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The Role of Boosting in Nuclear Weapon Programs

Introduction

There is a general lack of understanding regarding the role of boosting in nuclear weapon programs. It is commonly thought that boosting is an intermediate technology between pure fission weapons and two-stage thermonuclear weapons (hydrogen bombs). In this view, in nuclear weapon programs there is a progression from pure fission weapons whose yield might be in the low tens of kilotons, to boosted weapons with yields in the high tens of kilotons or low hundreds of kilotons, to two-stage thermonuclear weapons with yields in the hundreds of kilotons or megaton range.

However, this common view is incorrect in a number of aspects. First, pure fission weapons can have yields up to about one megaton. Boosting does not produce yields higher than pure fission weapons. Second, four of the five countries that possess two-stage thermonuclear weapons have developed and/or deployed these weapons before boosted weapons. Third, the main purpose of boosting is to produce yields similar to that of pure fission weapons while being smaller, lighter and requiring less nuclear material. In addition boosted weapons are "immune" to the problem of predetonation and as a result are ideal for use as the primaries of two-stage thermonuclear weapons. All weapons in the U.S. nuclear arsenal today are two-stage thermonuclear weapons that use boosted primaries.

The role of boosting in the second tier nuclear weapon states (Israel, Pakistan, India, and North Korea) is a little different since it appears that none of these countries have developed two-stage thermonuclear weapons. In general, it appears that these countries may use boosting to produce stand-alone weapons that are small, lighter, and probably require reduced quantities of nuclear material while producing yields in the tens of kiloton range.

This paper will first discuss the types of nuclear weapons that a country might develop after it has first developed nuclear weapons. It will then describe the role boosting played in the nuclear weapon development histories of the five nuclear weapon states that have developed two-stage thermonuclear weapons. It will then discuss how boosting may be used in the second tier nuclear weapon states.

Types of Advanced Nuclear Weapons

After a country has first tested an implosion nuclear weapon with a nominal 10 to 20 kiloton yield how might it improve its nuclear weapons? Countries have four options. They can increase the yield of pure fission weapons by increasing the nuclear material in the device, they

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can develop two-stage thermonuclear weapons (hydrogen bombs), they can develop boosted devices or they can develop what the Soviets nicknamed “Layer-Cake” type devices. These developments are not mutually exclusive.

Pure Fission Implosion Weapons With Higher Yields

Pure fission implosion weapons can have yields significantly higher than just 20 kilotons. In the Yoke shot of the 1948 Sandstone test series the U.S. tested a device with a yield of 49 kilotons. The first French test in 1960 had a yield of 70 kilotons.

Further, by putting large amounts of highly enriched uranium (HEU) into an implosion weapon, yields of up to a megaton are possible. The U.S. first tested such a weapon in 1952 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 of the Nagasaki weapon 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[2] known as Orange Herald (Small) which was 30 inches in diameter and weighed about 2000 lb. (900 kilograms).[3] It had a yield of 720 kilotons and was the largest pure fission weapon ever tested. One source says that this device used 117 kilograms of HEU.[4] 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 safety concerns regarding accidental criticality.

The British did not deploy the Orange Herald device. However, the British developed another King type weapon known as Green Grass. It was 45 inches (1.1 meters) in diameter and weighed 7,000 lb. (3,200 kilograms).[5] 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 (Small). It was deployed as a gravity bomb between 1958 and 1962 with the designations Violet Club and Yellow Sun Mk. 1.[6]

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[2] 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.

[3] 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.

[4] Nuclear Weapon Archive. Link Walker describes Orange Herald (Small) a little differently. He says that it 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.

[5] John Simpson, “British Nuclear Weapon Stockpiles, 1953-78, A Commentary on Technical and Political Drivers,” *RUSI Journal*, Vol. 156, No. 5, October/November 2011.

[6] John Walker, “British Nuclear Weapon Stockpiles, 1953-78,” *RUSI Journal*, Vol. 156, No. 5, October/November 2011.

Two-Stage Thermonuclear Weapons

Two-stage thermonuclear weapons, as the name implies, consist of two components: a primary which is a relatively low yield fission trigger and a thermonuclear burning secondary where most of the yield is produced. The secondary consists of a fissile material core (plutonium or enriched uranium) surrounded by alternating layers of thermonuclear fuel and natural uranium. The thermonuclear fuel is lithium deuteride (LiD). The secondary is commonly depicted as being a cylinder[7] but the Russians,[8] British[9] and French[10] have all stated that, in their early two-stage thermonuclear weapons, the secondaries were spheres.

