A *Hindenburg* in the Bomb Bay: The Transition from Liquid to Solid Fueled Thermonuclear Weapons, 1951-1954

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ABSTRACT

The first U.S. thermonuclear war plans were based on the early availability of large liquid-fueled weapons and all their attendant encumbering cryogenic apparatuses. *A Hindenburg in the Bomb Bay* explains the transition in U.S. Air Force planning and logistics for the replacement of liquid-fueled hydrogen weapons by solid-fueled devices. The objectives and results of both Nevada and Pacific Ocean proof tests of early thermonuclear weapons and their components are also described.

Overview

The first U.S. thermonuclear weapon design was to be fueled with liquid deuterium and tritium; this particular configuration eventually turned out to be physically impractical, economically unfeasible, and militarily undeliverable. A later liquid-fueled device design, although far more practical and economical, and based on a tested device, was still fraught with logistical complications and hazardous handling and delivery characteristics.The first solid-fueled weapons, although far more practical, deliverable, and safer than their liquid-fueled counterparts, were still not obviously economically feasible. This problem would not be resolved until the first test detonation of a solid-fueled thermonuclear device during Operation CASTLE in the spring of 1954.

The impracticality of the earliest liquid-fueled design followed from its massive estimated size -- which also made it undeliverable -- and its economic unfeasibility followed from its insatiable appetite for scare and expensive tritium, which could only be made at the expense of the nation's fission weapon stockpile.

The perceived economic unfeasibility of early solid-fueled weapons followed from the mistaken contemporary belief that only a single isotope of lithium could be used efficiently as fuel. This belief persisted right up to the first detonation of a solid-fueled thermonuclear device.

The first three thermonuclear devices tested by the U.S. used liquid fuels for several reasons.[2] First, by the times of these tests in 1951 and 1952, the fuel constituents -- tritium and deuterium - - had been studied for nearly ten years and much more was known about their theoretical and actual behavior at thermonuclear temperatures and pressures than was known about the behavior and characteristics of alternate possible solid fuels under the same conditions.

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[1] This paper was presented to scientists and historians at the Second Los Alamos International History Conference co-sponsored by the Los Alamos Historical Society and the University of New Mexico at Los Alamos in August 1998.

[2] These include the *Cylinder/Silex* and the *Booster* tested during Operation GREENHOUSE in 1951 and the *Sausage* tested during Operation IVY in 1952. The *Booster* was a conventional TX-5 implosion fission weapon boosted with cryogenic deuterium and tritium.

Second, even as scarce as they were during the early 195 0s, these two hydrogen isotopes were still more readily available than the single particular lithium isotope, lithium-6, then believed indispensable to solid-fueled hydrogen weapons.

Third, the use of elemental fuel constituents in their most basic form allowed for greater purity of reactions and eliminated complicated and multiple branching fusion reactions produced by other heavier elements from which deuterium and tritium could be generated. This simplicity of reaction allowed for much easier diagnosis of the behavior of the first liquid-fueled devices.

The three years between early 1951 and early 1954 were some of the most important years of the postwar U.S. nuclear weapons program. In a series of pivotal events during a relatively short period, the basic fundamental principles of thermonuclear weapon design were discovered and tested, and the first practical and deliverable weapons were developed, tested, and deployed. The U.S. Air Force also developed delivery systems and tactics for these new weapons during this period.

The most significant events were:

- The discovery and application of the so-called “three concepts” of U.S. H-bomb design
- The first large-scale field test of thermonuclear theories developed before 1951
- The first full-scale test of a liquid-fueled thermonuclear device based on the “three concepts”
- The construction and operation of facilities to produce both liquid and solid thermonuclear weapon fuels
- The field testing in Nevada of mockups and components of the first stockpiled thermonuclear bombs
- The first full-scale Pacific Proving Ground tests of solid-fueled thermonuclear weapons
- The abandonment of liquid-fueled weapons in favor of simpler solid-fueled designs
- Selection of thermonuclear weapon delivery aircraft and techniques

The first large-scale megaton-yield U.S. fusion explosion occurred in November 1952. It was produced by a heavy, multistage liquid-fueled test device which was not a deliverable weapon by any definition of the word and which depended upon fission for the majority of its power. Sixteen months later, in the spring of 1954, the first solid-fueled U.S. "emergency capability" weapons were tested. These shots included the highest-yield thermonuclear explosion ever conducted by the United States; this high yield was produced largely by accident.

