

(1) THE AMERICAN EFFORT

It took a decade for scientists in America to develop the first ideas for a 'Super' bomb into a device that ignited 'the first small thermonuclear flame ever to burn on Earth.'

The history of thermonuclear research traces its roots back to the year 1941. In a lecture delivered in May 1941, Tokutaro Hagiwara, a physicist at the University of Kyoto, postulated that a thermonuclear fusion reaction between hydrogen atoms could be triggered by the explosive fission chain reaction of uranium-235. In September 1941, Enrico Fermi at Columbia University proposed a similar idea to Edward Teller. Discussions between Fermi and Teller ultimately suggested the feasibility of using an atomic explosion to initiate thermonuclear reactions in a deuterium medium. The conversations with Fermi sparked in Teller a decade-long messianic obsession with the notion of building a thermonuclear superbomb.

In the summer of 1942 a team of brilliant American and European scientists, having assembled in Berkeley, California, to discuss plans for Los Alamos Laboratory, broached the subject of a deuterium superbomb. On that occasion, Teller set forth the first considerations that would become the basis of the "classical Super" project. Through the wartime efforts of Los Alamos scientists, by the end of 1945 the classical Super concept had become a cohesive reality. The concept was based on the idea

that a stream of neutrons emitted from a gun-type ^{235}U atomic bomb could initiate a nuclear detonation in a long cylinder of liquid deuterium (by way of an intermediate chamber containing a deuterium-tritium mixture). The idea of adding tritium to deuterium to lower the ignition temperature dates from 1942 and is credited to Emil Konopinski. It was based on unpublished, then-secret data on D-T reaction cross sections, which indicate that in the essential temperature range, the D-T reaction rate is about one hundred times the D-D rate in one of its channels. The practicability of the classical Super relied on the hope that nonequilibrium combustion could be achieved in a D-T mixture and in pure D.

Radiation implosion

Another concept of the utmost importance probably also evolved from an idea conceived in 1942. In that year, Teller suggested an autocatalytic atomic (fission) bomb design: a bomb with a boron-10 neutron absorber inside the active fissionable material. During a nuclear explosion the ^{10}B would become highly compressed when a pressure difference was created by the ionization of sub-



EMILIO SEGRE VISUAL ARCHIVES

EDWARD TELLER (LEFT) AND ENRICO FERMI in Chicago in 1951. US ideas for a thermonuclear bomb (the "Super") originated with discussions between these two in late 1941.



EMIL KONOPINSKI is credited with first suggesting, in 1942, that the ignition temperature for a deuterium-tritium mixture would be lower than that of pure deuterium.

stances having different numbers of electrons per atom. When the ^{10}B was compressed, its absorption of neutrons would diminish, increasing the bomb's criticality and boosting its energy release. This discovery could be called the ionization implosion principle.

In 1944, John von Neumann proposed that the ^{10}B in Teller's autocatalytic system be replaced by a D-T mixture. He assumed that thermonuclear ignition of the D-T mixture should occur as a result of heating and ionization compression in an atomic explosion. The D-T reaction would release fast neutrons, thereby increasing the number of fissions in the atomic bomb. Von Neumann's proposal was an important step toward the creation of a thermonuclear-boosted atomic bomb.

At Los Alamos in the spring of 1946, Klaus Fuchs was looking at the possibility of using a gun-type primary atomic bomb boosted by von Neumann's scheme to improve the initiation conditions of the classical Super. He had the idea of transferring the D-T mixture out of the ^{235}U into a radiation-heated beryllium oxide tamper. He calculated that under such conditions the D-T mixture would still be subjected to heating and ionization implosion, thereby establishing conditions for its thermonuclear ignition. To confine the radiation within the tamper volume, Fuchs suggested enclosing the system in a radiation-impermeable casing. Since the ionization compression of the D-T mixture is caused by radiation traveling from the

active zone of the atomic charge to the externally situated thermonuclear fuel containment zone, it constitutes a radiation implosion. So in spring 1946 the principle of radiation implosion was born. On 28 May 1946, Fuchs and von Neumann jointly filed a patent application for the invention of a new scheme for the initiator of the classical Super using radiation implosion.

Fuchs's design, the first physical scheme to use the radiation implosion principle, was a prototype for the future Teller-Ulam configuration. Fuchs's proposal, truly remarkable in the wealth of ideas that it embodied, was far ahead of its time. Indeed, mathematical modeling of the physical processes involved was not yet advanced enough to further develop Fuchs's idea. It would take another five years in the US for the enormous conceptual potential of the proposal to be fully substantiated.

Fuchs left Los Alamos on 15 June 1946.

