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Layer Cake Nuclear Weapons Are a Distinct Type: Neither True Hydrogen Bombs nor Boosted Nuclear Weapons

Layer Cake type nuclear weapons are a common design that initially suggested itself to scientists attempting to figure out how to build a hydrogen bomb. They discovered it was an incorrect design and eventually all five of the major nuclear powers settled on the correct one. Yet today there are still many misconceptions regarding Layer Cake type nuclear weapons. Some still believe that they are a version of a hydrogen bomb. Others refer to them as boosted. They are neither. Rather Layer Cake nuclear devices are a distinct category all on their own.

Many believe that the device (RDS-6s) tested as the Soviet Union's fourth nuclear test (Joe-4) was the main example of this type of nuclear weapon. Actually, the device was a unique example loaded with tritium. All other Layer Cake devices did not use tritium, including the Soviet Union's ultimate development of Layer Cake type weapons (the RDS-27). It is also not widely recognized that both France and China developed and tested (but did not deploy) Layer Cake devices.

There are some who believe that countries such as North Korea might actually try to develop and deploy Layer Cake type nuclear weapons today.[2] However, Layer Cake type nuclear weapons are heavy and difficult to manufacture and are outperformed by high yield pure fission weapons (King type) let alone hydrogen weapons. Since the correct design of hydrogen bombs is well-known today, it is unlikely that any country would build a Layer Cake device instead.

I will first describe in detail the four types of nuclear weapons that countries may develop after producing their first simple fission implosion weapon. These are hydrogen weapons, boosted weapons, King type weapons and Layer Cake weapons. I will then describe the varied paths that the five major nuclear powers took in developing hydrogen weapons and the role that Layer Cake devices played in those development paths.

Nuclear Weapon Designs After Simple Fission Implosion Weapons

All five of the major nuclear weapon states initially developed simple fission implosion type nuclear weapons. Once this goal was achieved, these countries considered as many as four additional types of weapons. This section describes these four types in detail. Though three of the four types (hydrogen weapons, boosted weapons and Layer Cake weapons) all utilize thermonuclear fusion reactions, the descriptions will make clear that they are distinct types.

[1] This paper is the product of the author's personal research and the analysis and views contained in it are solely his responsibility. Though the author is also a part-time adjunct staff member at the RAND Corporation, this paper is not related to any RAND project and therefore RAND should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com

[2] David Albright "North Korean Nuclear Weapons Arsenal: New Estimates of its Size and Configuration," Institute for Science and International Security, April 10, 2023, pp. 14-16. https://isis-online.org/uploads/isis-reports/documents/North_Korean_Nuclear_Weapons_Arsenal_New_Estimates_of_its_Size_and_Configuration_April_10_2023.pdf

Hydrogen Bombs (Two-Stage Thermonuclear Weapons)

The development of hydrogen bombs was the ultimate goal of the five major nuclear weapon states. These weapons consist of two components, a relatively low yield fission primary and a thermonuclear burning secondary where most of the yield is produced. The fusion fuel is lithium deuteride (LiD). Deuterium (D) is a rare isotope of hydrogen which is found in all hydrogen containing substances. X-rays released when the primary is detonated compresses the LiD and it is then heated. As a result, the deuterium undergoes two different fusion reactions, either producing He-3 and a neutron or tritium and a proton. Tritium (T) is the only radioactive isotope of hydrogen. The neutron reacts with the lithium to produce tritium as well. Deuterium and tritium (DT) fuse more readily then does deuterium with itself (DD) and is the key fusion reaction in a hydrogen weapon.

The DT fusion reaction produces neutrons with a much higher energy than do fission reactions. These high energy neutrons can cause fission in the U-238 that makes up over 99% of natural uranium. To take advantage of this fact, the secondary of a hydrogen weapon consists of layers of LiD and natural uranium.

Arnold provides the best description of a hydrogen device. The British Grapple X device was tested in November 1957.[3] The primary for this device was a Red Beard implosion fission weapon. It had a composite core (contained both plutonium and highly enriched uranium [HEU]) and had a yield of 45 kilotons. The secondary had only three layers, a central core of enriched uranium, a middle layer of LiD and an outer natural uranium layer. The masses of the materials in the secondary are unknown. The British used only three layers not because they thought it was necessarily superior but rather for analytical simplicity. Nevertheless, the device performed quite well, producing a yield of 1.8 megatons instead of the expected 1.0 megatons. Roughly half the yield of a hydrogen weapon is from the fission reactions in the secondary and the other half from the fusion reactions.[4] The primary contributes relatively little of the total yield.

Natural lithium is composed of two isotopes, lithium 6 which is about 7.5% and lithium 7 which is about 92.5%. Lithium 6 is more readily converted into tritium than is lithium 7, so in many weapons the lithium 6 is enriched to values as high as 95%. However, some test devices have successfully used natural lithium, though presumably the yield was somewhat reduced.

Since neither LiD nor natural uranium have a critical mass, it is possible to build weapons with large quantities of these materials and produce weapons with very high yields. In the early days of the development of hydrogen weapons, yields in the one megaton to ten megaton range were quite common. The Soviets even designed a weapon with a one hundred megaton yield. It tested a fifty megaton version in 1961.