The U.S. Thermonuclear Program up to 1951

Before March 1951, the so-called “classical *Super*” hydrogen bomb design pursued by the Los Alamos Scientific Laboratory (LASL) depended upon liquid cryogenic deuterium as its main fuel charge, enhanced by an admixture of an ever-increasing amount of tritium to lower the ignition temperature of the deuterium so that it could be ignited by a high-yield atomic bomb "trigger."

Work on the hydrogen bomb started in the U.S. in 1942 and it continued at LASL on a very limited basis through the end of World War II. Various physical models were investigated; the result sought was a bomb that burned about a cubic meter of deuterium, releasing energy equivalent to that of about 10 to 40 million tons of TNT (10 megatons). The probable weight of a fission-fusion device of this design was estimated at around 10 tons.[3]

In this proposed theoretical system, energy was transferred by high-velocity (high-energy) neutrons, spawned by triton-deuteron or deuteron-deuteron fusions, colliding with deuterium (D) nuclei, and transferring some of their kinetic energy to the impacted deuterons. In such a fashion, the D-D reaction was expected to be self-propagating. At this time, no thought was given to using high densities of fusion fuels.[4]

At an early stage of the development of the hydrogen bomb in April 1946, based on inconclusive calculations performed on the *ENIAC*, an early electronic computer, LASL believed that the *Super* -- as the nascent bomb was then known -- could be ignited with less than 200 grams of tritium, about seven ounces.[5]

Another idea considered by the end of World War II was the use of solid and compact lithium deuteride as a fusion fuel, a much more convenient and practical reactant than cryogenic liquid deuterium (lithium deuteride was not used in an American thermonuclear device until early 1954).

However, lithium has a distinct disadvantage. Lithium has a higher reaction rate at high temperatures than that of deuterium, even though its nuclear charge is three instead of one. However, atoms with higher nuclear charge radiate much more rapidly; in fact, this radiation rate proceeds at the square of the rate of increase in charge. Since tripling the charge increases the radiation rate by a factor of nine, lithium is far more difficult to ignite than deuterium.[6]

For most of the period between 1946 and 1950, the *Super* took a back seat to projects at LASL which promised rapid improvements to the design of the wartime implosion-type fission bomb. These improvements followed from developments and innovations in almost every bomb component: more compact and energetic high explosives; improved detonating systems; lighter

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[3] *The Swords of Armageddon,* Chuck Hansen, Chukelea Publications, 1998, Vol. III, pp. 29, 30. All volume and page citations are from the current working draft of Version 2.0 of *Swords.* The cited *Swords* pages contain references to primary sources. Material presented in this paper is drawn in part from Vols. III, IV, and VI of *Swords;* far more extensive and detailed information about all subjects in this paper is presented in the cited volumes.

[4] *The Swords of Armageddon,* Vol. III, pp. 19, 20.

[5] "Los Alamos, Thermonuclear Weapons, and Computing: Calculating the Hydrogen Bomb, 1942-1952," LA-UR-96-1646, Anne C. Fitzpatrick, paper submitted to ENIAC 50th Anniversary Symposium, May 15-18, 1996, University of Pennsylvania, p. 11.

[6] *The Swords of Armageddon,* Vol. III, p. 8.

and more efficient tampers and reflectors; improved initiators; and new core geometries and compositions which permitted higher yields from much less fissionable material than was contained in the 1945 *Fat Man* fission bomb design.

At this time, the proposed *Super* was so huge and unwieldy that delivery by boat or railroad train were the only choices (any probable enemy was unlikely to permit either). It seemed impossible to package the *Super* into a droppable bomb, and even if it were possible, its yield would be so great that the airplane carrying it would have to be sacrificed.

One *Super* design in early 1949 included a fission trigger that in itself weighed 30,000 lbs.; the overall length of the bomb was estimated at approximately 30 feet, with a diameter in excess of 162 feet. Under these circumstances, the scientists at Los Alamos preferred not even to estimate the gross weight: this configuration represented essentially a huge fission trigger in the middle of a container of liquid deuterium the size of a large oil storage tank.

President Harry Truman’s decision in January 1950 to accelerate *Super* development ironically only made the weapon even more unlikely, at least in its present configuration. As more physicists and mathematicians studied the best current design during 1950, its appetite for tritium only grew and its economic and physical unfeasibility became more and more apparent.

By the fall of 1950, LASL estimated that the *Super* would require three to five <u>kilograms</u> of tritium, at a time when the entire national tritium stockpile was measured in tens of grams and production of just one kilogram of tritium per year would require the construction of many new nuclear reactors.

