A report on nuclear weapons engineering essay

A nuclear weapon is an explosive device that derives its destructive force from nuclear reactions, either fission or a combination of fission and fusion. Both reactions release vast quantities of energy from relatively small amounts of matter; a modern thermonuclear weapon weighing little more than a thousand kilograms can produce an explosion comparable to the detonation of more than a billion kilograms of conventional high explosive.

Thus, even single small nuclear devices no larger than traditional bombs can devastate an entire city by blast, fire and radiation. Nuclear weapons are considered weapons of mass destruction, and their use and control has been a major focus of international relations policy since their debut.

In the history of warfare, only two nuclear weapons have been detonated offensively, both near the end of World War II. The first was detonated on the morning of 6 August 1945, when the United States dropped a uranium gun-type device code-named " Little Boy" on the Japanese city of Hiroshima. The second was detonated three days later when the United States dropped a plutonium implosion-type device code-named " Fat Man" on the city of Nagasaki, Japan. These bombings resulted in the immediate deaths of an estimated 80, 000 people (mostly civilians) from injuries sustained from the explosion. When factoring in deaths from long-term effects of ionizing radiation and acute radiation sickness, the total death toll is estimated at 120, 000. The use of these weapons remains controversial.

Since the Hiroshima and Nagasaki bombings, nuclear weapons have been detonated on over two thousand occasions for testing purposes and demonstration purposes. A few states have possessed such weapons or are suspected of seeking them. The only countries known to have detonated nuclear weapons—and that acknowledge possessing such weapons—are (chronologically) the United States, the Soviet Union (succeeded as a nuclear power by Russia), the United Kingdom, France, the People's Republic of China, India, Pakistan, and North Korea. Israel is also widely believed to possess nuclear weapons, though it does not acknowledge having them.

There are two basic types of nuclear weapon. The first type produces its explosive energy through nuclear fission reactions alone. Such fission weapons are commonly referred to as atomic bombs or atom bombs (abbreviated as A-bombs), though their energy comes specifically from the nucleus of the atom.

In fission weapons, a mass of fissile material (enriched uranium or plutonium) is assembled into a supercritical mass—the amount of material needed to start an exponentially growing nuclear chain reaction—either by shooting one piece of sub-critical material into another (the " gun" method) or by compressing a sub-critical sphere of material using chemical explosives to many times its original density (the " implosion" method). The latter approach is considered more sophisticated than the former and only the latter approach can be used if the fissile material is plutonium.

A major challenge in all nuclear weapon designs is to ensure that a significant fraction of the fuel is consumed before the weapon destroys itself. The amount of energy released by fission bombs can range from the equivalent of less than a ton of TNT upwards of 500, 000 tons (500 kilotons) of TNT.

The second basic type of nuclear weapon produces a large amount of its energy through nuclear fusion reactions. Such fusion weapons are generally referred to as thermonuclear weapons or more colloquially as hydrogen bombs (abbreviated as H-bombs), as they rely on fusion reactions between isotopes of hydrogen (deuterium and tritium). However, all such weapons derive a significant portion, and sometimes a majority, of their energy from fission (including fission induced by neutrons from fusion reactions). Unlike fission weapons, there are no inherent limits on the energy released by thermonuclear weapons. Only six countries—United States, Russia, United Kingdom, People’s Republic of China, France and India—have conducted thermonuclear weapon tests. (Whether India has detonated a “ true,” multi-staged thermonuclear weapon is controversial.)

The basics of the Teller–Ulam design for a hydrogen bomb: a fission bomb uses radiation to compress and heat a separate section of fusion fuel.

Thermonuclear bombs work by using the energy of a fission bomb to compress and heat fusion fuel. In the Teller-Ulam design, which accounts for all multi-megaton yield hydrogen bombs, this is accomplished by placing a fission bomb and fusion fuel (tritium, deuterium, or lithium deuteride) in proximity within a special, radiation-reflecting container. When the fission bomb is detonated, gamma and X-rays emitted first compress the fusion fuel, then heat it to thermonuclear temperatures. The ensuing fusion reaction creates enormous numbers of high-speed neutrons, which can then induce fission in materials not normally prone to it, such as depleted uranium. Each of these components is known as a “ stage,” with the fission bomb as the “ primary” and the fusion capsule as the “ secondary.” In large hydrogen bombs, about half of the yield, and much of the resulting nuclear fallout, comes from the final fissioning of depleted uranium.