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[3] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 160.

[4] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, Third Edition, United States Department of Defense and the Energy Research and Development Administration, U.S. Government Printing Office, 1977, p 22. https://www.osti.gov/servlets/purl/6852629

Over time the emphasis has shifted to weapons that are smaller, lighter and with lower yields. Today most hydrogen weapons have yields in the one hundred kilotons to one megaton range. Such weapons are rather lightweight. For example, it has been reported that the TN 71, a French ballistic missile MIRV warhead, could produce 150 kilotons while weighing only 175 kilograms (385 lb.).[5] It is also possible that in the shift to smaller, lighter-weight weapons, some of the natural uranium in the weapon is replaced by HEU.[6]

One question is the shape of the secondary in a hydrogen bomb. The secondary has often been depicted as being a cylinder[7] but the Russians[8], British[9], French[10], and Chinese[11] have all stated that, in their early hydrogen weapons, the secondaries were spheres. When British nuclear cooperation with the U.S. resumed in 1958, the British were surprised to discover that the U.S. nuclear weapon secondaries were cylindrical in shape rather than spherical.[12] However, the British stated that at that time the U.S. had recently tested a hydrogen device with a spherical secondary.[13] A U.S. House of Representatives report (the Cox Report) in 1999 showed a diagram of a modern U.S. hydrogen bomb with a spherical secondary.[14] Therefore current U.S. hydrogen bombs probably also use spherical secondaries.

Boosted Weapons

The British have revealed much information regarding boosted fission weapons.[15] These weapons use hollow cores of fissile material. Just before detonation a DT gas mixture is inserted into this hollow space. The detonation of the weapon causes the DT to undergo a fusion reaction. The energy output from this fusion reaction is a small fraction of the weapon's overall yield. As I have written elsewhere, boosted weapons use only about a mole or two of DT.[16] The complete fusion of a mole of DT produces 0.4 kilotons of yield. The British first test of a gas

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[5] Robert S. Norris, Andrew S. Burrows and Richard W. Fieldhouse, *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*, Westview Press, Boulder, CO, 1994, p. 218.

[6] Gregory S. Jones, "Constraints on Possible High Yield North Korean Nuclear Weapons: Weight and Nuclear Materials Requirements," August 24, 2021. https://nebula.wsimg.com/61d3180db8bdb240efe514099be86a6f?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[7] See for example: Richard Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, Touchstone, New York, 1995, p. 506.

[8] G A Goncharov, "American and Soviet H-bomb Development Programmes: Historical Background," *Uspekhi Fizicheskikh Nauk.*, Vol. 39, No. 10, 1996, p. 1041. https://nuke.fas.org/guide/russia/nuke/goncharov-h-bomb.pdf

[9] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, pp. 165-166.

[10] Pierre Billaud and Venance Journe, "The Real Story Behind the Making of the French Hydrogen Bomb: Chaotic, Unsupported, but Successful," *Nonproliferation Review*, Vol. 15, No. 2, July 2008, p. 364. https://www.tandfonline.com/doi/full/10.1080/10736700802117361

[11] By Hui Zhang, "The short march to China's hydrogen bomb," *Bulletin of the Atomic Scientists*, April 11, 2024. https://thebulletin.org/2024/04/the-short-march-to-chinas-hydrogen-bomb/

[12] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 209.

[13] Ibid., p. 212.

[14] "U.S. National Security and Military/Commercial Concerns with The People's Republic of China," Select Committee, United States House of Representatives, U.S. Government Printing Office, 1999, p. 78.

[15] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001.

[16] Gregory S. Jones, "U.S. Increased Tritium Production Driven by Plan to Increase the Quantity of Tritium per Nuclear Weapon," June 2, 2016. https://nebula.wsimg.com/08a60104185a91e6db9008fb929a0873?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

boosted weapon (Burgee—September 23, 1958) had a yield of 25 kilotons so boosting provided only about 2%-3% of the yield.

The point of boosting is the release of a large number of high energy neutrons from the DT reactions. These neutrons "enhance the yield of the fission explosion by increasing the burn-up of the fissile material."[17] Many experts mistakenly believe that this increased efficiency is used to increase the yield of the weapon but that is usually not its purpose. As the British have said, "But there was another way to look at boosting. Instead of using it to *increase* the yield of a warhead of given size and fissile content, it could be used to *reduce* the size and fissile content of a warhead while maintaining or even improving the yield."[18][Emphasis in original]

As the British have pointed out, boosted fission weapons have another important property. Implosion fission weapons that use plutonium are vulnerable to predetonation due to the neutrons from spontaneous fission. Even if such weapons contain only HEU, they are still vulnerable to predetonation from neutrons from other nearby nuclear detonations, which could be either defensive warheads or "friendly" weapons. Boosted fission weapons do not have this vulnerability and can be used to manufacture what the British termed "immune warheads." Such immune warheads are ideal as the primaries for hydrogen weapons.[19]

It is also possible to boost a weapon by using a solid boost material consisting of LiDT. But whatever the form, tritium is an essential component, since at low energies the DT fusion cross section is about one hundred times larger than the DD cross section. The availability of tritium is complicated by its being radioactive with a 12.3 year half-life. Countries that use boosted weapons must produce tritium to replace the tritium that decays away.

