Chapter 5

RACE FOR THE SUPER

11/9/2017

5.1 INTRODUCTION

On August 12, 1953, less than a year after the USA tested its first thermonuclear device, the Soviet Union detonated a 400 kT TNT equivalent weapon dubbed "Layer Cake" fueled by U^{235} and lithium deuteride LiD. The explosive power was 30 times that of the first fission weapon dropped on Hiroshima. The mushroom cloud and fireball it produced reached 5 miles into the troposphere.

At Kyoto University in Japan, physicist Tokutaro Higawara in May 1941 suggested in a lecture that a thermonuclear reaction in hydrogen nuclei could be initiated by an explosive chain reaction of U^{235} fission.

At Columbia University in the USA, Enrico Fermi in the same year in September 1941 suggested the same idea to Edward Teller. Their discussion resulted in a concept of using a fission device to initiate thermonuclear reactions in the deuterium ${}_1D^2$ isotope of hydrogen. Edward Teller persisted with the idea of building a thermonuclear weapon in a project designated as the Super Project in the USA. This was countered by a USSR program that evolved into a strategy of Mutual Assured destruction (MAD) and global posturing during the period of the Cold War.

Figure 1. The Los Alamos National Laboratory, New Mexico, USA.

5.2 CLASSICAL NEUTRON SUPER

Eleven years after the Tokutaro Higawara and Enrico Fermi suggestions in the summer and fall of 1942, Edward Teller outlined some initial ideas on which the concept of the Classical Super became based at the Los Alamos National Laboratory (LANL) in the USA. The concept of the Classical Super was formulated in a preliminary way by the end of 1945.

The Classical Super concept was based on the suggestion that a flow of neutrons generated in a primary gun type U^{235} device could ignite a nuclear detonation in a long cylinder filled with liquid deuterium by means of an intermediate chamber filled with a DT mixture.

Figure 2. Edward Teller in 1958.

In 1942 the idea of adding tritium to deuterium to induce the DT reaction rather than the DD reaction was suggested by Emil Koponinsky. This concept was based on the higher cross section of the DT reaction:

$$ {}_1D^2 + {}_1T^3 \rightarrow {}_2He^4(3.54\ \mathrm{MeV}) + {}_0n^1(14.06\ \mathrm{MeV}) + 17.60\ \mathrm{MeV} \qquad (1)$$

The rate of this reaction at the relevant temperatures is about two orders of magnitude higher that of the DD reaction rates with its proton and neutron branches:

$$\begin{aligned} {}_1D^2 + {}_1D^2 &\rightarrow {}_1T^3(1.01\ MeV) + {}_1H^1(3.02 MeV) + 4.03\ MeV \\ {}_1D^2 + {}_1D^2 &\rightarrow {}_2He^3(0.82\ MeV) + {}_0n^1(2.45 MeV) + 3.27\ MeV \end{aligned} \qquad (2)$$

The feasibility of the Classical Super was dependent on the belief that a non-equilibrium ignition regime in the DT mixture and pure deuterium D_2 could be achieved.

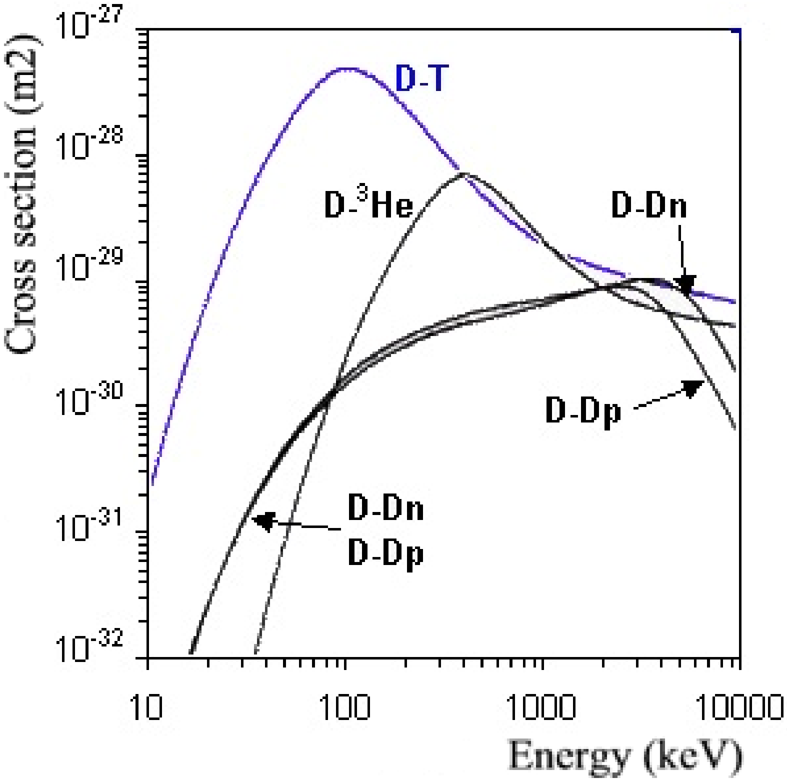

Figure 3. The cross section for the DT reaction reaches a maximum at about 100 keV at a lower temperature than the maximum of the DD reaction branches.

5.3 RADIATION COMPRESSION SUPER

In the spring of 1946 Klaus Fuchs and John von Neumann proposed another triggering concept with an importance realized later in time. It included an additional secondary charge with a liquid DT mixture that would be heated, compressed, and, as a result, ignited by radiation from the primary fission device.

Figure 4. Klaus Fuchs.

5.4 AUTOCATALYTIC REACTIONS CONCEPT

Edward Teller proposed in early 1942 an autocatalytic configuration of a nuclear device in the context of developing more efficient fission devices. The term “autocatalytic” is used to describe an arrangement where the motion of materials produced by the reaction will act for a time to increase the reaction rate.

He suggested placing bubbles of burnable poison B^{10} neutron absorber inside the active material of the device. These bubbles would absorb the neutron background and allow higher compression of the fission core before the spontaneous fission neutron source would initiate the reaction at an early compression stage.

The neutron background is caused by:

1. The cosmic rays, generating about a neutron flux of 1 neutron/(cm^2.min). These are too few to be considered important.
2. The spontaneous fission neutrons. These originate from isotopes such as Pu^{240} as shown in Table 1.
3. The (α, n) reactions with the light element impurities in the fissile fuel left over from its chemical processing. The light element impurities include; Li, Be, B, C, N, O and F. A typical reaction with Be would be:

$$_2He^4 + {}_4Be^9 \rightarrow {}_0n^1 + {}_6C^{12} \qquad (3)$$

The isotope B^{10} has a high absorption cross section for fast neutrons at about 1.52 barn (b). The relevant reaction is:

$$_0n^1 + {}_5B^{10} \rightarrow {}_2He^4 + {}_3Li^7 \qquad (4)$$

The produced Li^7 will undergo and (n, n’) endothermic reaction:

$$_0n^1 + {}_3Li^7 + \rightarrow {}_0n^1 + {}_2He^4 + {}_1T^3 \qquad (5)$$

Instead of B^{10}, the isotope Li^6 can be used as a neutron absorber. In this case it would absorb a neutron producing an alpha particle and a triton according to the breeding reaction:

$$_0n^1 + {}_3Li^6 + \rightarrow {}_2He^4 + {}_1T^3 \qquad (6)$$

The resulting tritium can act as a neutron multiplier through the reaction:

$$_1T^3 + {}_1T^3 + \rightarrow 2\,{}_0n^1 + {}_2He^4 \qquad (7)$$

The two emitted neutrons were thought at a certain time to constitute a dineutron particle.

Another alternative is to use bubbles containing lithium deuteride Li^6D, which would lead to the DT reaction with its 14.06 MeV energetic neutrons capable of fissioning the fissionable isotopes U^{238} and Th^{232} which can be used in the tamper for further energy multiplication. In fact, natural lithium deuteride can be used.

Table 1. Comparison of half-lives and partial Spontaneous Fission (SF) half-lives of the plutonium and uranium isotopes.

Isotope	Half life [years]	Partial Spontaneous fission half life [years]	Spontaneous fissions Neutrons emission [neutrons/(sec.kg)]
Pu^{236}	2.85	3.50×10^{9}	
Pu^{237}	45.6 d	-	-
Pu^{238}	87.74	4.30×10^{10}	
Pu^{239}	2.411×10^{4}	5.50×10^{15}	30.2
Pu^{240}	6537	1.22×10^{11}	1.36×10^{6}
Pu^{241}	14.7	-	-
Pu^{242}	3.76×10^{5}	6.80×10^{10}	2.40×10^{6}
Pu^{243}	4.956 h		
Pu^{244}	8.3×10^{7}	2.50×10^{10}	
U^{233}	$1,.592 \times 10^{5}$	-	-
U^{234}	2.44×10^{5}		
U^{235}	7.04×10^{8}	1.9×10^{17}	0.889
U^{238}	4.468×10^{9}	8.0×10^{15}	20.8
Np^{237}	2.14×10^{6}	$>10^{18}$	0.167

If the neutrons absorption mean free path in the active material is λ_a and the average diameter of the bubbles is d, the background neutrons will be readily absorbed if:

$$\lambda_a = \frac{1}{\Sigma_a} \leq d \qquad (6)$$

$$where: \Sigma_a = \text{ macroscopic absorption cross section}$$

If on the other hand the bubbles diameter is reduced to a smaller diameter d', such that:

$$\lambda_a > d' \qquad (7)$$

the neutrons will not effectively see the collapsed absorption bubbles any more, and the boron becomes less effective in absorbing the reaction neutrons

5.5 IONIZATION IMPLOSION CONCEPT

The nuclear density of particles as nuclei and electrons in boron is about 8.3×10^{23} (particles/cm^3), whereas it is 5 times larger in the active material such as uranium. As the chain reaction proceeds in the active material, a high degree of ionization is achieved and the material acts as a gas, preferentially compressing the boron bubbles to the rest of the active material. Turbulence may act against the boron compression, stirring up the boron uniformly in the active material, but its time scale is too short for it to be effective.