To shift nuclear reactors from plutonium production to tritium production would seriously impair the rapid postwar buildup of a sizable national stockpile of fission weapons. The reactor power required to make one gram of tritium was equivalent to that required to make 70 to 80 grams of plutonium, during a period when a typical moderate-yield atomic bomb required two to three kilograms of plutonium and an equivalent amount of uranium-235. An unproven hydrogen bomb that required three to five kilograms of tritium would in effect “cost” the national weapons stockpile between 70 and 200 proven atomic bombs; however, if a workable hydrogen weapon were developed, it would more than offset this loss of atomic bombs.

In addition, the physical feasibility of the current *Super* design was in grave doubt by late 1950. At one of the regularly-scheduled status review meetings at LASL during this period, physicist George Gamow graphically demonstrated the state of the hydrogen bomb design program by placing a can of cigarette lighter fluid, a small ball of cotton, and a piece of wood on a table. He squirted some lighter fluid on the cotton, placed the cotton next to the block of wood, and lit the cotton with a match. The cotton flared up briefly, then died out. He passed the piece of wood around the assembled group of scientists. It wasn't even warm -- and it was petrified wood.[7]

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[7] *The Curve of Binding Energy*, John McPhee, Farrar, Straus & Giroux, New York, 1974, p. 90.

1951: A Breakthrough and the First Thermonuclear Tests

Early in 1951, a synergistic exchange of ideas between Dr. Edward Teller and Dr. Stanislaw Ulam resulted in the so-called "three concepts" of modern thermonuclear design which are applicable to both liquid- and solid-fueled thermonuclear devices:

a. Separate stages -- a physically separate fission explosive (stage) and a capsule (stage) of thermonuclear fuel, centered at separate points.

b. Radiation coupling -- channeling (ducting) of thermoradiation from the first stage to ignite the second stage.

c. Compression -- implosion of the thermonuclear fuel capsule prior to ignition to achieve maximum yield.[8]

An additional feature of the design was the so-called "sparkplug," a fissile cylinder or hollow rod of uranium-235 or plutonium running axially through the center of the fusion fuel mass. When compressed, this "sparkplug" (which could also be boosted by being filled with a deuterium-tritium gas mixture) fissioned and generated tritium and fast neutrons in the middle of the fusion fuel. This fission reaction initiated and accelerated the fusion reaction amidst the highly compressed fusion fuel. Tritium was generated *in situ* and no external supply was required.

In terms of George Gamow's earlier analogy-by-demonstration, the Teller-Ulam configuration essentially pulverized the petrified wood (by compression), soaked the resultant dust with lighter fluid (the tritium produced amidst the fuel by the fissioning "sparkplug"), and then ignited the powder. The primary fission trigger no longer acted as the igniter for the fusion process but merely served as a catalyst to prepare the fusion fuel for ignition by the "sparkplug."

Increasing the fuel density had the same effect as adding tritium: raising density reduced heat loss, making ignition possible, while adding tritium reduced the ignition temperature, allowing for burning even with high heat loss. However, using up large amounts of tritium at the expense of many dollars and potential plutonium, i.e., dozens of fission weapons, was clearly uneconomical and impractical. After the advent of the "three concepts," tritium was only required for fusion-boosted weapons, primaries, and "sparkplugs."

When a tentative 50,000 lb., six-foot diameter, 20-foot long hydrogen bomb size was established in 1951, LASL advocated that the Air Force conduct drop tests using a drogue parachute to slow the falling bomb and allow the delivery aircraft more time to escape the blast. An immediate requirement was the development of a large parachute to support 50,000 lbs. dropped at release speeds in excess of 300 knots (345 MPH) at altitudes between 35,000 and 45,000 feet.

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[8] Brief of the Appellant, THE PROGRESSIVE, Inc., filed June 15, 1979, in the United States Court of Appeal for the Seventh Circuit, case no. 79-1428, pp. 19, 20.

The Air Force program that assisted this effort was known as Project *Caucasian. Caucasian* had seven subtasks, including the modification of four B-36H aircraft as prototype bomb carriers; the modification and redesign of the B-2 bomb lift to carry a 50,000 lb. load; development of a series of drogue parachutes to decelerate and stabilize the falling bomb; and development of practice drop shapes.[9]

1952: The First Full-Scale Test and Weapon Design Begins

The design of the first full-scale test device embodying the “three concepts” proceeded rapidly during 1951 and 1952, and by the fall of 1952, was ready for testing at Eniwetok atoll in the Marshall Islands. The test device, named the *Sausage* for its long cylindrical shape, was 80 inches in diameter and just over 20 feet long; it weighed 82 tons. Most of this weight was contained in a massive foot-thick outer steel casing which enclosed the device’s primary (a TX-5 unboosted fission bomb), and a complex cryogenic liquid-fueled secondary with a tritium gas-boosted plutonium “sparkplug.”