Many analysts believe that boosted weapons are intermediate devices on the path to the development of hydrogen weapons. However, the U.S., Soviet Union, UK and China all developed and/or deployed hydrogen weapons before they tested boosted weapons.[20] Today, though stand-alone boosted weapons are possible, these devices are exclusively used in the U.S., UK and French arsenals as the primaries of hydrogen weapons. This may well be the case for Russia and China also.

King Type (High Yield Pure Fission Implosion Weapons)

By putting large amounts of plutonium or HEU into an implosion weapon, yields much higher than the nominal 20 kilotons are possible from pure fission reactions. I have termed such weapons "King type." Due to criticality constraints, significantly more HEU can be placed in a weapon than can plutonium and the highest yield pure fission weapons use HEU.

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[17] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 87. The enhancement is achieved by the high energy neutrons significantly increasing the number of neutrons released per fission.
[18] Ibid., p. 177.
[19] Ibid., pp. 177-178.
[20] Gregory S, Jones, "The Role of Boosting in Nuclear Weapon Programs," July 25, 2017. https://nebula.wsimg.com/ccbc92a7e380925d944880521d489ea5?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

The U.S. first tested a weapon containing a large amount of HEU in 1952, known as the King shot in the Ivy test series. It had a yield of 500 kilotons. This weapon was large and heavy, being about the size and weight of the Nagasaki weapon (1.5 meters in diameter, roughly 4,000 kilograms in weight) but smaller, lighter versions are possible. The U.S. deployed this device as the Mark 18 bomb between 1953 and 1956.

In May 1957 the British tested a pure fission device[21] known as Orange Herald (Small) which was 30 inches (75 centimeters) in diameter and weighed about 2000 lb. (900 kilograms).[22] It had a yield of 720 kilotons and was the largest yield pure fission weapon ever tested. One source says that this device used 117 kilograms of HEU.[23] To produce 720 kilotons would require the complete fissioning of the U-235 contained in about 46 kilograms of 90% enriched uranium. The reported HEU content of the device would imply an efficiency of about 39%. If the King device had the same efficiency, then it contained about 82 kilograms of 90% HEU.

These weapons used approximately four to six times as much HEU as a nominal pure fission weapon and there were substantial safety concerns regarding accidental criticality. Despite these shortcomings, King type weapons provide an easy method of producing high yield nuclear weapons.

Layer Cake Weapons

When the Soviets were first trying to develop a hydrogen bomb, they produced a weapon which they nicknamed "Layer Cake," (formally known as the RDS-6s).[24] It had an enriched uranium core surrounded by alternating layers of LiD and natural uranium. This was essentially the secondary of a hydrogen bomb. However, since the Soviets had yet to discover the utility of using a fission weapon primary to ignite the secondary, they instead used high explosives which surrounded the device to compress it. The resulting device was large and heavy, 1.5 meters in diameter, 4,500 kilograms in weight, making it about the size and weight of the Nagasaki weapon

All five major nuclear powers initially considered the Layer Cake design during their development of hydrogen bombs. The Soviet Union, France and China all built and tested (but did not deploy) Layer Cake type nuclear devices. In all cases the yields were between about 200 and 250 kilotons.

[21] The British attempted to boost this device using a small amount of thermonuclear material but concluded that the boosting was unsuccessful. Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 147.

[22] Richard Moore, "The Real Meaning of the Words: a Pedantic Glossary of British Nuclear Weapons," UK Nuclear History Working Paper, Mountbatten Centre for International Studies, March 2004. https://www.nuclearinfo.org/wp-content/uploads/2020/09/The-Real-Meaning-of-the-Words-A-Pedantic-Glossary-of-British-Nuclear-Weapons.pdf

[23] Nuclear Weapon Archive. Britain's Nuclear Weapons - British Nuclear Testing Another source describes Orange Herald (Small) a little differently. It says that the device was 45 inches in diameter, 2,500 lb. and used "up to" 120 kilograms of HEU. See: John Walker, *British Nuclear Weapons and the Test Ban 1954-1973*, Ashgate, 2010.

[24] G A Goncharov, "American and Soviet H-bomb Development Programmes: Historical Background," *Uspekhi Fizicheskikh Nauk.*, Vol. 39, No. 10, 1996, pp. 1038-1041. https://nuke.fas.org/guide/russia/nuke/goncharov-h-bomb.pdf

Most sources consider the Soviet Union's fourth nuclear test (Joe-4) to be the prototype of the Layer Cake design but actually it was a unique variant. Joe-4 contained significant quantities of tritium. The tritium was added in order to ensure the device would perform as expected, since in the Soviet Union of the time, failure could carry severe and possibly fatal consequences to the weapon designers. Joe-4 produced a yield of 400 kilotons.