By chaining together numerous stages with increasing amounts of fusion fuel, thermonuclear weapons can be made to an almost arbitrary yield; the largest ever detonated (the Tsar Bomba of the USSR) released an energy equivalent of over 50 million tons (50 megatons) of TNT. Most thermonuclear weapons are considerably smaller than this, due to practical constraints arising from the space and weight requirements of missile warheads.

There are other types of nuclear weapons as well. For example, a boosted fission weapon is a fission bomb which increases its explosive yield through a small amount of fusion reactions, but it is not a fusion bomb. In the boosted bomb, the neutrons produced by the fusion reactions serve primarily to increase the efficiency of the fission bomb. Some weapons are designed for special purposes; a neutron bomb is a thermonuclear weapon that yields a relatively small explosion but a relatively large amount of neutron radiation; such a device could theoretically be used to cause massive casualties while leaving infrastructure mostly intact and creating a minimal amount of fallout.

The detonation of any nuclear weapon is accompanied by a blast of neutron radiation. Surrounding a nuclear weapon with suitable materials (such as cobalt or gold) creates a weapon known as a salted bomb. This device can produce exceptionally large quantities of radioactive contamination.

Most variation in nuclear weapon design is for the purpose of achieving different yields for different situations, and in manipulating design elements to attempt to minimize weapon size.

Nuclear weapons delivery—the technology and systems used to bring a nuclear weapon to its target—is an important aspect of nuclear weapons relating both to nuclear weapon design and nuclear strategy. Additionally, development and maintenance of delivery options is among the most resource-intensive aspects of a nuclear weapons program: according to one estimate, deployment costs accounted for 57% of the total financial resources spent by the United States in relation to nuclear weapons since 1940.

Historically the first method of delivery, and the method used in the two nuclear weapons actually used in warfare, was as a gravity bomb, dropped from bomber aircraft. This method is usually the first developed by countries as it does not place many restrictions on the size of the weapon and weapon miniaturization is something which requires considerable weapons design knowledge. It does, however, limit the range of attack, the response time to an impending attack, and the number of weapons which can be fielded at any given time.

With the advent of miniaturization, nuclear bombs can be delivered by both strategic bombers and tactical fighter-bombers, allowing an air force to use its current fleet with little or no modification. This method may still be considered the primary means of nuclear weapons delivery; the majority of U. S. nuclear warheads, for example, are free-fall gravity bombs, namely the B61.

More preferable from a strategic point of view is a nuclear weapon mounted onto a missile, which can use a ballistic trajectory to deliver the warhead over the horizon. While even short range missiles allow for a faster and less vulnerable attack, the development of long-range intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs) has given some nations the ability to plausibly deliver missiles anywhere on the globe with a high likelihood of success.

More advanced systems, such as multiple independently targetable reentry vehicles (MIRVs) allow multiple warheads to be launched at different targets from one missile, reducing the chance of a successful missile defense. Today, missiles are most common among systems designed for delivery of nuclear weapons. Making a warhead small enough to fit onto a missile, though, can be a difficult task.

Tactical weapons (see above) have involved the most variety of delivery types, including not only gravity bombs and missiles but also artillery shells, land mines, and nuclear depth charges and torpedoes for anti-submarine warfare. An atomic mortar was also tested at one time by the United States. Small, two-man portable tactical weapons (somewhat misleadingly referred to as suitcase bombs), such as the Special Atomic Demolition Munition, have been developed, although the difficulty of combining sufficient yield with portability limits their military utility.

Nuclear strategy

The United States' Peacekeeper missile was a MIRVed delivery system. Each missile could contain up to ten nuclear warheads (shown in red), each of which could be aimed at a different target. These were developed to make missile defense very difficult for an enemy country.

Nuclear warfare

Nuclear warfare strategy is a set of policies that deal with preventing or fighting a nuclear war. The policy of trying to prevent an attack by a nuclear weapon from another country by threatening nuclear retaliation is known as the strategy of nuclear deterrence. The goal in deterrence is to always maintain a second strike capability (the ability of a country to respond to a nuclear attack with one of its own) and potentially to strive for first strike status (the ability to completely destroy an enemy's nuclear forces before they could retaliate). During the Cold War, policy and military theorists in nuclear-enabled countries worked out models of what sorts of policies could prevent one from ever being attacked by a nuclear weapon.

