideration of a two-stage trigger for the 'tube'. In 1952, a start was made on the design search for the two-stage thermonuclear charge itself. The work plan of Zel'dovich's sector for 1953, which was drawn up in January 1953, included the clause "Feasibility study of the use of conventional RDS to compress a high-power RDS-6s (atomic compression)" [4, p. 1101]. The document included a note that the work was performed in cooperation with Tamm's sector. However, till the first months of 1954 it was assumed that the thermonuclear unit compression would be effected not by the radiation (the possibility had not been realized by that time) but by the shock wave or the material explosion products of the primary nuclear charge, thereby making highly conjectural the attainment of symmetrical compression of the thermonuclear unit.

The only document containing theoretical estimates for a two-stage thermonuclear charge operation, which reflects

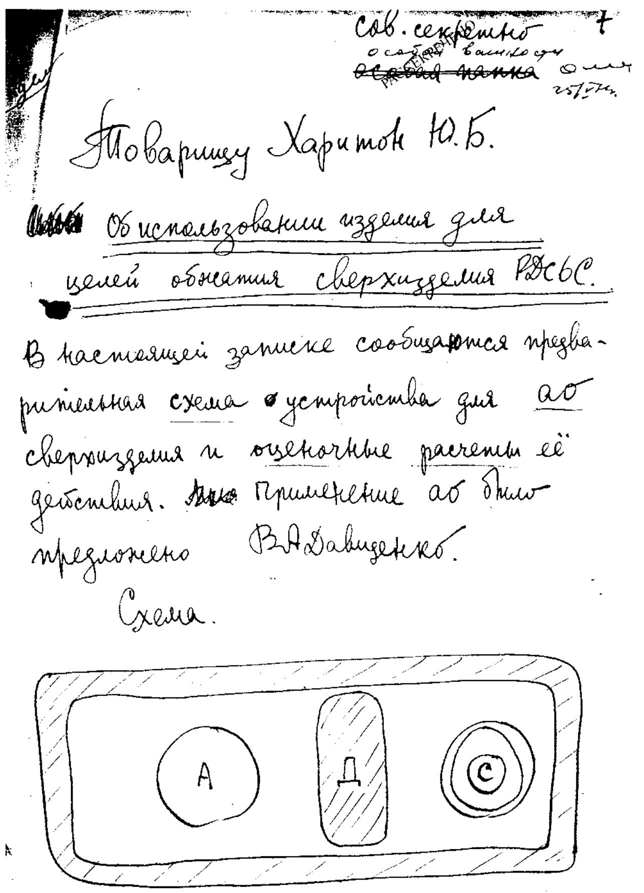

Сов. секретно
Товарищу Харитон Ю.Б.
Об использовании изделия для целей обжатия сверхизделия РДС-6С.
В настоящей записке сообщаются предварительная схема устройства для АО сверхизделия и оценочные расчеты её действия. Применение АО было предложено В.А.Давиденко.
Схема.

Figure 4. First page of a January 1954 report by Zel'dovich and Sakharov. The text reads:

"Top secret
Special dossier
To Comrade Khariton Yu.B.
About using the gadget [atomic bomb] for implosion of the supergadget RDS-6s.
This reports presents a preliminary schematic of a device for the AO [atomic implosion] of the supergadget and calculations evaluating its performance. The application of AO was proposed by V.A. Davidenko.
The schematic."

that stage of the work, is Zel'dovich and Sakharov's memo addressed to Khariton, dated January 1954 [4, p. 1102; 5, p. 58]. The first page of the memo is reproduced in Fig. 4. V A Davidenko was supposedly the author of the sketch plotted in it. The memo text contained in particular the following:

> "*The proposed system consists of a metal casing* (...) *partitioned by a diaphragm D* (...) *into two parts approximately equal in volume. The total weight of the structure is about 26 – 30 tons* (...). *One volume accommodates gadget A, and the other gadget C* (...).
> *We disregard the first period — the propagation of energy in gadget A; in this period more than half the energy initially comprises radiation energy and propagates by the mechanism of radiative heat conduction. By the end of the period, however, a shock wave is generated with a velocity that exceeds the rate of radiation diffusion...*" [8, pp. 118 – 120].

Therefore, the memo displays the lack of understanding of the fact that it was possible to conduct radiation out of the primary atomic bomb and employ it for compressing the thermonuclear unit. However, one can see from the contents of the memo that Soviet scientists had come quite close to the discovery of a new thermonuclear charge design concept: all the main elements required for its realization were already present in the above memo.