The Soviet scientists have touted Joe-4 as a deliverable weapon but its use of tritium ruled out the deployment of this device since it would have been costly. Additionally, it would only have had a service life of a half a year before it would have had to be remanufactured to renew the tritium.[25] The Soviets developed a non-tritium version (RDS-27) which they tested two years after Joe-4 (Joe-18, 250 kilotons), but it was overshadowed by the Soviets successful test of its first hydrogen bomb (Joe-19, 1.6 megatons) and the RDS-27 was never deployed. The French and Chinese never considered deploying their Layer Cake type devices.

The Soviets did attempt to design a higher yield version of Joe-4 but they found the Layer Cake design to be a technological dead end. The only way the yield could be increased would be to further increase the size and weight of Joe-4. It appears that a Nagasaki sized and weight weapon that produced about 250 kilotons in yield was the best that could be obtained from the Layer Cake design. The U.S., UK and France all found King type weapons to be superior.

Layer Cake nuclear devices were much inferior to hydrogen weapons. Layer Cake devices were limited to yields of about 250 kilotons whereas early hydrogen weapons could produce yields of more than 10 megatons. With the move to smaller lighter-weight weapons, again Layer Cake devices were vastly inferior. The French TN-71 hydrogen weapon could produce a yield similar to that of a Layer Cake device but weighed only one-twentieth as much.

Nor can the tritium loaded Joe-4 be considered a boosted device. The point of a boosted device is to enhance the yield of the fissile material in the weapon while producing minimal thermonuclear yield. However, the tritium was added to Joe-4 so as to try to produce significant thermonuclear yield as well as significant yield from U-238. It did so but the efficiency was nowhere close to that achievable in a hydrogen device.

The Five Major Nuclear Powers' Development Paths to Hydrogen Bombs

Each of the five major nuclear powers pursued their own path to the development of hydrogen weapons. It is instructive to see how varied the paths were. Each country considered developing Layer Cake type weapons and the Soviet Union, France and China tested such devices. However, no country actually deployed such devices as weapons. In contrast, the U.S, UK and France, not only tested King type devices but also deployed them as weapons. These weapons were replaced by hydrogen weapons and today all of the weapons in the U.S., UK and French arsenals are hydrogen weapons with boosted primaries. Less is known about the weapons in the current Russian and Chinese arsenals but given the practices in the other three major nuclear powers, it is fairly likely that these two countries also rely exclusively on hydrogen weapons with boosted primaries.

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[25] Yuli Kharition, Vikto Adamskii, and Yuri Smirnov, "The way it was," *The Bulletin of the Atomic Scientists*, November/December 1996, p. 57. https://www.tandfonline.com/doi/abs/10.1080/00963402.1996.11456679

U.S.

In 1938, Hans Bethe determined that hydrogen fusion reactions were powering the sun. Participants in the Manhattan Project realized that if a fission nuclear weapon could be produced, the energy from this device might be used to spark fusion reactions in deuterium. It was thought that the fusion reactions might be self-sustaining, which would allow for very large yields. The initial effort focused on a device known as the Classical Super, in which a fission device would start a fusion reaction in a tube of liquid deuterium. With the development of implosion fission weapons during World War II, the U.S. also designed a Layer Cake type device known as Alarm Clock. However, the pace of research after World War II was slow and neither device seemed to be very promising.

The situation changed after the first Soviet nuclear test in August 1949. In January 1950, President Truman publicly called for the development of a hydrogen bomb. In the first part of 1951, Edward Teller and Stanislaw Ulam proposed the correct design for a hydrogen device. It was somewhat unclear how to turn this concept into an actual weapon. In the fall of 1952, the U.S. tested the concept in the Ivy Mike nuclear test. It produced a yield of 10.4 megatons. However, this test was more like a science experiment than that of a nuclear weapon test since it used a large facility using liquid deuterium and weighed 74 metric tons.

In the same test series, the U.S. tested a high yield weapon that could be more rapidly used to produce a deployed weapon. This was the 500 kiloton King device that was discussed above. The U.S. apparently did not consider the Layer Cake design of Alarm Clock as an alternative.

In the first half of 1954, the U.S. further developed hydrogen devices in the Castle test series consisting of six high yield devices. Three of the devices had yields of over 10 megatons. All of the devices used LiD as the thermonuclear fuel and produced large amounts of fallout, which demonstrated that a significant proportion of the yield relied on the fissioning of U-238. The success of these tests and the superiority of hydrogen weapons compared to implosion fission weapons was summarized by Norris Bradbury, then Director of Los Alamos National Laboratory. In the aftermath of the Castle test series he said, "Is anyone going to care about using a B-47 to deliver kilotons when 3 MT bombs of the same weight are available?" [26]

In May 1956, the U.S. conducted its first airdrop of a hydrogen device, with the Cherokee test in the Redwing test series. The device had a 3.8 megaton yield. By 1958, the U.S. was beginning to focus on lighter-weight hydrogen bombs with boosted primaries. This led to the deployment of the very successful B-28 nuclear bomb which had a yield of over one megaton while weighing a little less than one metric ton. Over 5,000 of these weapons were produced, making it the most widely produced of any U.S. nuclear weapon.