At the time of its detonation, the *Sausage* was the largest and most complex cryogenic device in the world. An irony of its design was that in order to attain the highest temperature ever achieved on earth, the deuterium in the device had to be chilled to near absolute zero, the lowest temperature on earth.

The test of the device during the Operation IVY Mike shot on November 1, 1952 was successful. Even before the test, design of the first solid-fueled hydrogen bombs -- the *Alarm Clock, Zombie, Runt,* and *Shrimp* -- had begun at LASL. These devices later became prototype weapons named TX-14, TX-15, TX-17, and TX-21, respectively.

As work proceeded on this second generation of hydrogen weapons, the Department of Defense (DOD) began studying likely delivery systems. The ConVAir B-36 *Peacemaker*, the largest bomber then in the U.S. Air Force inventory, was the most obvious delivery vehicle for the H-bomb: On June 30, 1948, a B-36 had dropped 72,000 lbs. of conventional bombs during a test flight. The B-36B could carry 86,000 lbs., including conventional high explosive bombs weighing up to 43,000 lbs. and measuring 364 inches long and 54 inches in diameter, the size of the American variants of a World War II British *Grand Slam* bomb.

Availability of the first stockpile hydrogen weapon, the TX-14 *Alarm Clock,* was assured by the end of 1953. This bomb was equipped with a 64-foot diameter drogue parachute. The Air Force instituted Project *Caucasian,* using two B-36Hs, to make aircraft and bombing equipment modifications to carry the TX-14 in the B-36. The Air Force’s Strategic Air Command (SAC) authorized a “1A” priority for this program.['0]

At a conference at Wright Field in July 1952, attended by representatives of the Air Force, ConVAir, Sandia Laboratories, and LASL, an agreement was reached to “freeze” maximum bomb diameter to 62.5 inches and to limit its weight to 25 tons. This monster was to be

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[9] *The Development of Thermonuclear Weapon Delivery Techniques: Project CAUCASIAN*, pp. 2, 5, 6, 11.

'0*A History of the Air Force Atomic Energy Program, 1943 - 1953*, Lee Bowen and Robert D. Little, et. al., 1959, Vol. IV, *The Development of Weapons*, p. 209.

supported in its delivery aircraft by a sling suspension system, similar to those employed for large 12 and 22 ton conventional high explosive bombs. The first B-36H with a sling system was to be delivered to the Air Force Special Weapons Center on or before November 1, 1952, and a second modified bomber by mid-December 1952.**[11]**

The Wright Air Development Command in Ohio had developed a new ribbon parachute which would prolong the time-of-fall of a thermonuclear weapon to 200 seconds. After July 1952, several test bomb models were airdropped successfully with the new chutes. Results showed that there was now sufficient time for the delivery aircraft to escape before detonation, and that the B-36 could deliver a parachute-retarded bomb about as accurately as a conventional high explosive bomb. [12]

Bomb loading was not expected to be a problem. Loading a 25-ton bomb was not an easy matter, but the Air Force had developed during World War II a monstrous telescoping hydraulic lift called the B-2 to lift bombs weighing up to 22 tons. These devices, of which there were only 10 by the fall of 1952, could be modified to lift heavier weights, and two were to be ready for test at Kirtland AFB by the beginning of October. (Despite orders placed in 1953, there would still be only 10 B-2 lifts in service at USAF bases by January 1955.)**[13]**

Because of logistic problems and the dependence upon the B-2 lifts, "emergency capability" thermonuclear strike missions would have to originate at Kirtland AFB in Albuquerque, New Mexico. Presumably, there would be a limited number of advance bases, such as Limestone AFB near Limestone, Maine, which could be used as "stepping stones" to targets overseas. (Limestone was re-named Loring AFB in October 1954.) Facilities to accommodate B-36 operations at Limestone had been completed in December 1950, and the 42nd Bomb Wing of SAC's 8th Air Force was assigned to Limestone in February 1953.**[14]**

Since the new B-52 was not scheduled for production until 1954 (the first B-52s were not deployed to SAC until June 1955), and the B-47 could not carry much more than 22,000 lbs. for any distance without in-flight refueling, the Air Force concentrated its modification program on the B-36. The first of these aircraft, readied for thermonuclear weapons delivery, arrived at Kirtland AFB on November 3, 1952; on November 28, Headquarters USAF authorized modification of 36 of the bombers, with 20 of them to be completed by December 1953.**[15]** (By

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[11] *The Development of Thermonuclear Weapon Delivery Techniques: Project CAUCASIAN,* pp. 6, 7.