Different forms of nuclear weapons delivery (see above) allow for different types of nuclear strategies. The goals of any strategy are generally to make it difficult for an enemy to launch a pre-emptive strike against the weapon system and difficult to defend against the delivery of the weapon during a potential conflict. Sometimes this has meant keeping the weapon locations hidden, such as deploying them on submarines or rail cars whose locations are very hard for an enemy to track and other times this means protecting them by burying them in hardened bunkers.

Other components of nuclear strategies have included using missile defense (to destroy the missiles before they land) or implementation of civil defense measures (using early-warning systems to evacuate citizens to safe areas before an attack).

Note that weapons which are designed to threaten large populations or to generally deter attacks are known as strategic weapons. Weapons which are designed to actually be used on a battlefield in military situations are known as tactical weapons.

There are critics of the very idea of nuclear strategy for waging nuclear war who have suggested that a nuclear war between two nuclear powers would result in mutual annihilation. From this point of view, the significance of nuclear weapons is purely to deter war because any nuclear war would immediately escalate. out of mutual distrust and fear, resulting in mutually assured destruction. This threat of national, if not global, destruction has been a strong motivation for anti-nuclear weapons activism.

Critics from the peace movement and within the military establishment have questioned the usefulness of such weapons in the current military climate. The use of (or threat of use of) such weapons would generally be contrary to the rules of international law applicable in armed conflict, according to an advisory opinion issued by the International Court of Justice in 1996.

Perhaps the most controversial idea in nuclear strategy is that nuclear proliferation would be desirable. This view argues that, unlike conventional weapons, nuclear weapons successfully deter all-out war between states, and they are said to have done this during the Cold War between the U. S. and the Soviet Union. Political scientist Kenneth Waltz is the most prominent advocate of this argument.

The threat of potentially suicidal terrorists possessing nuclear weapons (a form of nuclear terrorism) complicates the decision process. Mutually assured destruction may not be effective against an enemy who expects to die in a confrontation and would not therefore be deterred by a sense of self-preservation. Further, if the initial act is from a rogue group instead of a sovereign nation, there is no fixed nation or fixed military targets to retaliate against. It has been argued, especially after the September 11, 2001 attacks, that this complication is the sign of the next age of nuclear strategy, distinct from the relative stability of the Cold War.

Disarmament

Beginning with the 1963 Partial Test Ban Treaty and continuing through the 1996 Comprehensive Test Ban Treaty, there have been many treaties to limit or reduce nuclear weapons testing and stockpiles. The 1968 Nuclear Non-Proliferation Treaty has as one of its explicit conditions that all signatories must “ pursue negotiations in good faith” towards the long-term goal of “ complete disarmament”. However, no nuclear state has treated that aspect of the agreement as having binding force

Only one country—South Africa—has ever fully renounced nuclear weapons they had independently developed. A number of former Soviet republics—Belarus, Kazakhstan, and Ukraine—returned Soviet nuclear arms stationed in their countries to Russia after the collapse of the USSR.

Uses

The Sedan test from 1962 formed a crater 100 m (330 ft) deep with a diameter of about 390 m (1, 300 ft), as a means of investigating the possibilities of using peaceful nuclear explosions for large-scale earth moving.

Apart from their use as weapons, nuclear explosives have been tested and used for various non-military uses, and proposed, but not used for large-scale earth moving. When long term health and clean-up costs were included, there was no economic advantage over conventional explosives.

Synthetic elements, such as einsteinium and fermium, created by neutron bombardment of uranium and plutonium during thermonuclear explosions, were discovered in the aftermath of the first thermonuclear bomb test. In 2008 the worldwide presence of new isotopes from atmospheric testing beginning in the 1950s was developed into a reliable way of detecting art forgeries, as all paintings created after that period may contain traces of cesium-137 and strontium-90, isotopes that did not exist in nature before 1945.

Nuclear explosives have also been seriously studied as potential propulsion mechanisms for space travel (see Project Orion).

Nuclear reactions

Nuclear fission splits heavier atoms to form lighter atoms. Nuclear fusion bonds together lighter atoms to form heavier atoms. Both reactions generate roughly a million times more energy than comparable chemical reactions, making nuclear bombs a million times more powerful than non-nuclear bombs, which a French patent claimed in May 1939.