As a result of the pressure difference due to ionization of materials with different numbers of electrons in their atoms, B^{10} or Li^{6} would be highly compressed in the process of implosion. This compression would lead to a smaller neutron absorption that would result in a higher criticality and energy released by the device. This process is known as ionization implosion.

5.6 DT IONIZATION IMPLOSION BOOSTER

John von Neumann suggested in 1944 replacing the B^{10} in Teller's autocatalytic configuration with a DT mixture in order to trigger the thermonuclear reaction through heating and ionization compression caused by the fission device shock or blast wave.

Fast neutrons generated by the DT reaction would induce further fissions in the plutonium of the device. These faster 14.06 MeV and more energetic neutrons would produce a larger number of neutrons from fission than the 2 MeV fast fission neutrons and thus act as a neutron multiplier, and hence an energy multiplier. The second generation of neutron multiplication can generate more energy than the initial first fission generation hence enhancing the efficiency of the device. John von Neumann's idea was a major step on the road to a nuclear device with a thermonuclear booster.

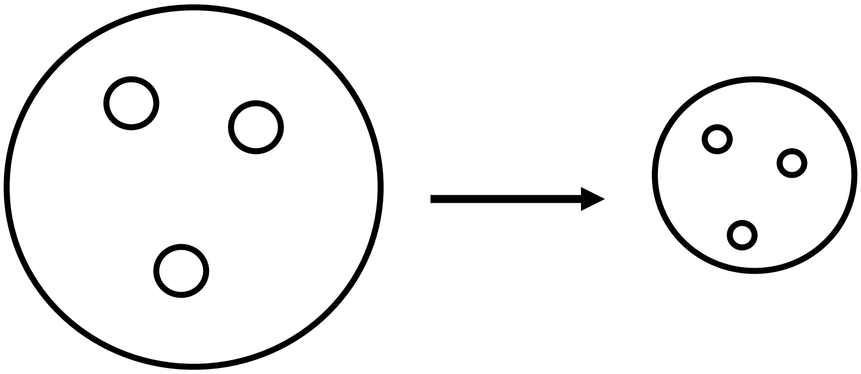

Figure 5. $Boron^{10}$ bubbles compression in the autocatalytic reaction.

5.7 RADIATION IMPLOSION

In the spring of 1946, Klaus Fuchs was working on how to improve the ignition conditions for the Classical Super. He considered the utilization for this purpose of a gunbarrel type U^{235} nuclear device with John von Neumann's booster.

He suggested the removal of the DT mixture bubbles from inside the fissile U^{235} and placing it inside a beryllium oxide BeO_2 tamper heated and compressed by radiation.

His expectation was that, as in the initial design, the DT mixture would be heated and compressed by ionization implosion, so that the conditions would be appropriate for igniting a thermonuclear reaction. Beryllium is known to be a high temperature and high strength material, which makes it suitable as a tamper. It also possesses another important property for the suggested application in that it can contain the tritium and deuterium gas preventing it from leakage.

However, a light element like beryllium is transparent to radiation which would leak through it. To contain the radiation field inside the BeO_2 tamper, Fuchs suggested enclosing the device in a radiation impervious casing. Since the compression of the DT mixture in this configuration would be caused by the transfer of radiation from the fission active zone of the nuclear charge to the zone of thermonuclear fuel outside the nuclear charge zone, this process was called radiation implosion.

The concept of radiation implosion was conceived in the spring of 1946. On May 28, 1946, Klaus Fuchs and John von Neumann filed a joint patent application for the invention of the new design of the triggering system for the Classical Super using radiation implosion.

5.8 ALARM CLOCK CONCEPT

Klaus Fuchs left Los Alamos on June 15, 1946 back to England. Edward Teller continued to pursue his ideas. At the end of August 1946, Edward Teller wrote a report proposing a new alternative to the Classical Super configuration of a thermonuclear device designated as the Alarm Clock.

The proposed configuration consisted of alternating spherical layers of fissionable materials and thermonuclear fuel as deuterium and tritium and possibly their different chemical compounds.

This design held several potential advantages. Fast neutrons generated in thermonuclear reactions were expected to initiate fissions in the adjacent layers of fissile materials, which would result in a considerable energy multiplication since the energy release from a fission reaction is about 190 MeV.

The ionization implosion of the thermonuclear fuel due to the fission explosion was expected to lead to its higher density, hence higher rates of thermonuclear reactions. The device could operate without achieving a non equilibrium regime of thermonuclear burn. On the other hand it demanded a very powerful nuclear trigger to initiate the reactions. The required power of the nuclear trigger was higher since the Alarm Clock, as an alternative to the Classical Super was proposed for the purpose for obtaining an energy release at the multi megaton range of TNT equivalent.

The large dimensions and weight of the structure required in this case made its compression by chemical explosives practically impossible. As of September 1946, theoretical research in the Classical Super and Alarm Clock projects continued concurrently without any significant breakthrough.

5.9 LITHIUM DEUTERIDE AS A FUSION FUEL

In September 1947, Edward Teller issued a report suggesting the use of lithium^6 deuteride, Li^{6}D which is a white powder, in the Alarm Clock concept.

With the Li^6 isotope included in the fuel, the quantity of bred tritium produced during the explosion would be considerably large, which would notably increase the thermonuclear reaction efficiency. The relevant exothermic tritium breeding reaction is:

$$ {}_0n^1 + {}_3Li^6 + \rightarrow {}_2He^4 + {}_1T^3 \qquad (8) $$

The Alarm Clock project showed little promise at that time. The research in this project slowed down because of almost insurmountable difficulties in triggering the reaction. Nonetheless, theoretical studies of the Alarm Clock continued at Los Alamos concurrently with the Classical Super in the following years.

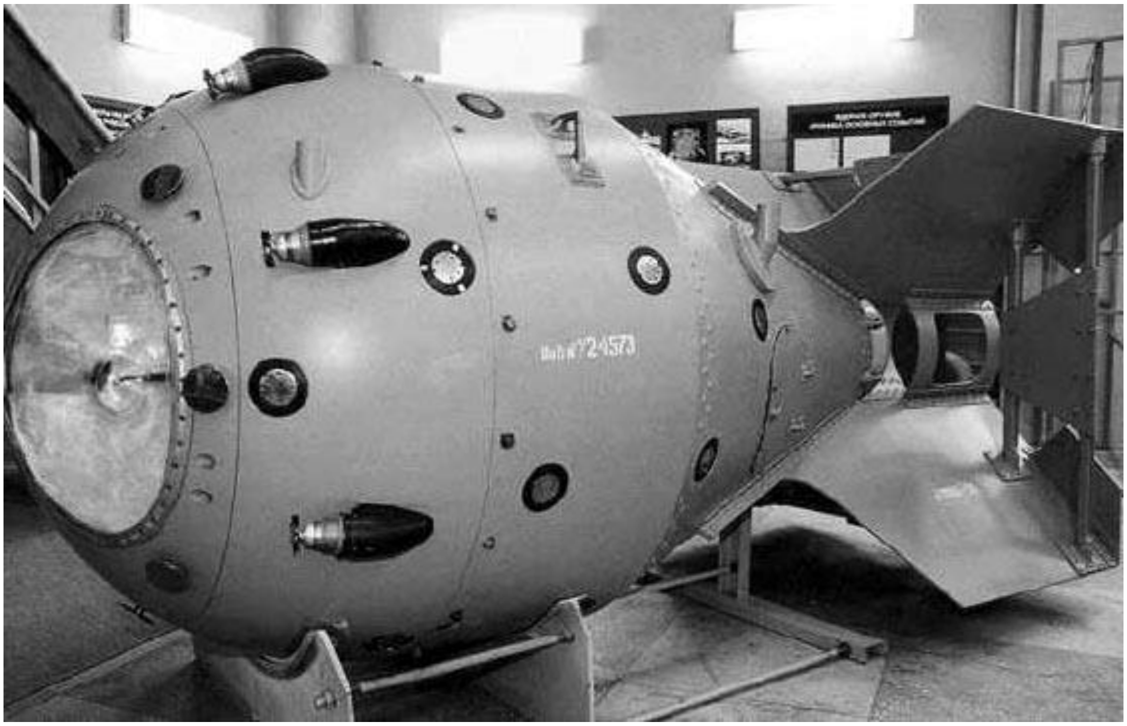

Figure 6. Replica of RDS-1 the fission Russian analog to the USA Fat Man Pu^{239} implosion design.

Figure 7. First Lightning, or Joe-1, referring to Joseph Stalin, the first Russian nuclear test.

5.10 THE BOOSTER CONCEPT

The Russians caught up with the USA and tested their First Lightning device, designated by the Western sources as Joe-1 in reference to Joseph Stalin, the Georgia-born Russian leader. It was a plutonium implosion device that was a replica of the USA Fat Man device dropped on Nagasaki.

In response, on January 31, 1950, President Harry Truman directed the USA Atomic Energy Commission: “To continue its work on all forms of atomic weapons, including the so called hydrogen or superbomb.” Truman's public statement gave new impetus to the feasibility study of the hydrogen bomb in the USA. The Russians were also given their own impetus to proceed with their Super Program, starting a historical arms race.

The decision was made to conduct testing explosions of a device using thermonuclear reactions in 1951. One of the planned experiments to be tested was an explosion of a boosted nuclear device code named: Item.