[12] *Encyclopedia of U.S. Air Force Aircraft and Missile Systems, Volume II, Post-World War II Bombers, 1945-19 73,* Marcelle Size Knaack, Office of Air Force History, United States Air Force, Washington, D.C., 1988, p. 128.

[13] *History of Atomic Logistics, 1948-1955,* Frederick A. Alling, Historical Division, Office of Information Services, Air Materiel Command, Wright-Patterson AFB, July 1956, p. 127.

[14] *AIR FORCE BASES, Vol. I, Active Air Force Bases Within the United States*, Robert Mueller, United States Air Force Historical Research Center, Office of Air Force History, Washington,

D.C., 1989, pp. 327, 328, 329; September 12, 1952 Walker memorandum, pp. 18, 19.
May 1953, only four B-36s had been modified.)

The Advent of the *Jughead*

Even before the successful Operation IVY Mike shot on November 1, 1952, LASL scientists and engineers had begun planning to produce a weaponized version of the liquid-fueled *Sausage* for use as a standby weapon in the unlikely event that the new solid-fueled thermonuclear weapons either would not work or might fail to achieve high yields.

In early December 1951, the U.S. Atomic Energy Commission (AEC) asked the Department of Defense if it would be interested in procuring one or more duplicate copies of the *Sausage*, which was then being designed at the American Car & Foundry Company in Buffalo, New York. The DOD replied that due to the size, weight, and shape of the device, it was not interested in a duplicate of the test device, but wished to reconsider when the device was redesigned into a more deliverable configuration.[16]

This redesign presented a formidable engineering challenge: the *Sausage*, with its attached cryostat, weighed 82 tons. Its weight would have to be cut by more than 50% to make it portable. The B-36 could, with a reduced fuel load and a resultant combat radius of only 1,765 miles, carry a 36-ton bomb. [17] By early January 1953, LASL believed that the TX-16 *Jughead* -- as the deliverable version of the *Sausage* was known -- could be reduced in size to a weight of about 21 tons.

By May 1953, the design of the TX-16 was fairly firm. The bomb was 61.4 inches in diameter, 297.6 inches long, and weighed approximately 40,000 lbs. There did not appear to be any compatibility problems for the TX-16 or TX-17 with either B-36 or B-52 delivery aircraft; however, there were problems inherent in the carriage of either of these weapons by the B-47.[18] A scaled-down version of the TX-17, the *Shrimp* (later known as the TX-21) could be carried by the B-47.

The first Trial Run Model (TRM) TX-14 arrived for testing at Kirtland in May 1953. By late June, the third and fourth modified B-36Hs had arrived at Kirtland, simultaneous with delivery of prototype weapon configurations from Sandia Laboratory.

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[15] Minutes of the Thirty-Fifth Meeting of the General Advisory Committee to the USAEC, May 14-16, 1953, p. 25; Alling, *History of Atomic Logistics*, p. 118.

[16] Minutes of 63rd AEC-MLC Conference, December 20, 1951.

[17] *B-36 in Action,* Meyers K. Jacobsen and Ray Wagner, Squadron/Signal Publications, Carrollton, Texas, 1980, p. 18.

[18] Semiannual Historical Report, Headquarters, Field Command, Armed Services Special Weapons Command, Sandia Base, Albuquerque, New Mexico, Activities for the Period 1 January 1953 - 30 June 1953, p. 187.

Loading and drop tests of the TX-16 started soon afterwards. (B-36 drops of TX-14 ballistic shapes weighing up to 50,000 lbs. had begun at Kirtland in November 1952.)[19] B-36 bomb bay racks and fittings for the 50,000 lb. drop shape were adapted from equipment once used for the Air Force's postwar experimental 44,000 lb. T-12 conventional "blockbuster" bomb.[20]

In the months following the arrival of the B-36s at Kirtland, 40 TX-14 drops and 70 weapon loadings were made. The addition of the TX- 16 to the “emergency capability” program at the end of 1952 resulted in a similar series of drop and loading tests for the cryogenic bomb.

During the B-36/TX-14 and B-36/TX-16 drop test series, ballistic drops of free-fall and drogue parachute-retarded weapon shapes were conducted at Aberdeen Bombing Mission Precision Bombing Range at Edwards AFB in California to test weapon case behavior and to obtain ballistics data for Sandia. Drop tests of the TX- 14 were similar, except for certain internal features peculiar to the TX-16. The TX-14 and TX-16 configurations were very similar, although the TX-16 was 75 inches longer and 13,000 lbs. heavier.[21]

Operation UPSHOT-KNOTHOLE -- A Prelude to CASTLE

Between March and June 1953, the AEC, DOD, LASL and the new University of California Radiation Laboratory at Livermore conducted Operation UPSHOT-KNOTHOLE at the Nevada Proving Ground. During UPSHOT-KNOTHOLE, LASL tested mockups of TX-14, TX-15, TX-16, and TX-17 weapons, including primaries and dummy secondaries.

