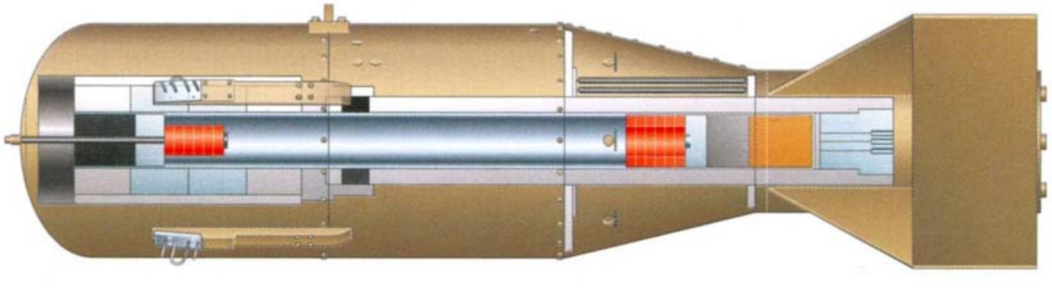
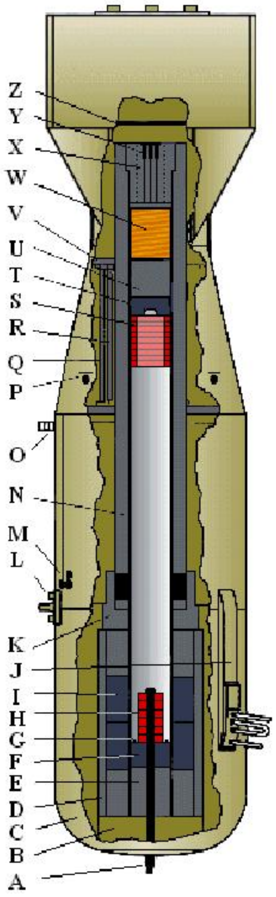
How to Build a Gun-type Bomb

The gun-type assembly method was the “obvious” way to construct a nuclear weapon. Two masses of subcritical size would be brought together quickly, resulting in a supercritical mass.

The original design, called *Thin Man* after a popular movie title of the era, was to be 17 feet long. The B-29 intercontinental heavy bomber had been ordered into production early in the war, and a squadron was diverted to the Manhattan Project. This became the 509th Composite Group, commanded by Col. Paul Tibbets. The B-29 had forward and aft bomb bays — these were reconfigured to be one very large bay to hold the (expected) weapon. These bombers were also stripped to save weight, retaining only a single 20mm cannon in the tail.



The detonation sequence of the Little Boy weapon was simpler than a plutonium core implosion. The bomb was essentially a powerful gun that fired a uranium projectile into a "target" of uranium-235, causing a chain reaction and a nuclear explosion.



Cross-section drawing of Y-1852 Little Boy showing major mechanical component placement. Drawing is shown to scale. Numbers in ( ) indicate quantity of identical components. Not shown are the APS-13 radar units, clock box with pullout wires, baro switches and tubing, batteries, and electrical wiring. (John Coster-Mullen)

Z) Armor Plate
Y) Mark XV electric gun primers (3)
X) Gun breech with removable inner plug
W) Cordite powder bags (4)
V) Gun tube reinforcing sleeve
U) Projectile steel back
T) Projectile Tungsten-Carbide disk
S) U-235 projectile rings (9)
R) Alignment rod (3)
Q) Armored tube containing primer wiring (3)
P) Baro ports (8)
O) Electrical plugs (3)
N) 6.5" bore gun tube
M) Safing/arming plugs (3)
L) Lift lug
K) Target case gun tube adapter
J) Yagi antenna assembly (4)
I) Four-section 13" diameter Tungsten-Carbide tamper cylinder sleeve
H) U-235 target rings (6)
G) Polonium-Beryllium initiators (4)
F) Tungsten-Carbide tamper plug
E) Impact absorbing anvil
D) K-46 steel target liner sleeve
C) Target case forging
B) 15" diameter steel nose plug forging
A) Front nose locknut attached to 1" diameter main steel rod holding target components

"Atom Bombs: The Top Secret Inside Story of Little Boy and Fat Man," 2003, p 112.
John Coster-Mullen drawing used with permission

Little Boy in the bomb pit on Tinian island, before being loaded into *Enola Gay's* bomb bay. A section of the bomb bay door is visible on the top right.

