

The Technology of Nuclear Weapons

- [Arms Control Today](#)

THE FIRST DESIGN of a nuclear weapon in the United States was a gun-barrel assembly, in which two sub-critical masses of very highly enriched uranium (HEU), were brought together by normal artillery propellant in a short gun barrel into a single over-critical configuration. (Criticality defines the minimum amount of a fissionable material in a particular configuration and density capable of a self-sustaining chain reaction).

The second type of fission weapon is the implosion assembly, in which a high explosive (with a much faster detonation speed than the propellant used in a gun-type weapon) compresses fissile material so that it reaches a super-critical mass. Less fissile material is required for an implosion assembly because the critical mass varies inversely as the square of density.

A nuclear explosion requires an exponentially growing fission chain reaction in which a neutron causes fission, producing energy and liberating two or three neutrons, more than one of which on average goes on to cause another fission, and so on. This chain breeding of neutrons and consequent fission is terminated by the disassembly of the system caused by the rapid energy release resulting from the fission process. In both the gun-barrel and implosion-type assemblies, neutron sources were devised that would emit neutrons at the appropriate time, and rapidly enough so that the chain reaction would, with high probability, be initiated before the material disassembled mechanically at speeds similar to that with which it was assembled.

In the fissionable materials used in nuclear weapons (U-235 and plutonium-239), the fission is caused mainly by fast neutrons, which travel only a distance of seven to 10 centimeters before colliding with a nucleus, so that each doubling of the neutron population occurs in about 0.01 microseconds (one-hundred millionth of a second). The power of compound interest is such that beginning with a single fission, the time required at this doubling interval to cause fission of 1 kilogram of fissionable material is the time required for 80 such doublings, or less than 1 microsecond (one millionth of a second). This corresponds to an energy release equivalent to about 17 kilotons (17,000 tons) of high explosive. The gun-type weapon used at Hiroshima, which contained approximately 60 kilograms of HEU, produced an energy release equivalent to about 15 kilotons of high explosive.

The Acquisition of a Weapon

The separation of U-235 from the 140-times-as-abundant isotope uranium-238 (U-238) in natural uranium is a costly and difficult process, which originally could not be counted on to provide fissile material as rapidly as was thought to be necessary in the U.S. weapon program during World War II. Accordingly, with the discovery of the new element plutonium (in particular, the Pu-239 isotope that is produced in natural-uranium nuclear reactors by the parasitic capture of neutrons by U-238), production reactors were built at Hanford, Washington. A reactor with a thermal power of 250 megawatts produces about 250 grams of plutonium per day. Approximately 6 kilograms of plutonium was used in the world's first nuclear explosion—the "Trinity" test conducted at Alamogordo, New Mexico, on July 16, 1945—and an identical weapon detonated over Nagasaki three days after Hiroshima.

The Technology of Nuclear Weapons

Published on Arms Control Association (<https://www.armscontrol.org>)

Plutonium cannot be used in a gun-assembly weapon because the components are moved too slowly. Pu-239 is accompanied by the isotope Pu-240, which has a "spontaneous fission" decay that injects neutrons continuously into any mass of plutonium. The relatively slow assembly of metallic blocks in a plutonium gun (measured in milliseconds) would allow time for such neutrons to start the chain reaction when the assembly is barely super-critical, leading to a much reduced yield. Thus, for the plutonium weapon, assembly is achieved through implosion, which occurs on a time scale of microseconds.

In the years following 1945, innovations were made to reduce the amount of costly fissionable material needed for nuclear weapons and to improve their safety. With the initial configuration much farther from criticality, the weapon was safer against undesired nuclear explosion. Nevertheless, one could conceive of accidents in which the high explosive would detonate at one point by, for instance, the impact of a rifle bullet on the explosive or the accidental dropping of the nuclear bomb. Almost from the beginning of the U.S. program, nuclear weapons were required to be safe against such undesired nuclear explosions. For some years, this was accomplished by systems in which some of the fissile core of the weapon would be kept separate from the explosive and inserted only during the flight of the aircraft on an actual mission. But because this impeded military readiness and flexibility, later weapons were designed with internal mechanical safing devices, or so that they were "inherently" one-point safe.

In 1951, the United States first tested the "boosting" concept, in which a small amount of thermonuclear fuel was added to the ordinary fission bomb. This is currently accomplished by the use of a gas mixture of deuterium and tritium within the hollow "pit" of an implosion weapon. At the temperatures reached in the incipient nuclear explosion, a fraction of the tritium nuclei react with the deuterium nuclei to form helium nuclei and a neutron of 14 million-volt energy; these neutrons are extremely effective at causing fission in the now compressed fissionable material. While the thermonuclear reaction produces a relatively small amount of the total energy, it does result in a substantial number of neutrons that steps up, or boosts, the fission reaction to a higher level. Boosting further increases the safety of such an explosive, because a larger amount of fissionable material would otherwise be required to reach the boosted yield.

However, boosting adds its own problems to nuclear weapon design and maintenance because hydrogen reacts chemically with plutonium and uranium, and the artificial isotope of hydrogen (tritium) has a half-life of 12.3 years, so that the tritium supply must be renewed on a scale of several years. Although the remaining tritium can be recycled, boosting imposes the requirement for continued production of tritium if nuclear weapon numbers do not fall with time faster than the decay rate of tritium.

In 1952, the United States demonstrated with its 10-megaton yield "MIKE" test the concept introduced in early 1951 by Edward Teller and Stanislaw Ulam, by which the energy from a "primary" nuclear explosion, emerging as thermal X-rays, is used to assemble a "secondary" charge containing thermonuclear fuel. Initially, the secondary contained liquid deuterium, which required refrigeration and was unwieldy. The secondary was soon replaced with solid thermonuclear fuel, using deuterium that was solidified by chemical binding to the naturally occurring lighter isotope of lithium, which captures neutrons in the process and yields tritium to burn with deuterium. —[R.L.G.](#)

Source URL: <https://www.armscontrol.org/act/1997-11/features/technology-nuclear-weapons>