In some ways, fission and fusion are opposite and complementary reactions, but the particulars are unique for each. To understand how nuclear weapons are designed, it is useful to know the important similarities and differences between fission and fusion. The following explanation uses rounded numbers and approximations.

Fission

When a free neutron hits the nucleus of a fissionable atom like uranium-235 (235U), the uranium splits into two smaller atoms called fission fragments, plus more neutrons. Fission can be self-sustaining because it produces more neutrons of the speed required to cause new fissions.

The uranium atom can split any one of dozens of different ways, as long as the atomic weights add up to 236 (uranium plus the extra neutron). The following equation shows one possible split, namely into strontium-95 (95Sr), xenon-139 (139Xe), and two neutrons (n), plus energy:

The immediate energy release per atom is 180 million electron volts (MeV), i. e. 74 TJ/kg, of which 90% is kinetic energy (or motion) of the fission fragments, flying away from each other mutually repelled by the positive charge of their protons (38 for strontium, 54 for xenon). Thus their initial kinetic energy is 67 TJ/kg, hence their initial speed is 12, 000 kilometers per second, but their high electric charge causes many inelastic collisions with nearby nuclei. The fragments remain trapped inside the bomb's uranium pit until their motion is converted into x-ray heat, a process which takes about a millionth of a second (a microsecond).

This x-ray energy produces the blast and fire which are normally the purpose of a nuclear explosion.

After the fission products slow down, they remain radioactive. Being new elements with too many neutrons, they eventually become stable by means of beta decay, converting neutrons into protons by throwing off electrons and gamma rays. Each fission product nucleus decays between one and six times, average three times, producing a variety of isotopes of different elements, some stable, some highly radioactive, and others radioactive with half-lives up to 200, 000 years In reactors, the radioactive products are the nuclear waste in spent fuel. In bombs, they become radioactive fallout, both local and global.

Meanwhile, inside the exploding bomb, the free neutrons released by fission strike nearby U-235 nuclei causing them to fission in an exponentially growing chain reaction (1, 2, 4, 8, 16, etc.). Starting from one, the number of fissions can theoretically double a hundred times in a microsecond, which could consume all uranium up to hundreds of tons by the hundredth link in the chain. In practice, bombs do not contain that much uranium, and, anyway, just a few kilograms undergo fission before the uranium blows itself apart.

Holding an exploding bomb together is the greatest challenge of fission weapon design. The heat of fission rapidly expands the uranium pit, spreading apart the target nuclei and making space for the neutrons to escape without being captured. The chain reaction stops.

Materials which can sustain a chain reaction are called fissile. The two fissile materials used in nuclear weapons are: U-235, also known as highly enriched uranium (HEU), oralloy (Oy) meaning Oak Ridge Alloy, or 25 (the last digits of the atomic number, which is 92 for uranium, and the atomic weight, here 235, respectively); and Pu-239, also known as plutonium, or 49 (from 94 and 239).

Uranium’s most common isotope, U-238, is fissionable but not fissile (meaning that it cannot sustain a chain reaction by itself but can be made to fission, specifically by neutrons from a fusion reaction). Its aliases include natural or unenriched uranium, depleted uranium (DU), tubealloy (Tu), and 28. It cannot sustain a chain reaction, because its own fission neutrons are not powerful enough to cause more U-238 fission. However, the neutrons released by fusion will fission U-238. This U-238 fission reaction produces most of the destructive energy in a typical two-stage thermonuclear weapon.

Fusion

Fusion is unlikely to be self-sustaining because it does not produce the heat and pressure necessary for more fusion. It produces neutrons which run away with the energy In weapons, the most important fusion reaction is called the D-T reaction. Using the heat and pressure of fission, hydrogen-2, or deuterium (2D), fuses with hydrogen-3, or tritium (3T), to form helium-4 (4He) plus one neutron (n) and energy

Notice that the total energy output, 17. 6 MeV, is one tenth of that with fission, but the ingredients are only one-fiftieth as massive, so the energy output per unit mass is greater. However, in this fusion reaction 80% of the energy, or 14 MeV, is in the motion of the neutron which, having no electric charge and being almost as massive as the hydrogen nuclei that created it, can escape the scene without leaving its energy behind to help sustain the reaction – or to generate x-rays for blast and fire.