How many generations are required for a 10-kiloton (Hiroshima-sized) weapon?

Each fission event releases about 200 MeV of energy, which is 3.2×10^{-11} joule. (This is NOT very much!) By direct measurement, the energy released in a 1-kiloton explosion is 4.2×10^{13} joules. Hence the total number of fissions required to release 10 kilotons of energy is

$$\mathcal{N} = \frac{4.2 \times 10^{13} \text{ joules}}{3.2 \times 10^{-11} \text{ joule/fission}} = 1.3 \times 10^{24} \text{ fissions}$$

If we doubled the number of fissions in each generation,

Generation	Fissions in this Generation	Total number of Fissions
1	1	1
2	2	3
3	4	7
4	8	15
5	16	31
6	32	63
…	…	…
80	6×10^{23}	1.2×10^{24}
81	1.2×10^{24}	2.4×10^{24}
82	2.4×10^{24}	4.8×10^{24}

we see that we need about 80 generations. (Since we actually get about 2.5 neutrons per fission instead of 2, we need fewer generations than this.)

This number of nuclei is present in about 2 moles of Uranium, (6×10^{23} atoms per mole), so that one might think that only 0.47 kg is required. But this is the number that actually fission, not the total number present. Assuming a10% efficiency, a more reasonable estimate would be about 5 kg. This is, in fact, ample for an implosion device. For a gun-type weapon, numerous other factors must be taken into account.

In the open literature, Wikipedia, the critical mass for a bare ^{235}U sphere is stated as being 52 kg, about 17 centimeters in diameter. This is consistent with various other sources, assuming an 80% average enrichment of the uranium.

If we add up the energy contributions from the last few generations, we find that 99.9% of all the energy is released in the last 10 generations.

How long does the explosion take?

The average kinetic energy of a neutron in the fission process is 1 MeV, or 1.6 x 10^{-13} joules. Since

$$KE = (1/2)\, m\, v^2,$$

then

$$v = (\, 2\, KE/m)^{½}.$$

The neutron's mass is 1.67 x 10^{-27} kg. So,

$$v = (2 \text{ x } 1.6 \text{ x } 10^{-13}\text{ J}/\ 1.67 \text{ x } 10^{-27}\text{ kg})^{½} = 1.4 \text{ x } 10^{7} \text{ meters/second.}$$

So, neutrons travel at about 10^7 meters/second. A characteristic time for each generation is less than the time it takes to travel the diameter of the sphere — if a fission doesn't take place in this time, the neutron will have left the sphere and no fission will occur. (This is an order-of-magnitude estimate only.) Let's take it to be 10 centimeters, 10^{-1} meters. Then

$$\text{Time} = \text{distance/velocity} = \frac{10^{-1}\text{ meters}}{10^{7}\text{ meters/second}} = 10^{-8}\text{ seconds}$$

In the code-talk of Los Alamos, this is called a *shake*. (As in "as fast as the shake of a lamb's tail".) Most of the energy comes out in the last 10 shakes, one-tenth of a microsecond.

How fast need the assembly be?

We want the weapon to transition from a subcritical to a supercritical configuration fast enough so that a stray neutron won't come along and initial a chain reaction before the weapon is completely assembled. That is, it should be assembled in a time short compared to the time between stray neutrons.

Let's assume that the assembly speed (the speed of the projectile in the gun) is 1 kilometer/second, and that we're concerned with the last 10 centimeters of travel. At that velocity, the assembly time is

$$\text{time} = \text{distance/velocity} = 0.1\text{ m} / 10^3\text{ m/s} = 10^{-4}\text{ seconds}$$

While we've been concerned with the probability (cross-section) for a nuclei to absorb a neutron and fission, it is also possible that a nuclei can fission spontaneously. For ^{235}U, that rate is 0.0004 neutrons/(gram second). Assuming 50 kg of material, that gives

$$\text{rate} = 0.0004 \frac{\text{neutrons}}{\text{gram second}} 50 \times 10^3\text{ gram} = 20\text{ neutrons/second}$$

and the average time between neutrons is (1/20) seconds = 5 x 10^{-2} seconds, 500 times longer than the assembly time. Thus the chances are about 1 in 500 that the bomb would fizzle, a probability deemed low enough that the Hiroshima-type weapon was never tested.