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[26] *Battlefield of the Cold War, Nevada Test Site*, Volume I, Atmospheric Nuclear Weapons Testing, 1951-1963, United States Department of Energy, p. 116. https://www.energy.gov/sites/prod/files/DOENTSAtmospheric.pdf

Soviet Union

Though until 1950 the main Soviet effort was focused on the development of its first fission nuclear weapon, they had also given some thought on how to use fusion reactions in a nuclear weapon. After their first successful nuclear test and with Truman's public announcement that the U.S. would be pursuing the development of a hydrogen bomb, the Soviets decided to build and test a Layer Cake device, the RDS-6s. This device would contain significant amounts of tritium.

During this phase, the Soviets were also aware that King type devices were also possible. Their design was designated RDS-7. However, the Soviets were interested not only in high yields but also in a device that used fusion reactions. They continued the development of the RDS-6s. On August 12, 1953, the device was tested as the fourth Soviet nuclear test (Joe-4) and produced a 400 kiloton yield.

The Soviets were quite pleased with the RDS-6s and based their ballistic missile development on this device as the warhead. However, the expected inaccuracy of the early ballistic missiles was such that a higher yield would be preferred. This would especially be the case since a practical warhead would not contain tritium and thereby have a lower yield than the RDS-6s. It was found that Layer Cake designs were a technological dead-end as higher yields would only be possible by further increasing the already large size and weight of the RDS-6s.

In the first part of 1954, the U.S. conducted its Castle test series which had three tests with yields greater than 10 megatons. Layer Cake designs could not produce such high yields and it was obvious that the U.S. was using some other design. It did not take the Soviets too long to hit upon the two-stage design used by Teller and Ulam. A fair number of Soviet scientists were involved in this breakthrough which the Soviets called "an impressive example of creative team work."[27]

On November 6, 1955, the Soviets tested a non-tritium version of the RDS-6s, known as the RDS-27. It was the Joe-18 and had a yield of 250 kilotons. Three weeks later on November 22, 1955, the Soviets tested their first true hydrogen bomb. This was the RDS-37 (Joe-19) with a yield of 1.6 megatons. Given the success of the later device, the Soviets stopped developing Layer Cake type devices and rapidly deployed hydrogen weapons. In the 1957-1958 time frame, the Soviets first tested boosted nuclear devices and by the early 1960s they had deployed hydrogen bombs using boosted primaries.[28]

UK

The satisfaction of the British in having successfully tested its first fission implosion weapon on October 3, 1952 was short-lived, as U.S. and Soviet tests of high-yield devices showed that the British would need to produce their own high-yield nuclear weapons. The British recognized

[27] G A Goncharov, "American and Soviet H-bomb Development Programmes: Historical Background," *Uspekhi Fizicheskikh Nauk.*, Vol. 39, No. 10, 1996, p. 1042. https://nuke.fas.org/guide/russia/nuke/goncharov-h-bomb.pdf

[28] "Manuscript on the History of the Soviet Nuclear Weapons and Nuclear Infrastructure, (Technical Report on Tasks A-1 and A-2,)" Project Manager Yury A. Yudin, ISTC Project # 1763 p. 119

that hydrogen weapons could produce yields of 10 megatons, but they did not see the need for such high yields and would be satisfied was a one megaton yield.[29] Further, they did not care how this high yield was produced, only that they would have high yield weapons and that a sufficient number could be provided to the RAF.

The first British effort to produce a more advanced nuclear weapon involved the unique British concept of "tamper boosting." This was a simplified version of the Layer Cake concept. The weapons of the time involved using a fissile core surrounded by a thick natural uranium reflector. High energy neutrons from the fissioning in the core of simple fission devices caused some fissioning in the natural uranium tamper. It is estimated that 20 percent of the yield of a Nagasaki weapon was produced by fissions in the tamper.[30]

In tamper boosting the British put a single layer of LiD between the fissile core and the natural uranium tamper in the hope that the neutrons produced by the fusion reactions would enhance the fissions in the tamper. The British conducted two tests of tamper boosting in the Mosaic test series in May-June 1956. The first test, on May 16, 1956, was a smaller version, but it was unsuccessful, producing only a 15 kiloton yield. The second test, on June 19, 1956, of a larger version was also unsuccessful producing no more "than a few percent changed in yield."[31] Its yield was 60 kilotons.

In the 1980s some media reports claimed that in fact, the second Mosaic test was quite successful, having a yield of 98 kilotons.[32] However, as was quoted above, the actual outcome was no significant change in the yield. This result is hardly surprising given that even full Layer Cake devices were not very successful, let alone the single layer used in Mosaic.

It is not clear how the British figured out the correct design for a hydrogen bomb. They made significant progress, between the latter part of 1955 and the early part of 1956, aided by the analysis of debris from U.S. and Soviet hydrogen bomb tests. No one has credibly claimed to be "the father of the British hydrogen bomb." During the phase of the most rapid progress, no reports were written and the scientists themselves apparently considered their success to be a group effort.[33]

The British also continued to develop non-hydrogen bomb designs. In May-June 1957, the British conducted three tests in the Grapple test series. The first test, on May 15, 1957, was a hydrogen bomb device that was only partially successful. Its yield was only 300 kilotons instead of the intended one megaton. The British made a quick "fix" to the design, which was the third test in the series on June 19, 1957. However, the yield was an even lower 200 kilotons.