The light was seen in March or April 1954, when the understanding of the possibility of releasing radiation from the primary atomic bomb and utilizing it for the symmetric compression of the secondary thermonuclear unit was reached. All available documentary evidence testifies to the fact that the domestic counterpart to the Teller–Ulam configuration was independently discovered by Soviet scientists — intelligence did not provide Soviet scientists with the Teller–Ulam configuration. It is pertinent to note that the international situation at that time was quite extraordinary. On February 17, 1954, the Chairman of the US Congress Joint Committee on Atomic Energy, W Sterling Cole, made a sensational public statement. He announced the immense destructive effect of the Mike explosion which the USA performed on November 1, 1952, and that the USA had a hydrogen bomb with an even higher yield. On March 1, 1954 the USA carried out the Bravo explosion which was responsible for severe radiation injuries to the crew members of the Japanese fishing boat 'Happy Dragon', far away from the explosion site, and which literally shocked the world [8, p. 125]. At that time, in the USSR there was no proposal to build a high-yield hydrogen bomb whose working capacity and efficiency would be beyond question. The 'tube' development was considered to show little promise and research on the 'tube' was deleted from the 1954 operations plan for KB-11. And the findings of research on the higher-yield version of a single-stage Layer Cake, which was pursued under a special resolution of the Soviet Government adopted in November 1953, testified that this line of work had limited potential and was a blind alley. Under the circumstances, the scientists of KB-11 could not help mounting an all-out effort in search of an efficient way of designing hydrogen bombs. And these efforts came to fruition. The advent of the new approach was acclaimed by the researchers of KB-11 as a sensation. It suddenly became clear how bright the prospects were for developing new thermonuclear charges. The team of KB-11 theorists embarked with great enthusiasm on research aimed at substantiation of the feasibility of a high-yield hydrogen bomb relying on the radiation implosion principle and subsequently on working out its specific design for the first test.

The project participants recollect how suddenly the new ideas erupted. This was vividly described by L P Feoktistov, one of Zel'dovich's closest coworkers:

"*New ideas dawned upon us suddenly like light in a dark room, and it became clear that the moment of truth had come. Common talks ascribed these fundamental thoughts in Teller's spirit now to Zel'dovich, now to Sakharov, now to both, or to somebody else, but always in some indecisive form: likely, possibly, and so on. By that time, I had come to know Zel'dovich quite closely, but I never heard a direct confirmation from him on that score* (*nor, indeed, directly from Sakharov*)" [20, p. 223].

Conceivably, the point was that scientific ethics did not permit Zel'dovich and Sakharov to discuss priority matters without referring to intelligence materials. A reference to these materials was made by Teller, and he mentioned Fuchs's name. We cite D Holloway's book *Stalin and the Bomb*:

"*In response to Bethe, Edward Teller argued* (in his comments of August 1952 upon H Bethe's memorandum — *Auth.*) *that the Soviet Union might well have advanced much farther than the United States towards the development of a deliverable hydrogen bomb. He disputed Bethe's thesis that intensive work on the ideas of 1946 would not have led to the development of a workable design. He disagreed with Bethe's characterization of the discovery of the Teller–Ulam idea as 'accidental': modifications to the earlier ideas, he argued, might have yielded practicable results. Teller argued that "radiation implosion is an important but not a unique device in constructing thermonuclear bombs". He went on to claim, moreover, that the "main principle of radiation implosion was developed in connection with the thermonuclear program and was stated in a conference on the thermonuclear bomb, in the spring of 1946. Dr. Bethe did not attend this conference but Dr. Fuchs did."* [2] *Teller was concerned that if Fuchs had communicated the idea of radiation implosion to Soviet scientists, they might have hit upon the Teller–Ulam configuration before Teller and Ulam did so*" [10, p. 311].

One can see from the materials cited in my paper that both the United States of America and the Soviet Union had a hard and long way to go from the idea of radiation implosion proposed in 1946 to a practicable design of the hydrogen bomb. However, owing to the unparalleled effort of our scientists and engineers, the USSR's lag behind the USA in the production of a deliverable two-stage thermonuclear bomb with lithium deuteride was minimized. The RDS-37 charge was tested only 1.5 years later than the Castle series of tests in which two-stage thermonuclear charges with lithium deuteride tested. And in the USA, the thermonuclear bomb was not dropped from a plane until 1956 — after the RDS-37 test.

The discovery of the design concept and the development of the two-stage thermonuclear RDS-37 charge was a major breakthrough on the track to the attainment of strategic nuclear parity with the United States of America and the prevention of a new world war. Commemorating the fiftieth anniversary of a brilliant achievement of our country — the successful test of RDS-37, the first domestic two-stage thermonuclear charge — and also remembering in this connection the name of Klaus Fuchs, we render homage to the creators of RDS-37.

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[2] Reinforcing his arguments, Teller also stated the following: "*It appears to me that the idea of the* (Teller–Ulam configuration — *Auth.*) *was a relatively slight modification of ideas generally known in 1946. In essence only two elements had to be added: to implode a larger volume and to achieve greater compression by keeping the imploded material cold as long as possible...*" [21; 4, p.1097]. However, despite the similarity between the new ideas and previous ones proposed in 1946, the passage from those ideas to the Teller–Ulam configuration in the USA took, as noted above, much time — 5 years. The available document reads, "*Dr. Teller considers it a miracle that the concept was not conceived sooner*" [22, p. 62].

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