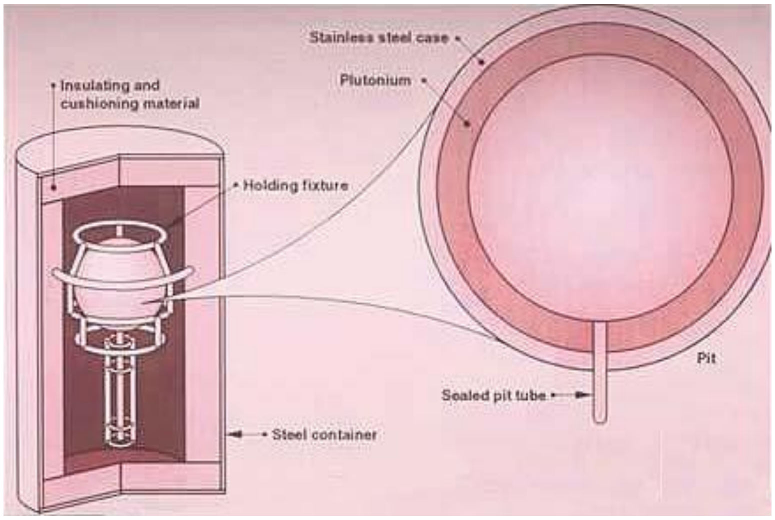

Figure 8. Plutonium pit in a stainless steel case and sealed pit tube used for boosting.

In boosting, reservoirs or cartridges containing gaseous DT could be used. In hollow boosting, for safety considerations, the boost gas is introduced into a hollow pit only at the detonation time.

5.11 BINARY TRIGGER

Another planned experiment was the test of a Classical Super prototype with a binary triggering device using radiation implosion. This test was code named: George and the tested device was code-named: Cylinder.

The design of the triggering system in this test was based on the one patented by Klaus Fuchs and John von Neumann in 1946. It included an autocatalytic configuration with a DT mixture in order to trigger the thermonuclear reaction through heating and ionization compression caused by the fission device shock or blast wave.

It was crucial for the USA thermonuclear program that the George test be included in the plan for 1951 and its preparation proceeded forward.

During the period of preparation to this test, the basic principle for thermonuclear weapons construction was reached in the USA. Its main component was confinement of the x-ray radiation energy released by a primary fission charge in a hohlraum or black-body radiator and its utilization for compressing and igniting an isolated secondary core containing thermonuclear fuel.

An important point in the USA thermonuclear program was that the expediency of conducting the George test had been recognized, and it was not deleted from the 1951 plan, in spite of the negative theoretical results concerning the feasibility of the Classical Super, which were obtained in 1950. The prediction of the Classical Super failure derived from some approximate calculations by Stanislav Ulam, C. Everett and Enrico Fermi, and was in agreement with John von Neumann's calculations performed on the Eniac digital computer at the end of 1950. Computers became a major technological spinoff from the Super program.

Figure 9. Stanislav Ulam.

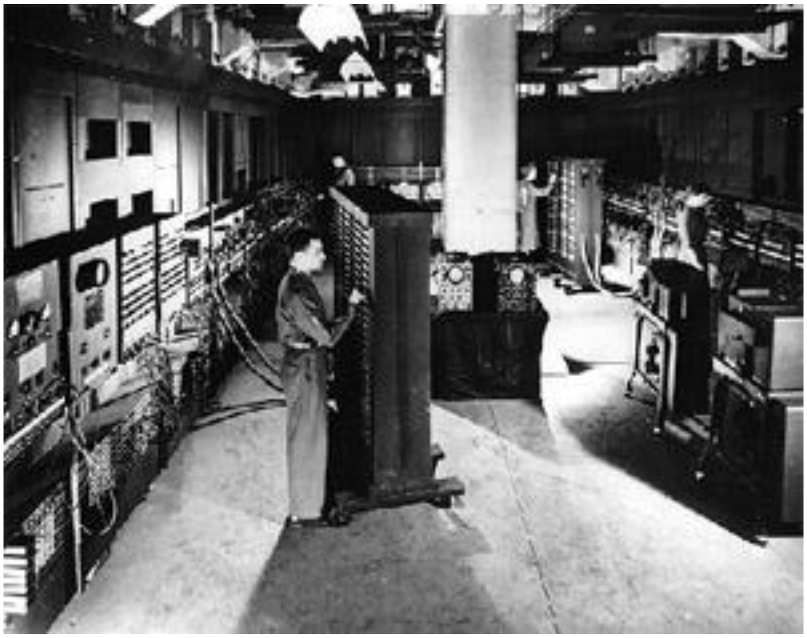

Figure 10. The Eniac computer used in the Super project computations.

5.12 HETEROCATALYTIC HYDRODYNAMIC LENSES, RADIATION MIRRORS

The new principle of heterocatalytic reactions did not directly derive from the results of work leading to the George test. Its discovery was stimulated by a brilliant new idea generated in another area of research.

Stanislav Ulam had continued his own feasibility study of a two stage fission nuclear device design, in which a second core with fissionable material was to be compressed by a first primary fission explosion and thus initiated.

In January 1951 he proposed a new approach to the thermonuclear device problem. He suggested utilizing the flow of neutrons generated in the first explosion for compression of a second isolated fusion core filled with thermonuclear fuel by means of specific hydrodynamic lenses. He showed that this configuration would lead to a strong compression of the thermonuclear fuel, which would, in turn, trigger a thermonuclear explosion. Stanislav Ulam also devised an iterative configuration of a thermonuclear device with a chain of similar fusion cores detonating sequentially.

At the end of January 1951, Stanislav Ulam presented his idea to Edward Teller, who endorsed the proposal, first with caution, then with enthusiasm, and soon suggested an alternative version, which was, in Stanislav Ulam's words, “Perhaps more convenient and general.”

Edward Teller suggested deriving energy for the shock compression of the secondary fusion core not from the *neutron* flow, but instead from the x-ray *radiation* emitted by the primary charge.

The Ulam-Teller's configuration of a thermonuclear device was, in many respects, similar to the design of the trigger in the George device. The differences were in that the thermonuclear fuel was not heated by radiation from the primary charge since the cold compression of matter yielded higher densities of the thermonuclear fuel, and that a secondary charge of a greater volume and larger mass could be used.

Bearing in mind the similarity between the new ideas and those proposed in 1946 and implemented in the George device, Edward Teller declared later that is was a miracle that the new concept of the Super device had not been proposed earlier. The conceptual breakthrough in the thermonuclear device design, however, could not come before Stalislav Ulam's ideas.

On March 9, 1951, Ulam and Teller wrote a joint report LAMS-1225: “On Heterocatalytic Detonations 1: Hydrodynamic Lenses and Radiation Mirrors.” The report set out the new concept of the thermonuclear device design. The new Super design, based on a synthesis of Stanislav Ulam's and Edward Teller's ideas; which, in turn, derived from the earlier concepts and proposals by Enrico Fermi, Konopinski, John von Neumann, and Klaus Fuchs, was named The Ulam-Teller Configuration.

On April 4, Teller issued a second report: LAMS-1230, which presented additional calculations related to the feasibility study of a new Super performed by Frederic de Hoffmann and suggested a new component, namely a triggering system using a fissionable material placed in the secondary core inside the thermonuclear fuel. Its function was to produce a triggering nuclear explosion inside the compressed thermonuclear materials and was designated as a spark plug.

5.13 THE GEORGE TEST

On May 9, 1951, the George test was performed successfully: “The largest fission explosion to date succeeded in igniting the first small thermonuclear flame ever to burn on Earth.” The test confirmed theoretical predictions about the feasibility of a non equilibrium burn of the DT mixture, which was, at least partly, outside the core made from the fissionable material of the primary nuclear charge.

The George test accomplished its main mission prior to its completion, since its explosive device was one of the main precursors of the Ulam-Teller design. The first thermonuclear explosion in the USA was its 40th nuclear test.

Figure 11. The George thermonuclear test.

5.14 ENHANCED FISSION, THE KING SHOT

In June 1951, Edward Teller and Frederic de Hoffmann wrote a report devoted to the desirability of using Li^6D in the new design. A conference took place in Princeton on June 16-17, 1951 that supported the need for the production of Li^6D.

The USA had no facilities for the large scale production of Li^6 at the time. One of the reasons for this was the realization that a U^{235} device with a TNT equivalent of several hundred kilotons could be built using an improved chemical implosion technique, and with boosting this device could be an alternative to the thermonuclear Super.

The work on such a device commenced in the USA in 1950 and ended on November 16, 1952, with the successful King shot.

Given the alternative project of a nuclear device with a yield of several hundred kilotons, it was decided in the USA that only construction of an Alarm Clock with a TNT equivalent well above one megaton made sense, although the feasibility of this project was questionable. This was a reason for a delay in the construction of a Li^6 enrichment plant.

Another reason was a vicious conflict that arose between Robert Oppenheimer who defended the idea that a device with a 100 kT of TNT yield equivalent was sufficient for all strategic and tactical purposes, whereas Edward Teller vehemently opposed Oppenheimer, accused him of treason, and advocated the construction of the multi megaton yield Super.

Edward Teller view prevailed over Robert Oppenheimer’s and the construction of the USA $_3Li^6$ enrichment plant was started only in May, 1952 at Oak Ridge, Tennessee using a mercury amalgam process, and it became fully operational in the middle of 1953.

5.15 THE ULAM-TELLER CONFIGURATION, THE MIKE TEST

It was decided at the Los Alamos National Laboratory in September 1951 to build a thermonuclear device based on the Ulam-Teller configuration for the Mike full scale test scheduled for November 1, 1952.

Liquid deuterium (D_2) was selected as a thermonuclear fuel. The all out effort in constructing the device, whose design was modified considerably in the process, made it possible to complete the task on time on November 1, 1952, when the Mike device was tested successfully.