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[29] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 238.

[30] George D. Kerr, "Findings of a Recent Oak Ridge National Laboratory Review of Dosimetry for the Japanese Atom-Bomb Survivors," ORNL/TM-8078, Oak Ridge National Laboratory, 1981, p. 44. https://www.osti.gov/servlets/purl/5296078

[31] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 238.

[32] On this issue see: Zeb Leonard, "Tampering with history: varied understanding of Operation Mosaic," *Journal of Australian Studies*, Vol. 38, No. 2, 2014. https://www.tandfonline.com/doi/full/10.1080/14443058.2014.895956

[33] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 244.

The second test, on May 31, 1957, was the King type device known as Orange Herald discussed above. It had a very successful yield of 720 kilotons. The British had also built a Layer Cake device known as Green Bamboo. Since the hydrogen devices were at least partially successful, Green Bamboo was not tested.

With more time to consider the problem, the British successfully tested a hydrogen design on November 8, 1957. It was the Grapple X device discussed above. It had a 1.8 megaton yield instead of the expected 1.0 megatons. The British then made rapid progress, successfully testing several more hydrogen devices as well as boosted fission devices during 1958. These were the last British only nuclear tests. An international nuclear test moratorium went into effect in October 1958, ending for a time British nuclear tests. When testing resumed, all British tests were joint ones with the U.S.

The British never deployed a hydrogen weapon of their own design. Nuclear weapon cooperation between the U.S. and the UK, which had been suspended in 1946, resumed in August 1958. The U.S. gave the UK the design of the B-28, which the British deployed as the Red Snow in 1961.

Notably, the first deployed British high yield weapon was a King type design. It was deployed as a gravity bomb between 1958 and 1962 with the designations Violet Club and Yellow Sun Mk. 1.[34] It was 45 inches (1.1 meters) in diameter and weighed 7,000 lb. (3,200 kilograms).[35] The device was never tested but was estimated to have a yield of 400 kilotons. Presumably it used significantly less HEU than did Orange Herald.

France[36]

After successfully testing its first nuclear weapon on February 13, 1960, surprisingly the French were not very interested in producing hydrogen weapons. Instead, they developed and deployed two high-yield light-weight ballistic missile warheads using different types of nuclear designs. In 1966 France tested a weapon apparently of a King type design. However, the French had not yet started producing HEU so the weapon used plutonium instead, making it a unique form of a King type weapon. It weighed only 700 kilograms (1,500 lb.)[37] and had a yield of 110 kilotons.[38] This device was deployed as the MR-31 and was used as the warhead of the S2, the

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[34] John Walker, "British Nuclear Weapon Stockpiles, 1953-78," *RUSI Journal*, Vol. 156, No.5, October/November 2011. https://www.tandfonline.com/doi/full/10.1080/03071847.2021.1956726

[35] John Simpson, "British Nuclear Weapon Stockpiles, 1953-78, A Commentary on Technical and Political Drivers," *RUSI Journal*, Vol. 156, No.5, October/November 2011. https://www.tandfonline.com/doi/full/10.1080/03071847.2011.626279

[36] Much of the information in the section is derived from: Pierre Billaud and Venance Journe, "The Real Story Behind the Making of the French Hydrogen Bomb: Chaotic, Unsupported, but Successful," *Nonproliferation Review*, Vol. 15, No. 2, July 2008. https://www.tandfonline.com/doi/full/10.1080/10736700802117361

[37] Robert S. Norris, Andrew S. Burrows and Richard W. Fieldhouse, *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*, Westview Press, Boulder, CO, 1994, p. 185.

[38] The 110 kiloton yield is different from what has been published in the past. However, the French had a strict policy of conducting full yield tests of all their deployed warheads and this weapon was tested in the atmosphere in the South Pacific. As part of their examination of the environmental damage caused by French nuclear testing in the South Pacific, the yields of the weapons tests have been released. This warhead was the Betelgeuse test on September 11, 1966. See: "La Dimension Radiologique Des Essais Nucleaires Francais En Polynesie," Ministere

first French nuclear-armed ballistic missile which was in service between 1970 and 1980. This missile was deployed in silos in southeastern France.

In 1968 France conducted a test of another unique design. This was a boosted version of a HEU King type weapon. In this case the purpose of the boosting was to produce a high yield in a smaller lightweight weapon. The weapon was 0.75 m (30 inches) in diameter, weighed 700 kilograms (1,500 lb.) and had a yield of 450 kilotons.[39] It was apparently a successful version of what the British had attempted with the Orange Herald (Small) device. The weapon used a large mass of HEU. To boost this sort of weapon the amount of DT required would have also been large, perhaps 5 to 10 moles. Note that even if the weapon used 10 moles of DT, the fusion yield would have only been 4 kilotons, which is only one percent of the total yield of the weapon. This low fusion output is typical of a boosted weapon. This device was deployed as the MR-41 and was used as the warhead for the first two versions of France's submarine launched ballistic missiles, the M1 and the M2. These missiles were in service between 1972 and 1980.