One of the most significant results of UPSHOT-KNOTHOLE was the discovery by LASL that its most important thermonuclear weapon primary design, the *Racer,* was not entirely reliable. At the last moment in the test series, a final shot, Climax, was added to test an alternate primary, the *Cobra.* This test was successful and the *Cobra* was used by LASL on four of its five Operation CASTLE shots in 1954.

Lithium requirements for CASTLE and "emergency capability" weapons were reviewed in mid-May 1953 at the 35th meeting of the General Advisory Committee to the AEC. Dr. Hans Bethe stated that lithium-6 was useful mainly for large weapons, and for all thermonuclear devices because it could be a source of tritium.

Making what would turn out to be a stunningly erroneous assumption, Dr. Bethe claimed that ordinary lithium-7 "won't work because it doesn't give tritium." Lithium-7 would generate tritium

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[19] Semiannual AFSWC History, 1952, pp. 325, 326; *History of Project BRASS RING,* Volume I -- Text, Delmer J. Trester, Historical Division, Chief of Staff, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, November 1953, p. 98.

[20] Alling, *History of Modification of USAF Aircraft For Atomic Weapon Delivery, 1948-1954,* p. 115; "American Aircraft Bombs, 1917 - 1974," James Wogstad and Phil Friddell, *REPLICA IN SCALE,* Volume 2 Nos. 3 & 4, Spring/Summer 1974, p. 136. A T-12 on display at the U.S. Army Ordnance Museum in Aberdeen, Maryland is stenciled as weighing 43,600 lbs. The T-12 was 54 inches in diameter and 32 feet long.

if it were struck by neutrons in the three to four million electron volt range (3-4 MeV); however, even though neutrons with energies between three and 17 MeV might be spawned by a thermonuclear reaction, these neutrons were not expected to have a high cross-section for tritium generation.

By mid-1953, the most desirable time-of-fall for the "emergency capability" thermonuclear weapons had not yet been determined. LASL believed that at least 200 seconds would be required to allow the delivery aircraft time to escape the blast. SAC was equally convinced that manned aircraft could escape safely from free-fall versions of the weapons. Sandia calculations indicated that 120 seconds, two minutes, would provide sufficient escape distance; parachutes contemplated for the "emergency capability" weapons provided 120 seconds time-of-fall if the bombs were released at 36,000 feet and fuzed for airburst at 8,000 feet.

This retardation worked out to a terminal velocity of 250 feet per second, about 170 miles per hour. The TX-14, TX-16, and TX-17 were being fitted with four wedge-shaped stub fins and five spoiler bands, which wind tunnel tests had shown would provide sufficient aerodynamic stability during a free fall. Because of the high density of these weapons, LASL estimated that free-fall terminal velocity would approach Mach 1.4.[22]

An Air Force operational concept in June 1953 called for 43 modified B-36H and B-36J aircraft with “beefed up” bomb bays as hydrogen bomb carriers.[23] As a result of a presidential directive which sped up the thermonuclear program, the number of B-36s to be modified to carry hydrogen bombs was raised in November 1953 to 108 aircraft. This requirement was soon increased to include all B-3 6s, even reconnaissance models, with the exception of 12 bombers which were set aside to carry the *Rascal* air-to-surface guided missile.

These modified aircraft were to carry the bomb or bombs selected by the AEC for stockpiling after Operation CASTLE in early 1954, namely, the TX-14, TX-16, and/or TX-17. By the end of 1953, 20 B-36s were to be modified for thermonuclear weapons carriage by February 1, 1954; 101 more aircraft during 1954; and 87 more during the first half of 1955, for a total of 208 aircraft by mid-1955.

The first full-scale drop test of a TX-16 dummy unit was held on December 7, 1953. Late in 1953, a B-36 had been modified to carry and prepare a TX-16 for drop. These modifications included the addition of a special strengthened bomb release mechanism and small liquid hydrogen pumps and dewars to top-off the liquid deuterium in the TX-16 secondary stage.[24]

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[21] *The Development of Thermonuclear Weapon Delivery Techniques: Project CAUCASIAN,* p. 8.

[22] Semiannual Historical Report, Headquarters, Field Command, Armed Services Special Weapons Command, Sandia Base, Albuquerque, New Mexico, Activities for the Period 1 January 1953 - 30 June 1953, p. 189.