Alarm Clock

At the end of August 1946, Teller issued a report proposing a new thermonuclear bomb configuration, an alternative to the classical Super that he called the Alarm Clock. This design consisted of alternating spherical layers of fissionable materials and thermonuclear fuel (D, T and possibly their chemical compounds). This system had quite a few potential advantages. Fast neutrons generated in thermonuclear reactions in the thermonuclear fuel layers would trigger fissions in the adjacent fissionable layers, significantly boosting the energy release. The ionization compression of the thermonuclear fuel would sharply increase the thermonuclear reaction rate. The proposed construction obviated the need for nonequilibrium thermonuclear combustion, but it did require a very powerful atomic initiator to trigger it. In fact, the Alarm Clock was expected to need a megaton or even multimegaton energy release. The large size and weight of the design made it difficult to achieve (or in practice ruled out) compression by chemical explosives. Beginning in September 1946, theoretical investigations of the classical Super and Alarm Clock projects were conducted in parallel at Los Alamos.

A year later, in September 1947, Teller issued a report proposing a new thermonuclear fuel for the Alarm Clock: lithium-6 deuteride. The ^6Li was supposed to greatly enhance the production of T during explosion and thereby substantially increase the thermonuclear combustion efficiency. At that time, however, the Alarm Clock project did not appear to hold much promise. The pace of subsequent work on the Alarm Clock slowed in the light of almost insurmountable initiation problems, but theoretical studies continued at Los Alamos in conjunction with work on the classical Super.

Teller-Ulam

On 31 January 1950, a few months after the first Soviet atomic bomb test, the US President, Harry Truman, issued a proclamation directing the Atomic Energy Commission to "continue its work on all forms of atomic weapons, including the so-called hydrogen or superbomb." Truman's public proclamation gave new impetus to hydrogen bomb feasibility studies in the US. The decision was made to

conduct test-site explosion experiments involving thermonuclear reactions in 1951. One such experiment was the testing of a boosted atomic bomb code-named Item.

Another planned experiment was the testing of a classical Super model with a binary initiator operating on the radiation implosion principle. This test was code-named George, and the tested device was called the Cylinder. The initiator in this test was based on the design patented by Fuchs and von Neumann in 1946. The inclusion of the George shot in the 1951 test plan and the preparations for it played an extremely important role in the American thermonuclear program. The fundamental principle of thermonuclear weapons construction was revealed during the preparations for the George shot, its most important conceptual constituent being the confinement and utilization of radiant energy from a primary atomic bomb to compress and ignite a secondary, physically isolated core containing the thermonuclear fuel.

A pivotal point in the American thermonuclear program was the retention of this test in the 1951 test plan, despite the negative results obtained in 1950 from theoretical studies of classical Super performance. The conclusion that the classical Super was a failure was inferred from approximate calculations performed in 1950 by Stanislaw M. Ulam, Cornelius Everett and Fermi and corroborated at the end of 1950 by von Neumann's computations on the ENIAC digital computer.

However, the discovery of the new principle was not solely a consequence of the work done preparing for the George shot. A powerful conceptual impetus also came from another line of investigation: Ulam's discovery in January 1951 of a new approach to building a thermonuclear bomb. The idea was born from the inquiry into the possibility of constructing a two-stage atomic bomb, in which an initial atomic explosion would cause a secondary sphere of fissionable material to implode and detonate. He conceived the idea of using a stream of neutrons generated in the explosion of a primary atomic bomb to compress, by means of special hydrodynamic lenses, a secondary, physically isolated fusion core containing the thermonuclear fuel. He showed that the thermonuclear fuel could be compressed powerfully enough to induce thermonuclear ignition and detonation. Ulam also proposed an iterative thermonuclear bomb configuration containing a train of thermonuclear units designed to operate on the same principle and to detonate sequentially.

Ulam presented his idea to Teller at the end of January 1951. Teller hesitated at first, then embraced Ulam's proposal with enthusiasm, but soon proposed a variant that was, in the words of Ulam, "perhaps more convenient and general." Instead of a stream of neutrons, Teller proposed that radiation emitted from the primary atomic bomb be used to generate a shock wave that would compress the secondary thermonuclear core in Ulam's scheme. The physical configuration proposed by Teller was similar in many respects to that of the initiator of the devices used in the George shot. It differed, however, in that the thermonuclear fuel was not *heated* by the radiation from the primary atomic bomb—"cold" compression was conducive to greater compaction of the thermonuclear fuel. Also, the design allowed for a secondary unit of



KLAUS FUCHS, a German-born British physicist, made significant contributions to the Super program at Los Alamos until 1946, when he returned to the UK. He also passed on US atomic and thermonuclear bomb secrets to the Soviets. Here he is shown in East Germany in 1960, after 9 years in an English prison, his British citizenship revoked. (Photo courtesy of RFYaTs-VNIIEF.)