Figure 12. The Mike Thermonuclear Test yield was 10 Mt of TNT equivalent.

The TNT yield equivalent of the explosion was about 10 Mt. The device, however, was not a deliverable weapon. The immediate task was construction of a deliverable thermonuclear warhead in the USA. The feasibility of this weapon was dependent on the accumulation of a sufficient quantity of the Li^6 isotope. The minimal required quantity was stockpiled only by the spring of 1954.

Initially produced in the Hanford reactors from lithium aluminate $LiAl_2O_3$, a heavy water moderated reactor was constructed at the Savannah River Laboratory for the production of tritium from LiAl alloy. Highly enriched U^{235} naval reactors fuel elements were used as drivers in a heavy water reactor to produce tritium in the LiAl targets.

Figure 13. The Savannah River Heavy Water Reactor for the production of tritium from highly enriched U^{235} naval reactors fuel in LiAl alloy.

5.16 LITHIUM DEUTERIDE, THE CASTLE SERIES OF TESTS

On March 1, 1954, the USA performed its first thermos-nuclear explosion in the Castle nuclear test series, namely the Bravo shot, which was the most powerful explosion in the history of USA tests.

Figure 14. The Bravo shot was the most powerful USA thermonuclear test.

The thermonuclear material in the device was lithium deuteride Li^6D with a Li^6

enrichment of 40 percent. Other tests in this series could afford only lithium deuteride with a low content of Li^6, including even natural lithium deuteride.

All the tests of the Castle series were ground-based, or on moored barges in lagoons in Pacific Ocean atolls. On May 21, 1956, the USA in the Cherokee test dropped from an aircraft its first thermonuclear device. The aim of that new series of tests performed in May-July 1956 was to achieve progress in designing new lighter and more efficient thermo nuclear prototypes for various types of warheads.

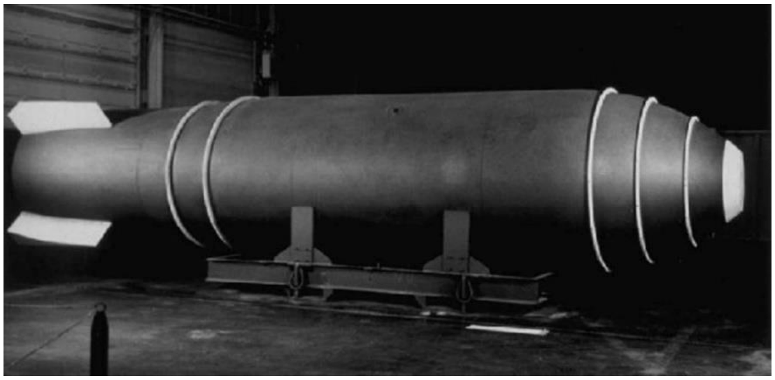

Figure 15. Mk 17, the Li^6D deliverable USA thermonuclear device had a casing 25 ft in length, 3.5 inches in thickness and weighted 21 tons.

Figure 16. Mark 17, the first air-droppable USA thermonuclear device.

5.17 NASCENT RUSSIAN INTEREST

The first Russian physicist who brought attention to the possibility of igniting the light elements was Yakov I. Frenkel. He did so in a memorandum addressed to Igor V. Khurchatov in September 1945 about the possibility of: “Using the high (billions of degrees) temperatures developed in a nuclear bomb explosion in conducting nuclear synthesis reactions (such as production of helium from hydrogen), which are the energy source of stars and could add to the energy released in the explosion of the basic fissionable materials (uranium, bismuth, and lead).”

The memo had an incorrect estimate of the temperature generated by a nuclear explosion and was wrong on the suggestion that bismuth and lead were fissile materials. However, Frenkel's proposal presented in the memorandum was the first suggestion in the then USSR to initiate the release of energy of light nuclei by a nuclear fission explosion.

Frenkel was unaware that Khurchatov had already received information about the USA research in this field. The first intelligence reports about these developments were delivered to the USSR in 1945.

In September 1945, the Russian intelligence service obtained a detailed report describing some elementary notions of the theory of the Classical Super and some characterizing features for a physical configuration for the device. The configuration was described as a combination of a U^{235} gun-type fission device with a BeO_2 tamper, an intermediate chamber containing a DT mixture, and a cylinder filled with liquid D_2.

The document described the DT reaction cross sections in the form of an approximate formula and indicated how the ignition temperature of the thermonuclear reaction could be reduced by supplementing deuterium with tritium.

There was another report where the super weapon was defined not as a thermonuclear device, but as a fission device of a higher energy release. The report stated that a first fission explosion in that device would compress a secondary Pu^{239} sphere and initiate nuclear fission in it. As a result, a higher efficiency and energy release of the device were expected, but it gave no clue as to how to implement the concept.

5.18 MARCUS OLIFANT DISCLOSURE

A disclosure by Marcus Oliphant was reported in the UK in The London Times newspaper on October 19, 1945. Speaking in Birmingham on October 18, 1945, he suggested that it was possible to manufacture a device about one hundred times more powerful than those dropped on Japan with a TNT yield equivalent of up to two megatons. He suggested that devices as powerful as one thousand times of the existing ones could be produced in the future.

The directors of the USSR nuclear project did not ignore these reports. On October 24, 1945, the issue of the superbomb was included in the list of questions given to Ya. P. Terletski| , who was sent by Lavrenti L. P. Beria to talk to Niels Bohr on his return to Denmark from the USA.

On November 14-16, 1945 Terletski had two interviews with Niels Bohr in Copenhagen. When asked whether the reports about a superbomb were true, Bohr responded: “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.”

Niels Bohr's reply did not persuade the Soviet project directors to ignore the reports about the USA studies concerning the Super.

5.19 NONEQUILIBRIUM DETONATION

Khurchatov assigned Yuli B. Khariton to consider, in cooperation with I. I.

Gurevich, Ya. B. Zeldovich, and I. Ya. Pomeranchuk, the possibility of using the energy of light nuclei and to report the findings to the Technical Council of the Special Committee chaired by Lavrenti Beria.

Their conclusions were included in a report: “Utilization of the Nuclear Energy of the Light Elements,” delivered by Zeldovich to the meeting of the Technical Council on December 17, 1945.

The suggested approach was based on the assumption of the feasibility of a nuclear detonation in a deuterium-filled cylinder in the non-equilibrium burn regime.

After Zeldovich's report, the Council adopted a resolution with a decision to measure the cross sections of reactions between light nuclei, but without any directives concerning the theoretical research and computations, or practical work on the Super.

In June 1946 a team of theoreticians at the Institute of Chemical Physics of the USSR Academy of Sciences in Moscow, including A. S. Kompaneets and S. P. Dyakov and under the direction of Zeldovich embarked on the theoretical study of the feasibility of releasing nuclear energy from light elements as part of the program on nuclear burn and detonation.

While the Zeldovich's group conducted its research, new intelligence reports were arriving to the USSR in 1946-1947 about the USA Super activities. They were supplemented with publications in the open press, including an article by Edward Teller in The Bulletin of the Atomic Scientists in February 1947.

5.20 KLAUS FUCHS AND FEKLISOV FIRST ENCOUNTER

On September 28, 1947, Klaus Fuchs, the German born British physicist, who had just returned to England from the USA, where he had worked on the Manhattan Project, had his first meeting in London with A. S. Feklisov, a Soviet intelligence officer.

Prompted by ideological incentives, Klaus Fuchs thought he would balance the USA monopoly on the Super by providing information about it to a socialist state.

Feklisov asked Fuchs ten questions, of which the first concerned the Super. According to Feklisov's report, Fuchs made a verbal statement that theoretical research directed by Edward Teller and Enrico Fermi was underway in Chicago.

Fuchs described some features of the Super structure and the principle of its operation, and mentioned the use of tritium alongside deuterium. Fuchs suggested that by the beginning of 1946, Fermi and Teller had proved that the Super was feasible.

In October 1947 an intelligence report was received in the USSR about attempts undertaken in the USA to initiate a chain reaction in a mixture of deuterium, tritium, and lithium. The report said that there were indications that Edward Teller intended to use such a reaction in a Super that would carry his name. It was the first and only intelligence report of that period mentioning lithium as a component of thermonuclear fuel. It is also possible that the latest report mentioned Teller's proposal to use Li^6D in the Alarm Clock concept. In the earlier reports of 1945 and 1947, lithium, and specifically Li^6, was only mentioned as a starting material for production of tritium in nuclear reactors.

5.21 RUSSIAN THEORETICAL STUDIES

On November 3, 1947, the results of Zeldovich's group were reported for the first time at a meeting of the Scientific Technological Committee of the First Central Administration at the Council of Ministers. The report by Dyakov, Zeldovich, and Kompaneets: "Utilization of Subatomic Energy of the Light Elements" was presented to the meeting. The authors placed their greatest hopes on non-equilibrium burn and a possibility of a detonation like ignition of the reaction by a shock front propagating through the main body of the thermonuclear fuel.

They investigated the possibility of detonation in an infinite unbounded medium of deuterium, tritium, and Li^7. The more important isotope Li^6 was not taken into account because the cross section of the DLi^6 reaction, according to the data available to them, was smaller than that of the DLi^7 reaction.

The problem was solved without taking into account the diffusion of radiation and neutrons. The authors came to the conclusion that a deuterium detonation was possible if the cross sections of secondary reactions were sufficiently large. Detonation in Li^7D was thought to be possible if the cross section of the Li^7D reaction were six times as large as the experimental value.

5.22 KLAUS FUCHS AND FEKLISOV SECOND MEETING

On March 13, 1948, Feklisov had a second meeting with Klaus Fuchs in London, during which the latter handed over information about a new theoretical study concerning the Super. It included a detailed description of the Classical Super with a triggering system different from the one designed in 1945.