In the beginning of 1966, French President de Gaulle suddenly realized that the Chinese might beat France to the development of hydrogen weapons and he demanded that such weapons be developed as soon as possible. Like other countries, France focused on Layer Cake type devices[40] and apparently tested two such devices in 1966 and perhaps another in 1967.[41] Since at the time, the French had neither HEU or tritium, these devices would have contained plutonium, LiD and natural uranium. Layer Cake devices using plutonium instead of HEU were unique to the French.

The French found the results "disappointing." The highest yield test was Sirius with a yield of 205 kilotons. Though this was the highest yield French test to date, the French did not consider weaponizing the device. Unlike the U.S., Soviet Union or the UK, the French were much more constrained in their delivery capability and their aircraft and ballistic missiles could not carry such a heavy weapon.

In April 1967, French scientist Michel Carayol proposed the correct design for a hydrogen weapon. Though some other French scientists were enthusiastic about the new design, many were not, including the leadership of the French effort, which continued to focus on Layer Cake type devices. The British had been analyzing the fallout from the French tests and knew that the French were using an incorrect design. In a strange turn of events, the British nuclear scientist Sir William Cook approached the French military attaché in London and essentially told him that

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De La Defense, Republique Francaise, 2006, Annexe 2, p. 353.
https://www.defense.gouv.fr/sites/default/files/ministere-armees/La%20dimension%20radiologique%20des%20essais%20nucl%C3%A9aires%20en%20Polyn%C3%A9sie%20fran%C3%A7ais.pdf

[39] This warhead was tested in the Castor shot on July 15, 1968. See: ibid..

[40] The French have not explicitly used the term "Layer Cake" but it is obvious that this was their design. They said, "At the time we did not think at all of separating fission and fusion in two different stages. In our designs in which LI6D was closely fitted to a fissile core, the heating was too rapid and the resulting efficiency was very low." See: Pierre Billaud and Venance Journe, "The Real Story Behind the Making of the French Hydrogen Bomb: Chaotic, Unsupported, but Successful," *Nonproliferation Review*, Vol. 15, No. 2, July 2008, p. 358.
https://www.tandfonline.com/doi/full/10.1080/10736700802117361

[41] These tests were Rigel, September 9, 1966, 125 kilotons; Sirius, October 4, 1966, 205 kilotons and Antares, June 27, 1967, 120 kilotons.

they were doing it wrong. It is unclear to this day whether Cook was acting in an official capacity and exactly how much information Cook provided. As a result of this interaction, the French realized that Carayol's design was correct. In 1968 the French tested their first hydrogen devices, with yields of 2.6 megatons (Canopus, August 24, 1968) and 1.3 megatons (Procyon, September 8, 1968).

In a series of at least five nuclear tests between 1968 and 1971, France perfected its first hydrogen warhead. This weapon was deployed as the TN-61, which was tested as the Rhea shot, August 14, 1971 with a yield of 955 kilotons. Including the reentry vehicle, it weighed 700 kilograms (1,500 lb.) and entered service in 1976.[42] The French have stated that the TN-61 was hardened against the effects of anti-missile defenses employing nuclear warheads in a way that was impossible for fission weapons to be hardened. This implies that the TN-61 used a boosted primary.[43] The TN-61 was the warhead on a new land-based ballistic missile, the S3 and replaced the MR-41 on the M2 submarine launched ballistic missile, which was then redesignated the M20.

China[44]

Initially, China received significant aid for its nuclear weapon program from the Soviet Union but in June 1959 the Soviet Union cut off all aid. Apparently, the Soviet Union had provided China with the components for a gaseous diffusion uranium enrichment plant.[45] After the Soviets cut off aid, it took the Chinese until January 1964 to assemble the components and for the plant to start producing HEU. By May 1964 the plant had produced sufficient HEU and on October 16, 1964, China tested its first nuclear weapon.

As of the early 1960s the Chinese had been considering how to produce a hydrogen bomb. During the period of cooperation with the Soviets, the Chinese had acquired the basic design of a Layer Cake type device. After its October 1964 first nuclear test, China began a sustained push to produce a hydrogen bomb. They set a goal of producing a yield of one megaton from a device weighing only about 1,000 kilograms with fusion reactions accounting for at least 30 percent of the yield. This latter requirement ruled out the use of King type devices.

It was clear that Layer Cake type devices could not meet these requirements. Nevertheless, the Chinese designed a Layer Cake device that weighed 5,000 kilograms and was two meters in diameter. Since at this time China had neither plutonium nor tritium, the device contained HEU, LiD and natural uranium. This device was tested as China's third nuclear test on May 9, 1966 and it produced a yield of 220 kilotons. The characteristics of this device were similar to that of the Soviet RDS-27. By increasing the device weight to 8,000 kilograms the Chinese believed that a yield of 800 kilotons could be produced. Clearly this was not the path to a hydrogen bomb.