The only practical way to capture most of the fusion energy is to trap the neutrons inside a massive bottle of heavy material such as lead, uranium, or plutonium. If the 14 MeV neutron is captured by uranium (either type: 235 or 238) or plutonium, the result is fission and the release of 180 MeV of fission energy, multiplying the energy output tenfold.

Fission is thus necessary to start fusion, helps to sustain fusion, and captures and multiplies the energy released in fusion neutrons. In the case of a neutron bomb (see below) the last-mentioned does not apply since the escape of neutrons is the objective.

Tritium production

A third important nuclear reaction is the one that creates tritium, essential to the type of fusion used in weapons and, incidentally, the most expensive ingredient in any nuclear weapon. Tritium, or hydrogen-3, is made by bombarding lithium-6 (6Li) with a neutron (n) to produce helium-4 (4He) plus tritium (3T) and energy:

A nuclear reactor is necessary to provide the neutrons. The industrial-scale conversion of lithium-6 to tritium is very similar to the conversion of uranium-238 into plutonium-239. In both cases the feed material is placed inside a nuclear reactor and removed for processing after a period of time. In the 1950s, when reactor capacity was limited, the production of tritium and plutonium were in direct competition. Every atom of tritium in a weapon replaced an atom of plutonium that could have been produced instead.

The fission of one plutonium atom releases ten times more total energy than the fusion of one tritium atom, and it generates fifty times more blast and fire. For this reason, tritium is included in nuclear weapon components only when it causes more fission than its production sacrifices, namely in the case of fusion-boosted fission.

However, an exploding nuclear bomb is a nuclear reactor. The above reaction can take place simultaneously throughout the secondary of a two-stage thermonuclear weapon, producing tritium in place as the device explodes.

Of the three basic types of nuclear weapon, the first, pure fission, uses the first of the three nuclear reactions above. The second, fusion-boosted fission, uses the first two. The third, two-stage thermonuclear, uses all three.

Pure fission weapons

The first task of a nuclear weapon design is to rapidly assemble a supercritical mass of fissile uranium or plutonium. A supercritical mass is one in which the percentage of fission-produced neutrons captured by another fissile nucleus is large enough that each fission event, on average, causes more than one additional fission event.

Once the critical mass is assembled, at maximum density, a burst of neutrons is supplied to start as many chain reactions as possible. Early weapons used an “ urchin” inside the pit containing polonium-210 and beryllium separated by a thin barrier. Implosion of the pit crushed the urchin, mixing the two metals, thereby allowing alpha particles from the polonium to interact with beryllium to produce free neutrons. In modern weapons, the neutron generator is a high-voltage vacuum tube containing a particle accelerator which bombards a deuterium/tritium-metal hydride target with deuterium and tritium ions. The resulting small-scale fusion produces neutrons at a protected location outside the physics package, from which they penetrate the pit. This method allows better control of the timing of chain reaction initiation.

The critical mass of an uncompressed sphere of bare metal is 110lb (50kg) for uranium-235 and 35lb (16kg) for delta-phase plutonium-239. In practical applications, the amount of material required for criticallity is modified by shape, purity, density, and the proximity to neutron-reflecting material, all of which affect the escape or capture of neutrons.

To avoid a chain reaction during handling, the fissile material in the weapon must be sub-critical before detonation. It may consist of one or more components containing less than one uncompressed critical mass each. A thin hollow shell can have more than the bare-sphere critical mass, as can a cylinder, which can be arbitrarily long without ever reaching criticallity.

A tamper is an optional layer of dense material surrounding the fissile material. Due to its inertia it delays the expansion of the reacting material, increasing the efficiency of the weapon. Often the same layer serves both as tamper and as neutron reflector.

Gun-type assembly weapon

Diagram of a gun-type fission weapon

Little Boy, the Hiroshima bomb, used 141lb (64kg) of uranium with an average enrichment of around 80%, or 112lb (51kg) of U-235, just about the bare-metal critical mass. (See Little Boy article for a detailed drawing.) When assembled inside its tamper/reflector of tungsten carbide, the 141lb (64kg) was more than twice critical mass. Before the detonation, the uranium-235 was formed into two sub-critical pieces, one of which was later fired down a gun barrel to join the other, starting the atomic explosion. About 1% of the uranium underwent fission; the remainder, representing most of the entire wartime output of the giant factories at Oak Ridge, scattered uselessly.