In a two-stage thermonuclear weapon about half of the yield is from fission reactions and half from fusion reactions. The fusion reactions release high energy neutrons which can fission the U-238 in the secondary. The primary contributes relatively little of the total yield.

The two-stage thermonuclear device for which there is the best description is the British Grapple X device tested in November 1957.[11] The primary for this device was a Red Beard tactical pure fission implosion weapon which had a composite core (containing both plutonium and HEU) and 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 megaton.

The production of a two-stage thermonuclear weapon was the ultimate goal of the five major nuclear weapon powers. For the British and French their initial goal was to produce a yield of one megaton in a weapon weighing about one ton. The British achieved this goal with their Flagpole test in September 1958. The primary for this device was the Indigo Hammer pure fission implosion bomb, which was smaller than the Red Beard device used in the Grapple X test.

Two-stage thermonuclear weapons do not require nearly as much HEU or plutonium as other types of large yield nuclear weapons since not only do they produce yield from LiD but also from the fissioning of U-238. Further they have far better yield-to-weight ratios. It is reported that the TN 71, a French ballistic missile MIRV warhead, could produce 150 kilotons while weighing only 175 kilograms (385 lb.).[12]

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[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.

[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.

[11] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, pp. 155-160.

[12] 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.

Boosted Weapons

The British have revealed a good deal of information regarding boosted fission weapons.[13] These weapons use hollow cores of fissile material. Just before detonation a deuterium/tritium (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 small but this reaction releases a large number of high energy neutrons which significantly increase the efficiency of the fission reaction in the weapon. 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."[14][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 two-stage thermonuclear weapons.

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.

Layer-Cake Weapons

When the Soviets were first trying to figure out how to make a two-stage thermonuclear weapon, they produced a weapon which they nicknamed "Layer-Cake," (formally known as the RDS-6s).[15] It had a fissile core surrounded by alternating layers of LiD and natural uranium. This was essentially the secondary of a two-stage thermonuclear weapon. 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, being about the size of the Nagasaki weapon.

Four of the five major nuclear weapon states considered developing Layer-Cake type weapons. Both the Soviets and French tested such devices, which produced yields in the low hundreds of kilotons. The Soviets initially claimed that their device was a hydrogen bomb but clearly it was not. Often these sorts of devices are said to be boosted but again this is not true. They generally

[13] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001.
[14] *Ibid.*, p.177.
[15] G A Goncharov, "American and Soviet H-bomb Development Programmes: Historical Background," *Uspekhi Fizicheskikh Nauk.*, Vol. 39, No. 10, 1996.

do not contain tritium and unlike true boosted weapons, which enhance the fission reactions in the weapon but do not produce much thermonuclear yield, Layer-Cake type devices attempt to produce a significant part of their yield from thermonuclear reactions and from the fission of U-238. However, as the French found out in the mid-1960s, the thermonuclear efficiency of Layer-Cake type devices is disappointingly low and most of the yield is produced by the large amount of nuclear material (HEU or plutonium) contained in the device. Layer-Cake type devices could produce about the same yield even if all of the LiD and natural uranium were removed (making them King type devices). Still, many accounts of nuclear weapon development often incorrectly claim that these are boosted devices.

Boosting in the Five Major Nuclear Weapon States

The U.S. considered developing a Layer-Cake type device known as "Alarm Clock" as it struggled to discover the correct design for a hydrogen bomb in the late 1940s and early 1950s. However, it did not move forward with the "Alarm Clock" design. The U.S. tested a boosted device in May 1951. It was the Item shot of the Greenhouse test series and had a yield of 45.5 kilotons. Note that the U.S. had already tested a 49 kiloton yield pure fission weapon as part of the Sandstone test series in 1948, so the Item shot did not represent an increase in yield.

As I have written elsewhere, the U.S. appears not to have decided to employ boosted devices until late 1955 and did not actually deploy them until 1957.[16] In the meantime, in November 1952, it successfully tested a two-stage thermonuclear device known as the Mike shot in the Ivy test series. It had a yield of 10.4 megatons and was unique in that it used a liquid deuterium secondary. During the Castle test series in early 1954, the U.S. tested six two-stage thermonuclear devices with LiD containing secondaries. Later that year the U.S. began to field two-stage thermonuclear weapons. This timeline shows that early U.S. two-stage thermonuclear weapons did not have boosted primaries and that the U.S. deployed two-stage thermonuclear weapons before boosted weapons.