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[42] Robert S. Norris, Andrew S. Burrows and Richard W. Fieldhouse, *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*, Westview Press, Boulder, CO, 1994, p. 216.
[43] Pierre Langereux, "Twenty Years of Progress in French Nuclear Weapons," Air and Cosmos, July 12, 1980.
[44] Most of this section is derived from: By Hui Zhang, "The short march to China's hydrogen bomb," *Bulletin of the Atomic Scientists*, April 11, 2024. https://thebulletin.org/2024/04/the-short-march-to-chinas-hydrogen-bomb/
[45] John Wilson Lewis and Xue Litai, *China Builds the Bomb*, Stanford University Press, 1988.

For the Chinese, the key breakthrough occurred in the fall of 1965. A computer run had produced very promising results but in fact this was due to a programing error where the density of LiD had been increased by a factor of 20. However, this result underlined the importance of increasing the density of the LiD in a weapon. Chinese researchers led by Yu Min began to consider how a fission device (primary) could produce such a result. Soon the Chinese found the correct answer.

On December 28, 1966 the Chinese tested a reduced yield version of this two stage hydrogen bomb. It produced a yield of 122 kilotons with about 20 kilotons of the yield produced by the primary and about 100 kilotons produced by the secondary. The shape of the secondary was a sphere.

Initially the Chinese planned to test a full-scale version of its hydrogen weapon in October 1967 but concerned that the French might beat them to a hydrogen weapon, the test was moved up to June 17, 1967. The test produced a yield of 3.3 megatons.

Since China did not produce tritium until 1968 and had not produced its first LiDT until 1972, it is clear that China's first hydrogen weapons did not use boosted primaries.[46] It is not known when China might have switched to using boosted primaries.

Though the June 1967 test is often referred to as China's first hydrogen bomb test, the Chinese argue that the December 1966 test should be considered their first hydrogen device since it used the correct design with a primary and a secondary. Interestingly, the Chinese have not suggested that their May 1966 Layer Cake test should be considered their first hydrogen bomb test. Clearly, the Chinese do not consider the Layer Cake design to be a hydrogen bomb.

Conclusions

Layer Cake type nuclear devices are neither true hydrogen weapons nor boosted nuclear weapons but rather are a separate category all of their own. A typical Layer Cake weapon is large and heavy (1.5 meters in diameter, weighing 4,500 kilograms) producing a yield of between 200 and 250 kilotons. Scaling up the yield of a Layer Cake device is difficult. Even for a weight of 8,000 kilograms, the yield is still less than one megaton.

In contrast, early hydrogen bombs produced yields of over 10 megatons and if desired could be scaled up to produce yields up to 100 megatons. Over time the desired yield declined to the range of 100 kilotons to one megaton. Though Layer Cake devices can produce such yields, hydrogen weapons can produce the same yield while weighing only about one-twentieth that of a Layer Cake type device.

Nor are Layer Cake type devices boosted. Boosted nuclear devices must use tritium which most Layer Cake devices did not have. The main purpose of boosting is to produce yields in the low tens of kilotons, while being lighter and using less fissile material than an equivalent unboosted

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[46] Gregory S, Jones, "The Role of Boosting in Nuclear Weapon Programs," July 25, 2017, p. 7. https://nebula.wsimg.com/ccbc92a7e380925d944880521d489ea5?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

fissile weapon. Further, boosted fission weapons are “immune” to predetonation, which makes such weapons ideal primaries for hydrogen weapons. Indeed, in the current U.S., UK and French arsenals, boosting is used exclusively in the primaries of hydrogen weapons.

Even the Soviet RDS-6s device, which did contain a substantial amount of tritium, was not boosted. Rather than being used to improve the efficiency of the fissile material as would be the case in a boosted device, the Soviets intended the tritium to produce a significant proportion of the yield from fusion reactions which in turn would cause significant fissioning in U-238 as would be the case in a hydrogen weapon. The RDS-6s achieved this latter goal but only with very poor efficiency when compared to a hydrogen weapon.

King type weapons (high yield pure fission weapons) can produce yields greater than Layer Cake devices while being easier to manufacture. The U.S., UK and France not only tested such devices but deployed weapons using this design. The Soviets and Chinese set a requirement for their high yield weapons that a significant portion of their yield should come from fusion reactions, which ruled out their development of King type weapons. Even in the case of the U.S., UK and France, once hydrogen weapons were available, their King type devices with their extravagant use of nuclear material and significant safety concerns were rapidly phased out.

Though some have suggested that countries such as North Korea might try to develop Layer Cake devices today, in fact no one is likely to do so. In the past, the initial efforts of scientists trying to develop hydrogen weapons focused on the Layer Cake design as the possible answer. Since the design of hydrogen weapons is now well-known, it is unlikely that any country today would try to manufacture a Layer Cake type nuclear weapon. Further, any country trying to develop an easy method of producing high yield weapons will focus on King type devices as they are superior and more desirable. Layer Cake devices are only of interest as a part of nuclear weapon development history.