The inefficiency was caused by the speed with which the uncompressed fissioning uranium expanded and became sub-critical by virtue of decreased density. Despite its inefficiency, this design, because of its shape, was adapted for use in small-diameter, cylindrical artillery shells (a gun-type warhead fired from the barrel of a much larger gun). Such warheads were deployed by the United States until 1992, accounting for a significant fraction of the U-235 in the arsenal, and were some of the first weapons dismantled to comply with treaties limiting warhead numbers. The rationale for this decision was undoubtedly a combination of the lower yield and grave safety issues associated with the gun-type design.

Implosion type weapon

Fat Man, the Nagasaki bomb, used 13. 6lb (6. 2kg, about 12 fluid ounces or 350 ml in volume) of Pu-239, which is only 39% of bare-sphere critical mass. (See Fat Man article for a detailed drawing.) Surrounded by a U-238 reflector/tamper, the pit was brought close to critical mass by the neutron-reflecting properties of the U-238. During detonation, criticality was achieved by implosion. The plutonium pit was squeezed to increase its density by simultaneous detonation of the conventional explosives placed uniformly around the pit. The explosives were detonated by multiple exploding-bridgewire detonators. It is estimated that only about 20% of the plutonium underwent fission, the rest, about 11lb (5. 0kg), was scattered.

An implosion shock wave might be of such short duration that only a fraction of the pit is compressed at any instant as the wave passes through it. A pusher shell made out of low density metal—such as aluminum, beryllium, or an alloy of the two metals (aluminum being easier and safer to shape and beryllium for its high-neutron-reflective capability) —may be needed. The pusher is located between the explosive lens and the tamper. It works by reflecting some of the shock wave backwards, thereby having the effect of lengthening its duration. Fat Man used an aluminum pusher. The key to Fat Man's greater efficiency was the inward momentum of the massive U-238 tamper (which did not undergo fission). Once the chain reaction started in the plutonium, the momentum of the implosion had to be reversed before expansion could stop the fission. By holding everything together for a few hundred nanoseconds more, the efficiency was increased.

Two-point linear implosion

A very inefficient implosion design is one that simply reshapes an ovoid into a sphere, with minimal compression. In linear implosion, an untamped, solid, elongated mass of Pu-239, larger than critical mass in a sphere, is embedded inside a cylinder of high explosive with a detonator at each end

Detonation makes the pit critical by driving the ends inward, creating a spherical shape. The shock may also change plutonium from delta to alpha phase, increasing its density by 23%, but without the inward momentum of a true implosion. The lack of compression makes it inefficient, but the simplicity and small diameter make it suitable for use in artillery shells and atomic demolition munitions – ADMs – also known as backpack or suitcase nukes.

All such low-yield battlefield weapons, whether gun-type U-235 designs or linear implosion Pu-239 designs, pay a high price in fissile material in order to achieve diameters between six and ten inches (254mm).

Fusion-boosted fission weapons

The next step in miniaturization was to speed up the fissioning of the pit to reduce the minimum inertial confinement time. The hollow pit provided an ideal location to introduce fusion for the boosting of fission. A 50-50 mixture of tritium and deuterium gas, pumped into the pit during arming, will fuse into helium and release free neutrons soon after fission begins. The neutrons will start a large number of new chain reactions while the pit is still critical or nearly critical. Once the hollow pit is perfected, there is little reason not to boost. The concept of fusion-boosted fission was first tested on May 25, 1951, in the Item shot of Operation Greenhouse, Eniwetok, yield 45. 5 kilotons. Boosting reduces diameter in three ways, all the result of faster fission:

- Since the compressed pit does not need to be held together as long, the massive U-238 tamper can be replaced by a light-weight beryllium shell (to reflect escaping neutrons back into the pit). The diameter is reduced.

- The mass of the pit can be reduced by half, without reducing yield. Diameter is reduced again.
- Since the mass of the metal being imploded (tamper plus pit) is reduced, a smaller charge of high explosive is needed, reducing diameter even further.

Since boosting is required to attain full design yield, any reduction in boosting reduces yield. Boosted weapons are thus variable-yield weapons. Yield can be reduced any time before detonation, simply by putting less than the full amount of tritium into the pit during the arming procedure.

The first device whose dimensions suggest employment of all these features (two-point, hollow-pit, fusion-boosted implosion) was the Swan device, tested June 22, 1956, as the Inca shot of Operation Redwing, a