The fourth Soviet nuclear test was a Layer-Cake type device which had a yield of 400 kilotons. Though the Soviets initially thought that such a device was a true hydrogen bomb, they soon realized it was not, as this design could not produce the large yields that the U.S. had produced in the Ivy and Castle test series. In 1955, the Soviets tested their first two-stage thermonuclear weapon. It was designated RDS-37, produced a yield of 1.6 megatons, was readily deliverable and was airdropped for this test. The Russians say that they developed boosting in tests conducted in late 1957 and early 1958.[17] This shows that the Soviets, like the U.S., developed and deployed two-stage thermonuclear weapons before they developed boosting.

In May and June 1956 the British tested two devices in their Mosaic test series which involved what the British called "tamper boosting." This description has led some to believe that these tests involved boosting and were so successful that the second test in this series produced a higher than expected yield. However, these tests could not have involved boosting, since the

[16] The U.S. twice stopped tritium production, once in 1952 and again in 1954 see: Gregory S. Jones, "History of U.S. Tritium Production 1948-1988," June 12, 2017. Link

[17] "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.

British did not have any tritium at the time. Indeed, the British have explained that the tests were simplified versions of Layer-Cake designs using a single layer of LiD outside the fissile core.[18] The British have stated that this tamper boosting was unsuccessful, producing no more "than a few percent change in the yield." The first British attempt at boosting using tritium was the Breakaway shot in Buffalo test series in October 1956. It was a failure, as "the presence of the deutero-tritide in the centre of the fissile core lowered the unboosted yield by a factor of order 2."[19]

The British tested two partially successful two-stage thermonuclear devices in May/June 1957. For this same test series the British prepared a Layer-Cake type device known as Green Bamboo which reportedly contained 87 kilogram of HEU but they did not test it.[20] The British successfully tested the Grapple X two-stage thermonuclear device in November 1957. In April 1958, they successfully tested the Grapple Y two-stage thermonuclear device. This latter device had a yield of 3 megatons.

In the August/September 1958 Grapple Z test series, which was the final British test series before resuming nuclear cooperation with the U.S., the Flagpole shot was a successful test of a two-stage thermonuclear weapon which produced a one megaton yield while weighing about one ton. The British also successfully tested two boosted devices. The Pendant shot used solid LiDT and had a yield of 24 kilotons and the Burgee shot used DT gas and had a yield of 25 kilotons. Therefore, the British tested a number of two-stage thermonuclear devices before successfully testing boosted ones. When they did test boosted devices, the yields produced were only a little higher than that of a nominal 20 kiloton pure fission weapon.

In 1966, the French tested a plutonium-based King type device which had a reported yield between 120 and 150 kilotons. If this device had the same 39% efficiency as Orange Herald (Small), then this device would have contained between 17 and 21 kilograms of plutonium. This device became the first French land-based ballistic missile warhead, the MR-31 and was in service between 1970 and 1980. In 1966, the French attempted to develop a hydrogen bomb and tested several Layer-Cake type devices but the French found the results "disappointing."[21]

In 1968, France tested its first boosted device and its first two-stage thermonuclear device in the same test series. The boosted device was designed to produce a high yield and used a large amount of HEU as well as deuterium and tritium. Its yield was 500 kilotons. It was apparently a boosted version of a King type device. The French have termed the device "inelegant" and "bulky."[22] It became the first French sea-based ballistic missile warhead, the MR-41 and was in service between 1972 and 1980.

After at least five two-stage thermonuclear tests between 1968 and 1971, the French developed a device which produced a one megaton yield while weighing less than one ton. It apparently had

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[18] Lorna Arnold, *Britain and the H-Bomb*, Palgrave, New York, 2001, p. 238.
[19] *Ibid.*, p. 239.
[20] Nuclear Weapon Archive Link
[21] 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.
[22] *Ibid.*, p. 356.

a boosted primary.[23] This device was deployed as the TN-61. It entered service in 1976 and eventually replaced the MR-31 and MR-41. France is the only one of the five major nuclear powers to have developed and/or deployed a boosted weapon before a two-stage thermonuclear one.

China conducted a nuclear test in 1966 which was apparently some sort of thermonuclear experiment. It is often reported as being a boosted test but it could not have been since China had not yet produce tritium. Later in 1966 China conducted a reduced scale two-stage thermonuclear test and in June 1967 it conducted a full scale two-stage thermonuclear test with a yield of 3.3 megatons. China began production of tritium in May 1968 and produced LiDT in 1972.[24] By this time, China had already conducted four high yield two-stage thermonuclear tests. It appears that the Chinese used solid boosting material instead of DT gas. The Chinese have not explicitly stated when they conducted their first boosted nuclear test but it was clearly at least five years after they had developed two-stage thermonuclear devices.