[23] *The Development of Thermonuclear Weapon Delivery Techniques: Project CAUCASIAN,* p. 20.

[24] Alling, *History of Modification of USAF Aircraft For Atomic Weapon Delivery, 1948-1954,* p. 115.

By the end of 1953, TX-16 design was complete and a prototype had been fabricated and was ready for shipment to the Pacific for test during Operation CASTLE. Although successful drops from a B-47 of TX-14 casings loaded with ballast to simulate the TX-16 had been made, it appeared that unrefueled B-47 range was too short to make it a practical carrier of the TX-16, mainly because the high weight of the bomb required the B-47 to carry a small fuel load.

The logistic complications attendant to the cryogenic nature of the *Jughead* were formidable and not unlike those associated with cryogenically-fueled rockets. A truck-mounted mobile liquefaction, production, and transfer plant that could be set up near or on continental U.S. SAC bases was under consideration by mid-1953. The AEC would deliver either gaseous deuterium, heavy water, or liquid deuterium to these plants, which would then either liquefy the gas, electrolyze the heavy water, or store the liquefied gas.

Also under consideration were a number of airborne dewars having approximately the same external dimensions and profile as the Air Force's road-transportable H-46 dewar. These proposed dewars were to hold 1,000 liters each of liquid deuterium, and could be used to carry liquid deuterium overseas, or to "top off" *Jughead* bombs at forward staging bases.

The dewar in the *Jughead* could hold liquid deuterium for 20 hours after being filled, but future plans called for the construction of portable refrigeration equipment that could be connected to the weapon after it was filled and while it was in its delivery aircraft. This would allow the bomb to be kept in a "ready" condition in case of a delay at a staging base.

Carriage of the *Jughead* was not without its dangers to the bomber crew. Because of the heat generated by the spontaneous conversion of liquid orthohydrogen to liquid parahydrogen, after being filled, the *Jughead* would vent gaseous deuterium at the rate of approximately 50 liters per hour, and provisions were being made to vent the evolved gas to an area of negative pressure on the outer skin of the B-36 while in flight.[25] Any accumulation of explosive hydrogen gas while the bomber was in flight would be tantamount to carrying a potential *Hindenburg* in the bomb bay.

A program started in April 1953 to modify B-36s to carry the TX-14 and the TX-16 was named Project *Barroom.* It included all cryogenic fittings and equipment necessary for the TX-16, and procurement of special ground handling equipment, including B-2 bomb lifts, cranes, and special cryogenic trailers.

1954: Operation CASTLE and Weapons Stockpiling

LASL conducted full-scale tests of its TX-14, TX-15, and TX-17 bombs during Operation CASTLE in the spring of 1954. The test schedule before March 1, 1954 is shown below. The yields shown include the probable range and the best estimated value before March 1, 1954. The dates include the originally-scheduled date and the actual test date.

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[25] Semiannual Historical Report, Headquarters, Field Command, Armed Services Special Weapons Command, Sandia Base, Albuquerque, New Mexico, Activities for the Period 1 January 1953 - 30 June 1953, p. 187.

When this schedule was prepared, the solid-fueled *Alarm Clock* was to use lithium enriched to 95% in the lithium-6 (Li-6) isotope. The *Shrimp* was to use lithium enriched to only 40% Li-6, while the *Runt* was to use natural lithium, which contained only 6.5% Li-6 and 93.5% Li-7. Due to uncertainty about the utility of Li-7, LASL had wavered repeatedly about whether or not to even test the *Runt* during CASTLE.

There were a number of very logical reasons for this CASTLE shot sequence. Firing the 40%-enriched lithium-fueled *Shrimp* first allowed analysis of its results to be applied to the subsequent 95%- enriched *Alarm Clock* and unenriched *Runt* shots, for better yield prediction and for any required last-minute, minor on-site redesign, as had been done with the IVY Mike device.

Whether or not the *Runt* would be fired depended directly and almost entirely on results of the S*hrimp* test: if the *Shrimp* performed well, then an unenriched system would probably work at least reasonably well. There was no question that if the highly-enriched secondary in the *Alarm Clock* could be ignited, it would burn even better than the partially-enriched secondary in the *Shrimp.*

If the *Shrimp* "fizzled," then the *Runt* test would very probably be canceled. Since the *Shrimp, Runt,* and *Alarm Clock* all used the LASL *Cobra* primary, problems with one device might carry over into the others. If the *Shrimp* “fizzled,” LASL would have determine the cause almost immediately, and either cancel both the *Runt* and *Alarm Clock* shots, or, if the primary were the problem, use another primary, possibly the tested *Racer.*

Original "Final" CASTLE Shot Schedule[26]