The system had a two stage configuration and used radiation implosion in its operation. The primary component was a gun type U^{235} device with a BeO_2 tamper. The secondary unit contained a DT mixture with a high content of T.

In order to confine radiation within the triggering unit, it was equipped with a heavy element tamper impervious to radiation. The primary unit was joined to a long cylinder filled with liquid deuterium. In the upstream section deuterium was doped with tritium. The operation of the triggering system was described.

The disclosure included several diagrams characterizing the system operation. The experimental data included measurements of DT and DHe^3 reaction cross sections. The calculations confirmed that the detonation of the DT mixture in the second stage of the triggering system was possible. The theoretical report dispatched in 1945, lacked calculations that would confirm the possibility of ignition and propagation of the thermonuclear reaction in the main body of the thermonuclear fuel shaped like a cylinder.

The ignition of the DT mixture in the upstream section and the propagation of nuclear burn through the main body of deuterium were taken for granted, provided that the two stage trigger operated as expected. This information was consistent with that contained in the Fuchs and von Neumann patent of 1946.

5.23 ARZAMAS-16 NUCLEAR CENTER IN SAROV, RDS-6 PROJECT

On April 20, 1948 the administration of the USSR Ministry of State Security sent the Russian translation of the materials handed over by Fuchs to Russian leaders Joseph V. Stalin, V. M. Molotov, and L. P. Beria.

The Soviet political leadership interpreted the new intelligence documents on the Super and advanced designs of nuclear devices given by Klaus Fuchs as a sign that the USA had made considerable progress in the development of nuclear weapons, so they called for urgent measures to push through the feasibility studies of similar Soviet nuclear devices and decided to launch a comprehensive program officially supported by the central authorities.

On April 23, 1948, Beria ordered Boris L. Vannikov, Khurchatov, and Khariton to analyze carefully the materials and submit proposals concerning organization of studies in connection with the new intelligence.

The recommendations in connection with these materials were presented by Khariton, Vannikov, and Kurchatov on May 5, 1948, and formed the basis for the resolutions adopted by the Council of Ministers on June 10, 1948.

Theoretical and experimental feasibility studies were generated of several types of advanced configuration fission devices and a fusion device which was code-named RDS-6.

In the section concerning the fusion device, KB-11 was commissioned to perform by June 1, 1949, in cooperation with the Physical Institute (FIAN), theoretical studies of thermonuclear ignition and burn of deuterium and DT mixtures. It also mandated organization of a special group at KB-11 for studies related to the RDS-6 project.

5.24 SLOIKA, LAYER CAKE DESIGN

In June 1948 the special group of the Physical Institute, which consisted of I. E. Tamm, Semyon Z. Belenki, and A. D. Sakharov, started their research on the deuterium nuclear burn. V. L. Ginzburg and Yu. A. Romanov were enlisted in the effort. The task of the Tamm's group was formulated in the resolution so that they had to fulfill it without access to intelligence documents.

The task of the Tamm's group was defined as verification and improvement of calculations by Zeldovich's group at the Institute of Chemical Physics related to the deuterium nuclear detonation.

In analyzing the calculations by Zeldovich's group in September and October 1948, Sakharov began thinking about an alternative solution to the problem and considered the feasibility of a combined device using D_2 mixed with U^{238}. As a result of this work, he conceived, independently of Edward Teller, the concept of a heterogeneous device with alternating layers of deuterium and U^{238}, or a design similar to the USA’s Alarm Clock.

The design proposed by Sakharov was code named Sloika, which is translated as Layer Cake. The process of ionization compression, which was the underlying concept of this design, was dubbed by his colleagues as sakharization.

5.25 WATSON DAVIS ARTICLE

An article entitled: “Superbomb Is Possible” by Watson Davis appeared in Science News Letter on July 17, 1948, shortly before Sakharov's proposal. The article presented general considerations concerning the feasibility of a D_2 device, and contained a section entitled “Combined Bomb”, which began with a remark: “Because in one of the DD reactions a neutron is produced, it may prove practical to make a sort of combined D and

Pu bomb, using neutrons of the DD reaction to fission plutonium. For this reason, any competent chemist could tell you that the material of the Super might be a solid consisting of a chemical combination of plutonium and deuterium." He was implying the use of uranium or plutonium deuteride.

The design of a heterogeneous bomb was not mentioned in the article. On November 16, 1948, Tamm sent an official letter to Vavilov as director of the Physical Institute to notify him that the research by Tamm's group in the feasibility of the deuterium detonation had led to a conclusion that this material could be detonated differently in a composition of deuterium or heavy water with natural uranium.

On December 2, 1948, Vitali L. Ginzburg produced his second report G-2 on the topic investigated by Tamm's group: "Investigation of the Deuterium Detonation II." Like his first report, this one was dedicated to the feasibility of nuclear detonation in an unbounded liquid deuterium medium.

When addressing configurations that could be of practical interest, Ginzburg presented his estimates of the efficiency of a configuration including a nuclear device surrounded by a layer of deuterium as an outer shell. He remarked that liquid deuterium could be replaced in this structure by heavy water and made another important note: "Another possibility to consider is the burning of mixtures containing Li^6 (with a view to utilizing the heat released in the reaction $Li^6+n \rightarrow T+He^4+4.8$ MeV), U^{235}, Pu^{239}, etc."

Thus Ginzburg reached the idea of using Li^6D as a thermonuclear fuel. The advantage which initially attracted Ginzburg's attention was an increase in the heat energy release directly related to the neutron capture by Li^6, rather than the increase in the quantity of tritium produced by the reaction.

5.26 LAYER CAKE, SLOIKA WITH LITHIUM DEUTERIDE

Sakharov issued a first report S-2 on January 20, 1949, about the Layer Cake configuration: "Stationary detonation Wave in the Heterogeneous System of $Uranium^{238}$ and Heavy Water," at the Russian Research Centre or Kurchatov Institute.

In Russian, the name "Sloika" is a pun on Sakharov's name meaning caramelization, since "sakhar" is the Russian word for "sugar."

Another report was issued: "Layer Cake design and calculations of stationary detonation wave parameters in a Layer Cake unbounded in all dimensions with planar layers." It took into account the secondary reactions with tritium. Sakharov assumed that the cross section for the DT reaction was equal to that of the DD reaction in one of its two proton and neutron branches. The DT and TT reactions had not been studied experimentally. He suggested that the investigation of a stationary detonation wave in the layer cake was a prerequisite to solving the problem of igniting the thermonuclear reaction in it.

The simplest configuration studied theoretically was that of a fission device placed at the center of a large virtually infinite spherically symmetrical Layer Cake. Other configurations that were more efficient in terms of the required quantity of plutonium were suggested. Among these configurations was the utilization of an additional plutonium charge for the preliminary compression of the Layer Cake which was the concept of a two stage thermonuclear device.

In the spring of 1954, Zeldovich and Sakharov realized the possibility of compressing a thermonuclear device of the Layer Cake type by radiation generated in a primary fission device.

On March 3, 1949, Ginzburg issued a report: “Utilization of Li^6D in the Layer Cake.” In considering the efficiency of Li^6D utilization, he took into account the generation of tritium due to the neutron capture by Li^6 and of the fast fission of U^{238} by the energetic DT 14.06 MeV neutrons.

The cross sections for the DT reaction were published in Physical Review in the USA on April 15, 1949. The General Advisory Committee to the USA Atomic Energy Commission, chaired by J. Robert Oppenheimer, recommended in October 1947 the declassification of the nuclear properties of tritium.

With the DT cross section available to him, Ginzburg reconsidered his estimates of the efficiency of Li^6D in the Layer Cake, and presented his new calculations on August 23, 1949, in a report: “Detonation wave in the Li^6D system.” The cross sections for the DT reaction were two orders of magnitude larger that in the DD reaction. The advantage of the Layer Cake design with Li^6D became substantial.

On April 11, 1949, S. I. Vavilov, director of the Physical Institute, informed Beria about Sakharov's proposal during his work in Tamm's group. On May 8, 1949, Khariton sent to Boris L. Vannikov a document supporting the concept of the Layer Cake: “The underlying idea of the proposal is very ingenious and easily understandable from the physical viewpoint.”

The Special Committee organized several conferences with the participation of Vannikov on June 4-9 1949 at Arzamas-16. On orders from Beria, Sakharov was sent on his first visit to KB-11 to participate in the conferences. Information was given to Sakharov about the design of the RDS-1 device, the analog of the USA Pu^{239} implosion Fat Man device, which was under preparation for the first Soviet nuclear test.

The Tamm's group redirected the main thrust of their effort to the spherical layered structure compressed by a chemical explosive.

5.27 TUBE DESIGN ANALOG OF CLASSICAL SUPER

The plan of research and development of the RDS-6 project for 1949-1950 was signed by Kurchatov, Zeldovich, Khariton, Sakharov and included investigations of both the Layer Cake and the Tube design.

The Tube design was the code name of the Soviet analog for the USA Classical Super. It included “Triggering of a cylindrical deuterium charge by a gun bomb explosion or an auxiliary charge containing tritium.” This suggests that at the time of the conference Sakharov had some information about the concept and configuration of the Classical Super from the intelligence reports of 1945 and 1948.

By mid 1949, Sakharov's scientific interests in the field of the hydrogen bomb were devoted to the realization of the Layer Cake concept.

Beria refrained from any administrative decision about the fusion RD-6 until President Truman in the USA set out his directive about the continuation of the work on the Super on January 31, 1950. The directive was in turn issued after the first USSR fission test called: “First Lightning.”

Figure 17. Replica of RDS6s, with the designation s standing for Sloika or layer cake Russian thermonuclear design.