Boosting in the Second Tier Nuclear Weapon States

Though not formally acknowledged, Israel is believed to have a significant nuclear weapon arsenal. Given the lack of any large yield nuclear testing, it is unlikely that Israel has developed two-stage thermonuclear weapons. However, in a one year interval in 1977 and 1978, Israel provided South Africa with 30 grams of tritium, which demonstrated that Israel was producing tritium at a substantial rate.[25] Therefore, it is likely that by this time Israel had developed boosted nuclear weapons. However, since the types and yields of Israeli nuclear weapons are unknown, it is not clear what role boosting plays in Israel's nuclear weapon program.

Pakistan has an acknowledged nuclear weapon program and there are indications that it may have developed boosted nuclear weapons, perhaps with foreign assistance. Since 2005 Pakistan has tested two cruise missiles (the Babur/Hatf-7 and the Ra'ad/Haft8) and since 2011 it has tested two short-ranged ballistic missiles (Abdali/Hatf-2 and Nasr/Hatf-9). The Pakistanis describe all of these missiles as "nuclear capable" but the low payload and small diameters of these missiles would seem to rule out the use of pure fission implosion weapons. This raises two possibilities. First, Pakistan is bluffing and is just conveniently applying the label "nuclear capable" to every missile regardless of whether it actually is. Second, Pakistan has developed small, light-weight boosted fission weapons. If so, this could explain why Pakistan is operating four military production reactors. One or more of these reactors may be needed to produce tritium in addition to plutonium. If Pakistan has developed boosting, there is no indication that it has used this technology to produce higher yield weapons. Rather it may be producing small, light-weight weapons that economize on nuclear material.

Not much is known about the specific nuclear weapons in India's arsenal, though its limited nuclear testing and relatively low yield nuclear tests make it unlikely that India has developed

[23] The French have indicated 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. See: Pierre Langereux, "Twenty Years of Progress in French Nuclear Weapons," *Air & Cosmos*, July 12, 1980.
[24] JPRS Report: Science & Technology, China, "Selections from 'China Today: Nuclear Industry," JPRS-CST-88-002. January 15, 1988, p. 31.
[25] David Albright, "South Africa's Secret Nuclear Weapons," *ISIS Report*, May 1994, p. 5.

two-stage thermonuclear weapons. India has developed pilot scale facilities to extract tritium from the heavy water moderator of its nuclear power plants.[26] It is unknown whether India has built full-scale facilities that could produce large amounts of tritium but this at least raises the possibility that India has developed boosted weapons.

Since 2006 North Korea has conducted five nuclear tests, all with yields of about 20 kilotons or less. After its fourth nuclear test in January 2016, North Korea claimed to have developed a two-stage thermonuclear device. The relatively low yield of this and the other North Korean nuclear tests led to widespread skepticism regarding this claim. However, experts speculated that perhaps North Korea had tested a boosted device. North Korea, using its graphite moderated plutonium production reactor at Yongbyon, could be producing enough tritium to boost roughly five nuclear weapons per year.[27] Until more information is available, however, it is impossible to determine whether North Korea has actually developed boosted nuclear weapons.

Conclusions

Boosting is not an intermediate technology on the road to two-stage thermonuclear weapons. Four of the five countries that possess two-stage thermonuclear weapons developed and/or deployed such weapons before boosted ones. In at least three of these five countries, boosted devices mainly serve as the primaries of two-stage thermonuclear weapons. Therefore, the emphasis is generally on devices that are smaller, lighter-weight and use less nuclear material than pure fission weapons. Only France, which produced a 500 kiloton boosted King type weapon (its first submarine-launched ballistic missile warhead, the MR-41) is known to have used boosting to increase the yield of a nuclear weapon.

The situation is a little different for the second tier nuclear powers. None of them appear to have developed two-stage thermonuclear weapons. However all four countries may have developed stand-alone boosted weapons. Little is known about the weapons in Israel or India but if Pakistan and/or North Korea have developed boosted weapons, the emphasis appears to be on small, light-weight weapons that use reduced amounts of nuclear material, not on producing high yields. If these countries wanted to produce high yield nuclear weapons, their best bet would be to develop King type weapons. However, the large amount of nuclear material required for each weapon would severely limit the number of weapons that they could produce. There would be no point for these countries to develop Layer-Cake type weapons since a King type weapon would be able to produce the same yield while being simpler, smaller and lighter.

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[26] V. K. Tangri and S. K. Das, "Heavy Water Purification: Design and Development of Combined Electrolysis and Catalytic Exchange Technology," *BARC Highlights: Chemical Sciences and Engineering*, 2006-2007.
[27] Gregory S. Jones, "The Implications of North Korea Testing a Boosted Nuclear Weapon," January 11, 2016. Link