# / Name	Laboratory	Device Name	Location	Date
1 / Bravo 6 MT (4-8 MT)	LASL	*Shrimp* (TX-21 prototype; *Cobra* primary)	Bikini-on reef 2,950 from SW tip of Namu	1 March (1 March)
2 / Union 3-4 MT (1-6 MT)	LASL	*Alarm Clock* (EC14; *Cobra* primary)	Bikini-barge in lagoon near Yurochi	11 March (26 April)

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[26] Letter dated 26 January 1954 from Lewis L. Strauss, Chairman, U.S. Atomic Energy Commission, Washington, D.C., to President Dwight D. Eisenhower; memorandum dated October 30, 1953 to Dr. Gordon M. Dunning, Division of Biology and Medicine, USAEC, from Capt. W. L. Guthrie, USN, Chief, Test Branch, DMA/USAEC, Subject: Changed Concept of CASTLE; Semiannual Historical Report, Headquarters, Field Command, The Armed Services Special Weapons Command, Sandia Base, Albuquerque, New Mexico, Activities for the Period 1 January 1954 - 30 June 1954, John Wendell Bailey, Lt. Col., QMC, Field Command Historian, 30 June 1954, p. 333.

3 / Yankee LASL 8 MT (6-10 MT)	*Jughead* (EC16) (cryogenic)	Bikini-barge at Union shot site	22 March (5 May)
4 / Echo UCRL 125 KT (65-275 KT)	*Ramrod* (cryogenic)	Eniwetok- Eberiru island	29 March (canceled)
5 / Nectar LASL 1.8 MT (1-2.5 MT)	*Zombie* (TX-15; *Racer* primary)	Bikini-barge at Union shot site	5 April (14 May)
6 / Romeo LASL 4 MT (1.5-7 MT)	*Runt* (EC17/24; *Cobra* primary)	Bikini-barge at Union shot site	15 April (27 March)
7 / Koon UCRL 1 MT (1/3-2.5 MT)	*Morgenstern* (solid-fueled; *Racer* primary)	Bikini- Eninman island	22 April (7 April)

The probable high-yield test of the liquid-fueled *Jughead* was slated to follow the first two tests of solid-fueled devices; after *Jughead* was fired, unless all of the first three shots "fizzled," the U.S. would have successfully proof-fired at least one deployable "emergency capability" weapon: either the "dry" TX-14 or the "wet" TX-16, or both.

This order of priority of shots was in keeping with the "emergency capability" program which dictated that all possible efforts must be directed toward early stockpiling of a deliverable thermonuclear weapon. [27]

The wisdom of this shot sequence was inadvertently proven when the *Shrimp*, fired as the CASTLE Bravo shot on March 1, 1954, yielded 15 megatons, two-and-a-half times its most likely predicted yield and nearly twice its highest expected yield. LASL had seriously underestimated the cross-section of lithium-7 for tritium generation, and all of the lithium-fueled weapons proved to be much more efficient than expected. The *Alarm Clock* yielded 6.9 MT, and the *Runt* -- finally tested twice during the CASTLE Union and Yankee shots -- yielded 11 and 13.5 MT. As a result of the unexpected success of the *Shrimp* and the *Runt* during CASTLE, the *Jughead* shot was canceled and the second *Runt* test substituted for it.

The AEC canceled the TX-16 program on April 2, 1954 and stockpiled the TX-14, TX-15, and TX-17 weapons (the TX-21 was later stockpiled as the MK 21). The results of CASTLE showed that even ordinary lithium, unenriched beyond 6.5% in the Li-6 isotope, was useful as a thermonuclear fuel and that many new and expensive lithium isotope-separation plants would not be required beyond those already planned.

Solid-fueled thermonuclear weapons, of relatively light weight and high yields in the megaton range, were now practical and usable. The elaborate and expensive plans and arrangements made by the armed services for the deployment, servicing, and delivery of liquid cryogenically-fueled

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[27] CASTLE, TG 7.1 History, Installment 1, November 20, 1953.

bombs were no longer necessary. The CASTLE tests had proven that even ordinary lithium hydride -- unenriched in the rare and expensive lithium-6 and deuterium isotopes -- could be used as a hydrogen bomb fuel.

With the withdrawal of the TX-16, the USAF project name *Barroom* was changed to *Cauterize*.[28] In March 1954, the Air Force decided to include the 12 *Rascal*-carriage aircraft in the H-bomb effort, bringing the new total to 220 B-36s to be modified to carry hydrogen bombs.

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[28] Alling, *History of Modification of USAF Aircraft For Atomic Weapon Delivery, 1948-1954*, pp. 111-116.