Four days after President Truman's directive, the topic of RDS-6 was on the agenda of the meeting of the Special Committee. The First Central Administration of the Council of Ministers, Laboratory No. 2 of the USSR Academy of Sciences, and KB-11 were directed to organize theoretical, computational, experimental, and design oriented works materials handed over by Fuchs to J. V. Stalin, V. M. Molotov, and L. P. Beria. The Soviet political leadership interpreted the new intelligence documents on the superbomb and advanced designs of nuclear devices, which were also given by Fuchs, as a sign that the USA had made considerable progress in the development of nuclear weapons, so they called for urgent measures to push through the feasibility studies of similar Soviet nuclear weapons and decided to launch a comprehensive program officially supported by the central authorities.

Sakharov considered the feasibility of a combined device using deuterium mixed with U^{235}. As a result of this work, he conceived, independently of Teller, the concept of a heterogeneous bomb with alternating layers of deuterium and U^{235} which would be a design similar to the USA Alarm Clock. The design proposed by Sakharov was code named Sloika, which can be translated as Layer Cake.

The process of ionization compression, which was the underlying concept of this design, was dubbed by his colleagues as sakharization.

Theoretical, computational, experimental, and design oriented efforts were initiated and aimed at the construction of the RDS-6s, Sloika, or Layer Cake, and RDS-6t, Truba, or Tube devices.

A higher priority was attached to RDS-6s, whose TNT equivalent was designed to be one megaton and total weight within 5 metric tonnes. Tritium was used in both RDS-6t and RDS-6s. The target date for the construction of the first RDS-6s device with a small amount of tritium was set to be 1954. Khariton was appointed scientific director of the RDS-6s and RDS-6t projects with Tamm and Zeldovich as his deputies.

On the same day the Council of Ministers adopted resolutions on both tritium and Li^6 production with the construction of a dedicated reactor facility for the production of tritium.

5.28 RDS-7 DISCONTINUED EFFORT

The construction of a nuclear device with a TNT equivalent of several hundred kilotons using an advanced chemical implosion technique, probably communicated by Fuchs, was proposed. Calculations demonstrating that the proposed technique could result in the construction of a bomb with a power 50-100 times that of RDS-1. Although the amount of fissionable materials needed for this bomb was considerably larger, it seemed fully competitive with RDS-6s.

This design was later assigned the code-name RDS-7, and its development continued for several years to be completed in the first half of 1953, but, unlike its American counterpart, which was completed with the full scale test in 1952, RDS-7 was never tested.

The Scientific and Technical Council decided at that meeting that the high power nuclear fission device was a poor substitute for RDS-6s and RDS-6t because the latter two projects, in addition to the highly powerful bombs, solved the problem of how to utilize the nuclear energy of the light elements and to generate virtually unlimited energy releases.

This decision and the above mentioned resolution of February 26, 1950, paved the way for the Layer Cake with a TNT equivalent in the high kiloton range. This decision was prophetic since it laid the groundwork for a more efficient two stage thermo nuclear device and allowed the Soviet team to gain time in their race with the USA.

By December 17, 1950, Khariton had written a report: “Brief Report on the Status of RDS-6 devices.” He asserted that the work in the Layer Cake was proceeding satisfactorily. Referring to the Tube, he wrote that the problem of ignition conditions of a DT mixture with a high content of tritium confined in a heavy shell around a gun type bomb had been thoroughly investigated. The result was positive. The mixture should burn out rapidly and generate an intense flow of neutrons, which could trigger, possibly with an additional stage as a volume containing deuterium lightly doped with tritium the main deuterium charge, if thermonuclear reactions could propagate through this medium.

The idea of using an intermediate charge containing a DT mixture with a high content of tritium had been endorsed by the designers of the Tube. It was assumed, however, that the intermediate DT charge could be easily heated and compressed; thereby a thermonuclear reaction could be ignited by shock energy. Therefore the basic design selected for this structure contained a gun-type nuclear device with a heavy outer shell impervious to radiation.

Fuchs's design with a light shell of BeO_2 tamper easily penetrated by radiation was considered too complicated and was placed on the back burner. No computations concerning its feasibility had been performed. The USA researchers, on the other hand, launched intense research on this configuration and based on it the design of the new Cylinder device for the George test.

The delay in the discovery of the Soviet counterpart of the Teller-Ulam configuration was offset by the development of the Layer Cake.

While work on the RDS-6s prototype continued, the USA tested on November 1, 1952, the Mike high yield thermonuclear device. In reaction to this test, on December 2, 1952, Beria sent a memo to the First Central Administration and Kurchatov, stating: “To I. V. Kurchatov: The solution to the problem of the construction of RDS-6s is of paramount importance. Judging by some information obtained from the USA, experiments with devices of this type had been conducted. When you and A. P. Zavenyagin go to KB-11, tell Yu. B. Khariton, K. I. Shchelkin, N. L. Dukhov, I. E. Tamm, A. D. Sakharov, Ya. B. Zeldovich, E. I. Zababakhin, and N. N. Bogolubov that no effort should be spared to success: fully complete research and development on RDS-6s. You will also convey this message to L. D. Landau and A. N. Tikhonov." This lists the names of most of the scientific group involved in the project.

5.29 TWO STAGE RDS-6s SLOIKA LAYER CAKE TEST

On June 15, 1953, Tamm, Sakharov, and Zeldovich finalized the development work on the RDS-6s prototype. The TNT equivalent of the device was estimated to be 300-400 kT of TNT equivalent. It was tested on August 12, 1953.

Figure 18. RDS-6s, Sloika, Layer Cake test yield was 400 kT of TNT equivalent.

This was the fourth Soviet test in a series of tests that started on August 29, 1949. The test of the RDS-6s charge was an event of unprecedented significance in the history of the USSR's nuclear program and a very important step in the construction of Soviet thermonuclear weapons.

The measured energy release from the RDS-6s explosion was 400 kT of TNT equivalent and corresponded to the upper limit of the estimated range. The RDS-6s charge was manufactured in the form of a deliverable weapon.

The RDS-6s design was adapted to large scale industrial production. The main result of the work on RDS-6s was the accumulated experience in both science and technology that would guarantee rapid progress in the development of Soviet thermonuclear weapons. This experience was efficiently used in developing a considerably advanced design of a two stage thermonuclear bomb, and this essentially accelerated its production.

The path to the two stage thermonuclear charge was a thorny one. Although the idea of the preliminary compression of the Layer Cake by an auxiliary nuclear explosion was proposed by Sakharov as early as 1949, the main difficulty in designing the two-stage device was to find a straightforward way to implement this concept. This fundamental difficulty was further exacerbated by one event that had an impact on further progress.

5.30 FUTILE RDS-6sD EFFORT

A version of a single-stage thermonuclear device was presented by Sakharov after the successful RDS-6s test. He pinned his hopes on certain exotic features of the design. It was soon realized that this powerful version of RDS-6s, which was code-named RDS-6sD, showed little promise. It included an attempt to increase the RDS-6s yield by compressing layers of thermonuclear materials and uranium using chemical explosives. This effort was futile but led to intensification of the search for the way to implement the two stage thermonuclear charge.

Research in this field was started back in 1952, before the Mike test in the USA. The plan of the theoretical sector directed by Zeldovich for the year 1953, included the “Feasibility Study of Compression of the High-Yield RDS-6s Gadget Using a Conventional RDS (Nuclear Compression).”

In 1953 A. P. Zavenyagin and D. A. Frank-Kamenetski| suggested an original design of two stage thermonuclear charges using the material component of energy generated by a primary nuclear explosion.

An important event which shifted the focus of all scientists to the two-stage version was the decision to abandon all research on the Tube. The decisive contribution to the final stage of research proving the impossibility of nuclear detonation in the Tube was made by groups directed by Zeldovich and Pomeranchuk.

5.31 RDS-37 TWO STAGE DESIGN

On January 14, 1954 Zeldovich and Sakharov sent Khariton a memo “Concerning Utilization of the Gadget for Implosion of the RDS-6s Supergadget,” which described the design and contained estimates of operating parameters of a two-stage thermonuclear charge.

The thermonuclear charge, whose diagram was given in the memorandum, was composed of two units, namely the primary fission device and the secondary thermonuclear charge encased in a massive shell.

The memorandum suggested that the charge should be compressed by pressure produced by gases due to the primary explosion of the primary charge flowing to the zone of the thermonuclear charge. The physical processes during the explosion were described as follows: “The first cycle, i.e., propagation of energy from gadget A (The fission primary) has not been considered. At the beginning of this cycle, more than half of the energy is in the form of radiation, and it is transferred by the radiational heat conductance mechanism. By the end of this cycle, however, a shock is generated with a velocity which exceeds that of the radiation diffusion.”