PHOTO BY ALAN W. RICHARDS, AIP NIELS BOHR LIBRARY

JOHN VON NEUMANN and Fuchs in 1946 filed a patent application for a thermonuclear initiator based on a type of radiation implosion.



STANISLAW ULAM, around 1951, the year he proposed a two-stage thermonuclear bomb using neutrons to implode the secondary. Teller modified Ulam's idea to use radiation implosion. The resulting "Teller-Ulam" configuration has served as the basis for thermonuclear weapons.

greater volume and a larger mass of thermonuclear fuel.

Bearing in mind the similarity between the new ideas and the earlier ideas of 1946 that took shape in the initiator of the George shot, Teller later maintained that it was a miracle the new superbomb concept had not been proposed earlier. However, this conceptual breakthrough took place only after it was initiated by Ulam's 1951 proposal.

In March 1951, Ulam and Teller published a joint report (LAMS-1225), setting forth the new concept. The new superbomb design was named the Teller-Ulam configuration.

Less than a month later, Teller signed his name to a second report (LAMS-1230), in which he presented the results of further theoretical justification of the new superbomb by Frederic de Hoffmann, and he proposed a new component: an initiator of active fissionable material situated in the secondary core right inside the thermonuclear fuel. The purpose of the initiator was to trigger an atomic detonation in the interior of the compressed thermonuclear fuel.

The George shot was performed successfully on 9 May 1951. In the words of Herbert York,¹ "the largest fission explosion to date succeeded in igniting the first small thermonuclear flame ever to burn on Earth." The test confirmed that nonequilibrium combustion of a D-T mixture was possible, with at least some of the mixture located outside the fissionable material of the primary atomic bomb. However, being a major precursor to the discovery of the Teller-Ulam configuration, the George shot had

played its leading role well before its actual detonation. The first thermonuclear test by the US was roughly its 40th nuclear test.

Lithium

In June 1951, Teller and de Hoffmann issued a report on the effectiveness of using ${}^6\text{LiD}$ in the new superbomb configuration. The need for production of ${}^6\text{LiD}$ was acknowledged at a conference on the problems of the superbomb, held in Princeton, New Jersey, on 16–17 June 1951. However, the organization of large-scale ${}^6\text{Li}$ production had never before been undertaken in the US. This situation was fostered by the 1950 discovery of an alternative to thermonuclear developments: By using a more sophisticated chemical implosion technique, one could build a ${}^{235}\text{U}$ atomic bomb with a TNT equivalent of several hundred kilotons. Work began on the construction of such a bomb in the US in 1950 and culminated in successful testing on 16 November 1952 (the King shot). Because of this nonthermonuclear path to yields of several hundred kilotons, the US took the position that the only sensible thermonuclear plan was to develop an Alarm Clock releasing energy well in excess of one megaton. However, creating such a large bomb of that design was problematic. This accounts for the delay in proceeding with ${}^6\text{LiD}$ production. The erection of a US plant to produce highly enriched ${}^6\text{Li}$ did not start until May 1952. The plant, in Oak Ridge, Tennessee, went into full operation in the middle of 1953.

In September 1951 the decision was made at Los Alamos to develop a thermonuclear device using the new Teller-Ulam configuration for a full-scale test, code-named Mike, scheduled for 1 November 1952. Liquid D was chosen as the thermonuclear fuel. Accelerated work on the device, which required major reconfiguration, made it possible to meet the target date. The first day of November 1952 was a day of glorious achievement in the American thermonuclear program: the successful completion of the Mike shot. The explosion had a TNT equivalent of ten megatons. The Mike device was not a deliverable weapon, and the immediate problem for the US was to build a deliverable thermonuclear weapon. The feasibility of creating an effective deliverable weapon would entail the accumulation of a sufficient quantity of ${}^6\text{Li}$. It was spring 1954 before the minimum required quantity of ${}^6\text{Li}$ could be stockpiled.

On 1 March 1954 the US detonated the first thermonuclear explosion in the new Castle test series: the Bravo shot, which was the most powerful explosion ever in the history of American nuclear testing. The thermonuclear fuel in this shot was LiD with 40% ${}^6\text{Li}$. In other tests in the Castle series, it was necessary to make do with LiD having a relatively low concentration of ${}^6\text{Li}$ (including natural LiD). All thermonuclear tests of the Castle series were conducted on the ground or from a barge on the ocean. Not until 21 May 1956 did the US carry out its first airdrop of a thermonuclear bomb (the Cherokee shot). That series of tests, conducted from May through July of 1956, was aimed at further progress in the construction of lighter and more efficient nuclear weapon prototypes designed to operate in various categories of warheads.

Reference

1. H. F. York, *The Advisors: Oppenheimer, Teller, and the Superbomb*, W. H. Freeman, San Francisco (1976), p. 77. ■