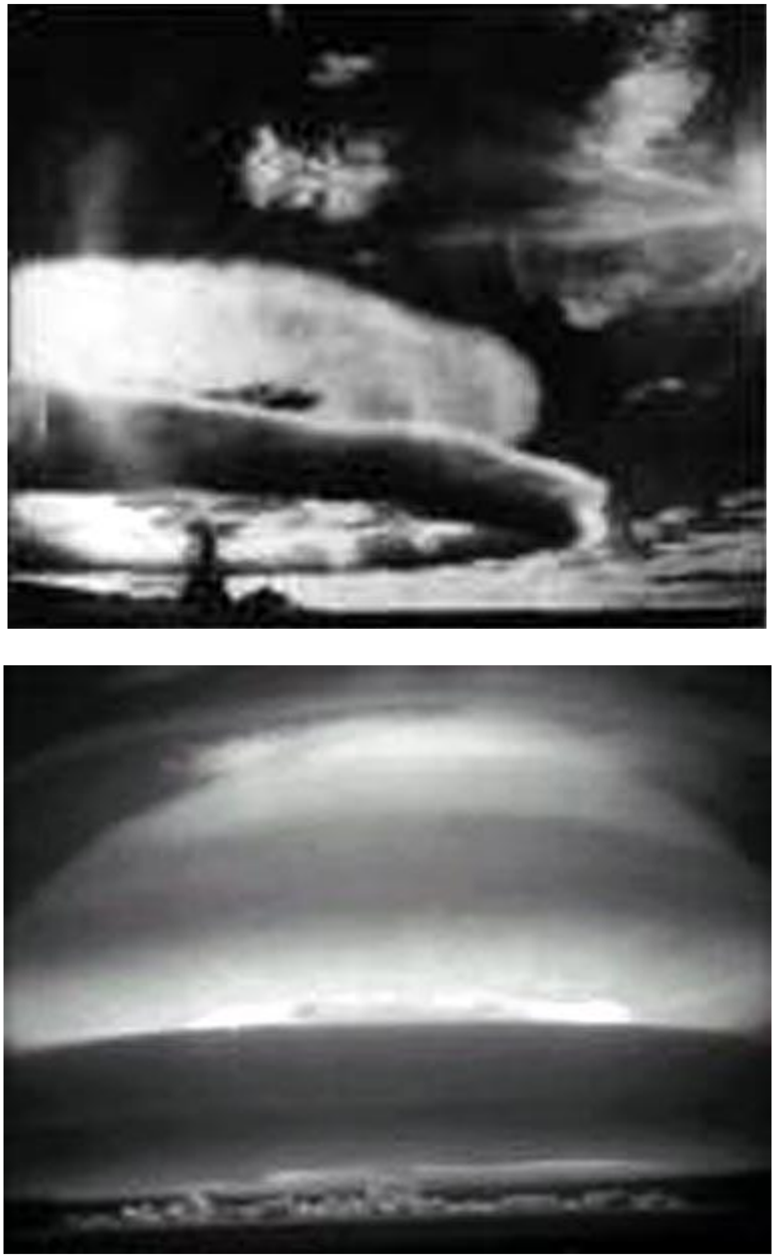

Figure 19. RDS-37 test explosion.

5.32 NUCLEAR COMPRESSION CONCEPT

The memo lacked in the understanding that it was possible to conduct radiation out of the primary for compression of the secondary thermonuclear unit. The memo acknowledged that “The utilization of Nuclear Compression was suggested by V. A. Davidenko." Davidenko's contribution to the nuclear compression concept was primarily in insistently attracting theorists' attention to the two-stage configuration of the nuclear charge.

Although the configuration proposed in the memo by Zeldovich and Sakharov was simple, its feasibility was questionable. However tempting the concept of the two stage thermonuclear charge might be, understanding the great difficulties in its implementation using this and similar approaches drained theorists of any optimism or enthusiasm.

Information about the new powerful explosion conducted by the USA team on March 1, 1954, renewed the drive of Soviet researchers to invent an efficient design of a high yield thermonuclear device. The latest test demonstrated considerable progress in the USA nuclear weapons program and indicated that it had entered a new phase. It finally became clear that there was an efficient design technique, which had been invented by the American team. The ultimate configuration could be neither the Tube, which had been abandoned by that time, nor the one stage configuration like RDS-6s. The only configuration left was a two stage device.

5.33 RADIATION IMPLOSION CONCEPT

After a lot of intense thinking and analysis of all the available information and accumulated experience, the Soviet team achieved their goal. A new mechanism for compression of the secondary thermonuclear core by radiation from the primary nuclear charge was formulated.

This happened in March and April 1954. The emergence of the new principle was acclaimed by the workers at KB-11 as a sensation. It suddenly became clear how bright the prospects were for constructing new thermonuclear devices. Not only construction of highly efficient thermonuclear charges had become feasible, but also bright horizons for new research in a branch of modern physics of utmost interest, namely the physics of high pressures and high temperatures.

The basic configuration in the further investigation was similar to that described earlier by Zeldovich and Sakharov in their memo, but the alternative mechanism of energy transfer between the primary and secondary units, namely propagation of radiation, was taken into account.

In order to confirm the feasibility of the secondary thermonuclear unit compressed by radiation implosion, several intricate problems related to physical processes in interaction between radiation and matter had to be solved.

At this point Sakharov made an important contribution by finding self-similar solutions to the underlying partial differential equations. These solutions yielded estimates which confirmed the possibility of constructing an efficient device. The work on the fundamentally new design, which was a counterpart of the Ulam-Teller configuration, proceeded at KB-11 so fast that no documents or scientific papers of a priority nature were produced.

A report on August 6, 1954, by Sakharov and Romanov, contained the following passage in the section Nuclear Compression:

“Theoretical research of Nuclear Compression (NC) is conducted in cooperation with

sector No 2. Investigation of the main issues of nuclear compression is under way.
1. Output of radiation from the nuclear bomb for compressing the main body. The calculations have demonstrated that at (deleted) radiation is emitted quite strongly...
2. Conversion of radiation energy to mechanical energy for compressing the main body. It was suggested (deleted). These principles are results of the joint effort by sectors No 2 and No 1 (Ya. B. Zel'dovich, Yu. A. Trutnev, A. D. Sakharov)..."

By February 3, 1955, technical documents concerning the design of the experimental charge code named RDS-37 were completed. At that time the crucial theoretical calculations confirming its feasibility were also ready.

5.34 RDS-27 DEVICE TEST

On November 6, 1955, a single stage RDS-27 thermonuclear charge was tested. It was a modification of the RDS-6s Sloika device tested on August 12, 1953. The main difference between RDS-6s and RDS-27 was the absence of tritium in the latter, which enhanced the operational parameters of the charge, but reduced the TNT yield equivalent within the calculated limits. The charge was fabricated in the form of an air deliverable device and dropped from an aircraft during the test.

5.35 RDS-37 TEST

On November 22, 1955 the two-stage RDS-37 thermonuclear charge was successfully tested. It was constructed as an air-deliverable device dropped from an aircraft. It was so large that it could not be fitted to a missile.

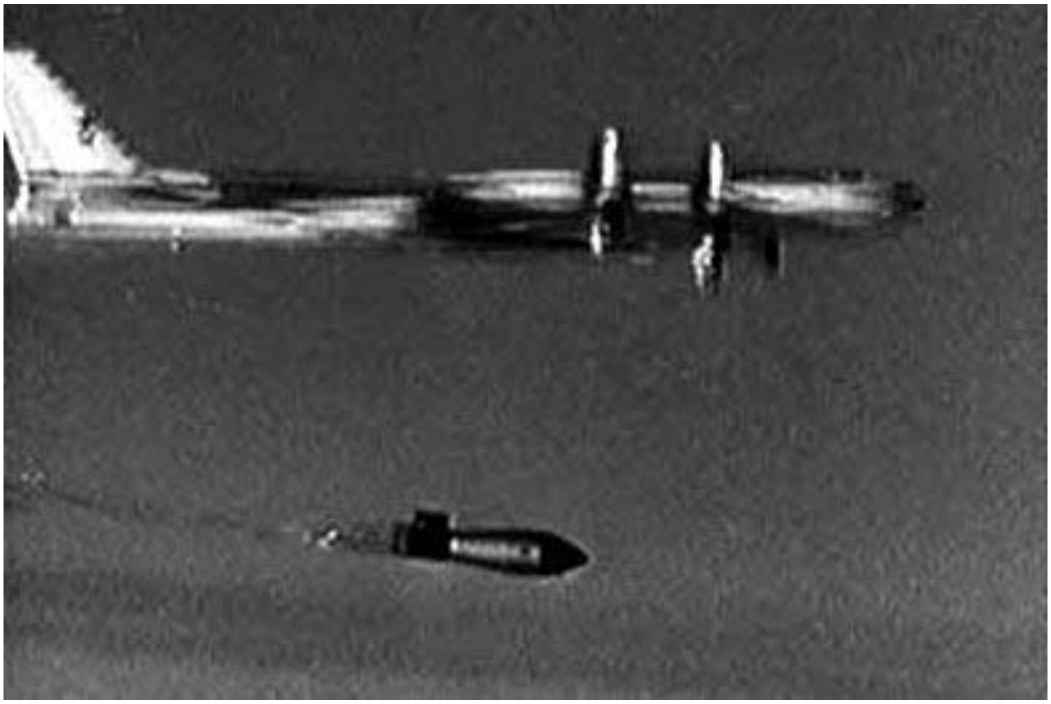

Figure21. Russian air drop of 50 Mt TNT equivalent RDS-37 device. A Tupolev Tu-95 Bear bomber was used.

The RDS-37 design was distinguished not by the new technical solutions derived from the physical principle implemented in its design, and by its genetic relationship to the RDS-6s design of 1953, specifically the use of the Li^6D powder.

Tritium was not contained in the RDS-37 device. In order to increase the probability of triggering the charge at the nominal operational parameters, its design had special features. One of the properties of the tested RDS-37 charge was its deliberately diminished power in view of limiting the risk to the local population. The TNT yield equivalent of the charge was reduced from 100 Mt to 57 Mt by replacing a fraction of the Li^6D in the thermonuclear section with a passive material and possibly the U^{238} in the third stage by lead.

As a result, the energy of the explosion was approximately half of the initial calculated value. Even in this limited yield version, RDS-37 was a charge in the megaton range. The measured TNT equivalent of RDS-37 was slightly higher than the expected value, but in good agreement with preliminary calculations with a difference of about 10 percent.

The successful test of the first two stage thermonuclear charge was a milestone and an epochal event in the Soviet nuclear program. Modifications of RDS-37 with some materials replaced by others, more suitable for large scale production, were tested. Measures were taken to additionally reduce the TNT yield equivalent.

The first physical experiment had been performed in 1956, that is, a charge was exploded not for the purpose of testing a new version of a nuclear weapon, but rather of measuring parameters of materials under conditions of a thermonuclear explosion. First experiments had been performed with the aim to design lighter and more efficient versions of nuclear weapons.

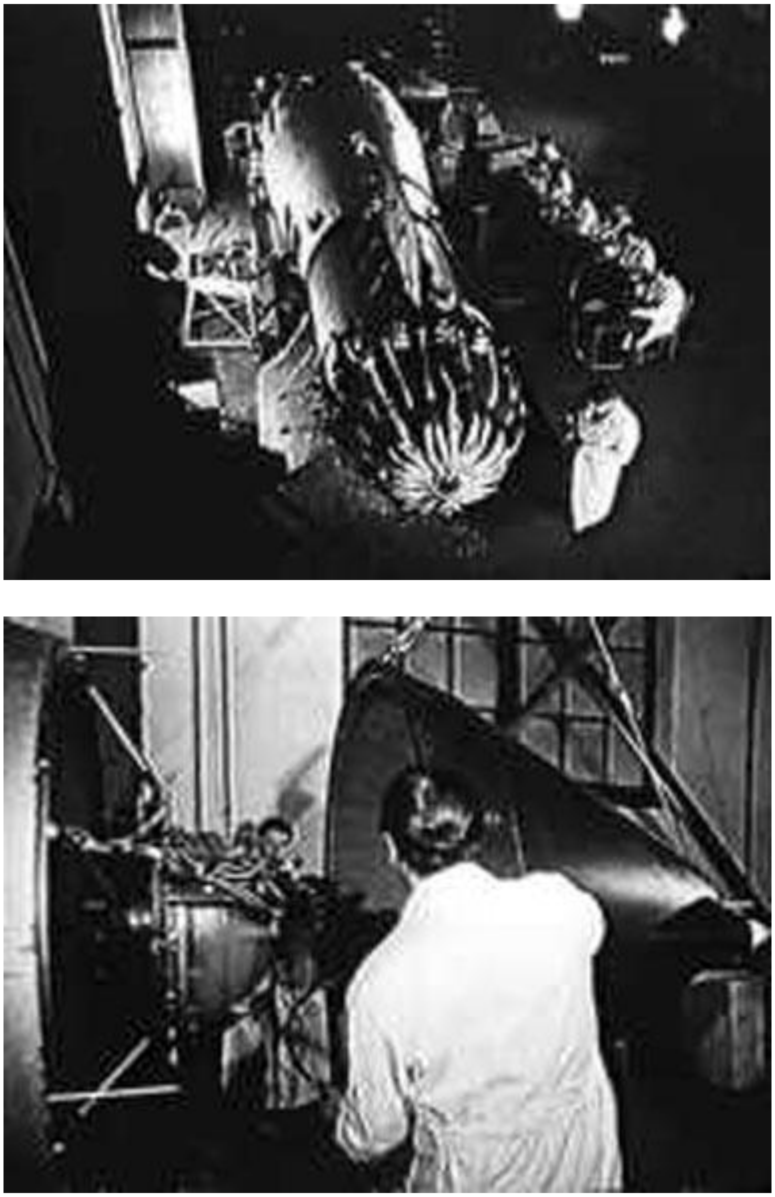

Figure 22. Assembly of the 100 Mt of TNT equivalent Russian device, Tsar Bomba. Its yield was intentionally reduced to 57 Mt by reducing the fusion charge and possibly using a lead damper instead of U^{238} in the third stage.

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Figure 23. Museum replica of Novaya Zemlya 100 Mt of TNT equivalent half yield device, tested on November 31, 1961.

THE TSAR BOMBA 57 Mt TNT EQUIVALENT TEST

On the morning of October 30, 1961, a Soviet four-engines Tupolev Tu-95 Bear bomber took off from the Olenya airfield in the Kola Peninsula in the far north of Russia. After the August 29, 1949, first nuclear device test Joe-1 on the remote steppes of Kazakhstan, the Russians detonated more than 80 devices; in 1958 alone, they tested 36 devices.

The Tu-95 carried the device underneath its belly, as it was too large to fit inside the aircraft’s internal bomb-bay. The bomb was 8 m long or 26 ft, had a diameter of nearly 2.6 m or 7 ft and weighed 27 metric tonnes. The bomb had been known by several designations: Project 27000, Product Code 202, RDS-220, and Kuzinka Mat or Kuzka’s Mother and the Tsar Bomba detonated at the the remote archipelago of Novaya Zemlya on the Barents Sea.

The Tupolev 95 pilot, Major Andrei Durnovtsev, brought the aircraft to Mityushikha Bay, a Soviet testing range, at a height of about 34,000 ft or 10 km. A smaller, modified Tu-16 bomber flew beside to film the blast and monitor air samples. To ensure the survival of the two planes, theTsar Bomba was deployed by a parachute weighing nearly one metric tonne. The bomb drifted down to 13,000 ft or 3,940 m before detonation. The two bombers were then 50 km or 30 miles away.

The Tsar Bomba detonated at 11:32, Moscow time. It created a fireball five miles in diameter. The flash could be seen from 1,000 km or 630 miles away. The mushroom cloud soared to 64 km or 40 miles high, its cap spreading stretched 100 km or 63 miles.

In the village of Severny, 55 km or 34 miles from Ground Zero, all houses were completely destroyed. Hundreds of miles from the blast zone, houses collapsed, roofs fell down, damage to doors, and windows shattering. Radio communications were disrupted for more than an hour. The blast wave from the Tsar Bomba caused the Yu-95 bomber to plummet more than 1,000 m or 3,300 ft.

A cameraman described the event:

> “The clouds beneath the aircraft and in the distance were lit up by the powerful flash. The sea of light spread under the hatch and even clouds began to glow and became transparent. At that moment, our aircraft emerged from between two cloud layers and down below in the gap a huge bright orange ball was emerging. The ball was powerful and arrogant like Jupiter. Slowly and silently it crept upwards... Having broken through the thick layer of clouds it kept growing. It seemed to suck the whole Earth into it. The spectacle was fantastic, unreal, supernatural.”

The energy release of 57 megatons is more than 1,500 times that of the Hiroshima and Nagasaki bombs, and 10 times more powerful than all the munitions expended during World War II. The bomb’s blast wave circled the Ear three times. The fireball did not made contact with the ground and there was a low amount of fallout.

The USA had a spy plane monitor the blast with an optical device called a bhangmeter. The spy plane code-named Speedlight was used by the Foreign Weapons Evaluation Panel. It is hard to find a use for such a device other than the destruction of very large cities. These devices were designed to be able to destroy a target even if it were a few miles off. Increased missiles accuracy and multiple warheads negated such a need.

The concern over the test which was 20 percent of the size of every atmospheric test combined before it, hastened the end of atmospheric testing in 1963 by the Partial Test Ban Treaty. The amount of radioactive carbon^{14} that was being emitted into the atmosphere was a major concern. This was diluted by the CO_2 produced by hydrocarbon fuels.

5.36 DISCUSSION

The final outcome of the race between the USA and the Soviet Union was that by 1955 the Soviet program had caught up with the USA. The USSR was the first to use Li^6D as thermonuclear fuel in 1953, in a single stage thermonuclear charge. It used it later in 1955 in a two stage device.

In comparison, the USA had earlier tested in 1952 a two stage thermonuclear device with liquid deuterium and in 1954 two stage thermonuclear charges with Li^6D with a relatively small enrichment of Li^6. Lithium deuteride with a high enrichment of Li^6 has been used in the USA by 1956.

Figure 24. Nuclear weapons staging bunkers or igloos.

Figure 25. Gravel gerties used for the assembly and disassembly of weapons cores.

For the USSR program in 1953 the calculated and experimental tests energy releases were in agreement to within about 30 percent, and in 1955 the discrepancy was about 10 percent. The calculations and measurements of USA thermonuclear explosions differed by a factor of two or more. This was due to the utilization of LiD with a high content of Li^7, which produces tritium, causes a neutron multiplication but is associated with a loss of energy through the endothermic (n, n') reaction:

$$_0n^1 + {}_3Li^7 + \rightarrow {}_0n^1 + {}_2He^4 + {}_1T^3$$

In the two 1955 tests, the USSR tested air deliverable thermonuclear devices. The first thermonuclear test in which the device was dropped from an aircraft was conducted in the USA in 1956.

With intelligence information about the USA thermonuclear research in 1945-1946 and discovering some key concepts independently such as the Layer Cake configuration, the use of Li^6D, and the feasibility of an alternative fission device free of thermonuclear materials with a TNT equivalent of several hundred kilotons, the USSR had a collection of ideas about equal to that of the USA, supplemented with help from their intelligence sources.

Ironically, publications in the open literature and press, including disclosures by Edward Teller himself, created the impetus and paved the way for the Russian program. President Truman's statement of January 31, 1950, about his directive to continue the USA program on thermonuclear weapons played a role in initiating a serious thermonuclear program. This directive was a response to the first USSR nuclear test.

The development of the Soviet two stage thermonuclear charge was an addition to the first idea of the layer cake, the second idea of use of Li^6D and the third idea of compression and initiation of the thermonuclear charge by radiation from the primary fission charge. It allowed it to reach parity in the sophisticated thermonuclear armaments and subsequent progress in designing more advanced versions of thermonuclear devices.

The USA Ulam-Teller configuration and its USSR analog unleashed a potential for further improvements in nuclear weapons designs and turned the competition between the USA and USSR nuclear researchers into an unlimited nuclear arms race under the doctrine of Mutually Assured Destruction (MAD) during the period of the Cold War.

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