The original intention had been to use this assembly method for the plutonium weapon as well. The spontaneous neutron emission rate for ^{239}Pu is about 0.025 neutrons/gram second, and 10 kg are required. Thus the rate of neutron production is

$$\text{rate} = 0.025 \frac{\text{neutrons}}{\text{gram second}} 10 \times 10^3\text{ gram} = 250\text{ neutrons/second}$$

and the average time between neutrons is (1/250) seconds = 4 x 10^{-3} seconds, about 40 times the assembly time, so that the probablility of a fizzle is 1 in 40. This is getting a bit larger than we would like, but maybe we can tweak the assembly and make the numbers more favorable.

However, this much plutonium can only be produced in a reactor. (The first plutonium was made in particle accelerators.) Neutron capture by ^{238}U yields ^{239}U, which beta decays (with a halflife of 23 minutes) to ^{239}Np. The Neptunium then beta decays (with a

halflife of 2.4 days) to ^{239}Pu. However, as the ^{239}Pu is sitting in the reactor, it can absorb another neutron, yielding ^{240}Pu. While the plutonium can be separated from the other elements in the fuel rods by chemical means, the two isotopes can not be separated from one another. Thus it must be assumed that this isotopic contaminant is present.
The problem is that the spontaneous neutron emission rate for ^{240}Pu is 1030 neutrons per gram second, about 40,000 greater than for ^{239}Pu. If there is only a 1% contamination of this isotope, then there is still some 100 grams of ^{240}Pu present, so that

$$\text{rate} = 1030 \ \frac{\text{neutrons}}{\text{gram second}} \ 100 \text{ gram} = \ 103{,}000 \ \text{neutrons/second}$$

and the average time between neutrons is 1/103000 seconds = 10^{-5} seconds. That is, on average, there will be 10 neutrons emitted during the crucial assembly period and a fizzle is practically guaranteed!

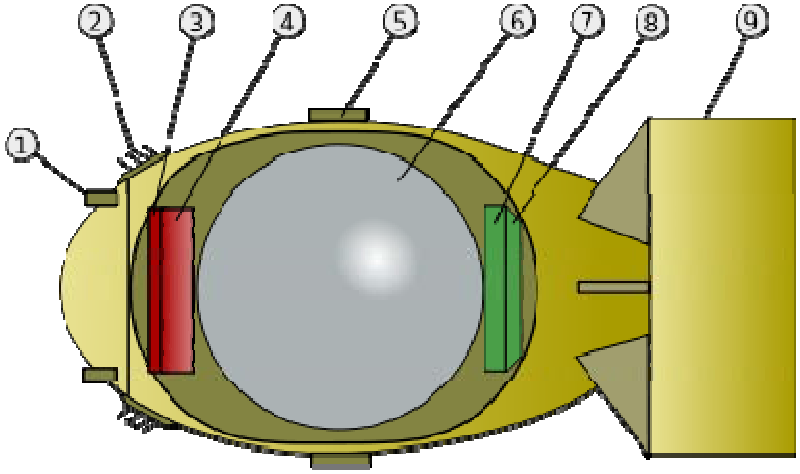
When this was discovered, it was immediately realized that the gun-type assembly would not work for plutonium. The Los Alamos lab had to completely reorganize, to develop a different mechanism.

Work on the uranium weapon was turned over to the ordnance group. Since assembly time was not an issue, a smaller assembly speed was acceptable. This meant that the gun could be shorter, about 10 feet long. This evolved into *Little Boy*, a design so well understood that no test was deemed necessary. Besides, ***essentially all the ^{235}U in the world was contained in the one weapon!***

How to Build an Implosion Bomb

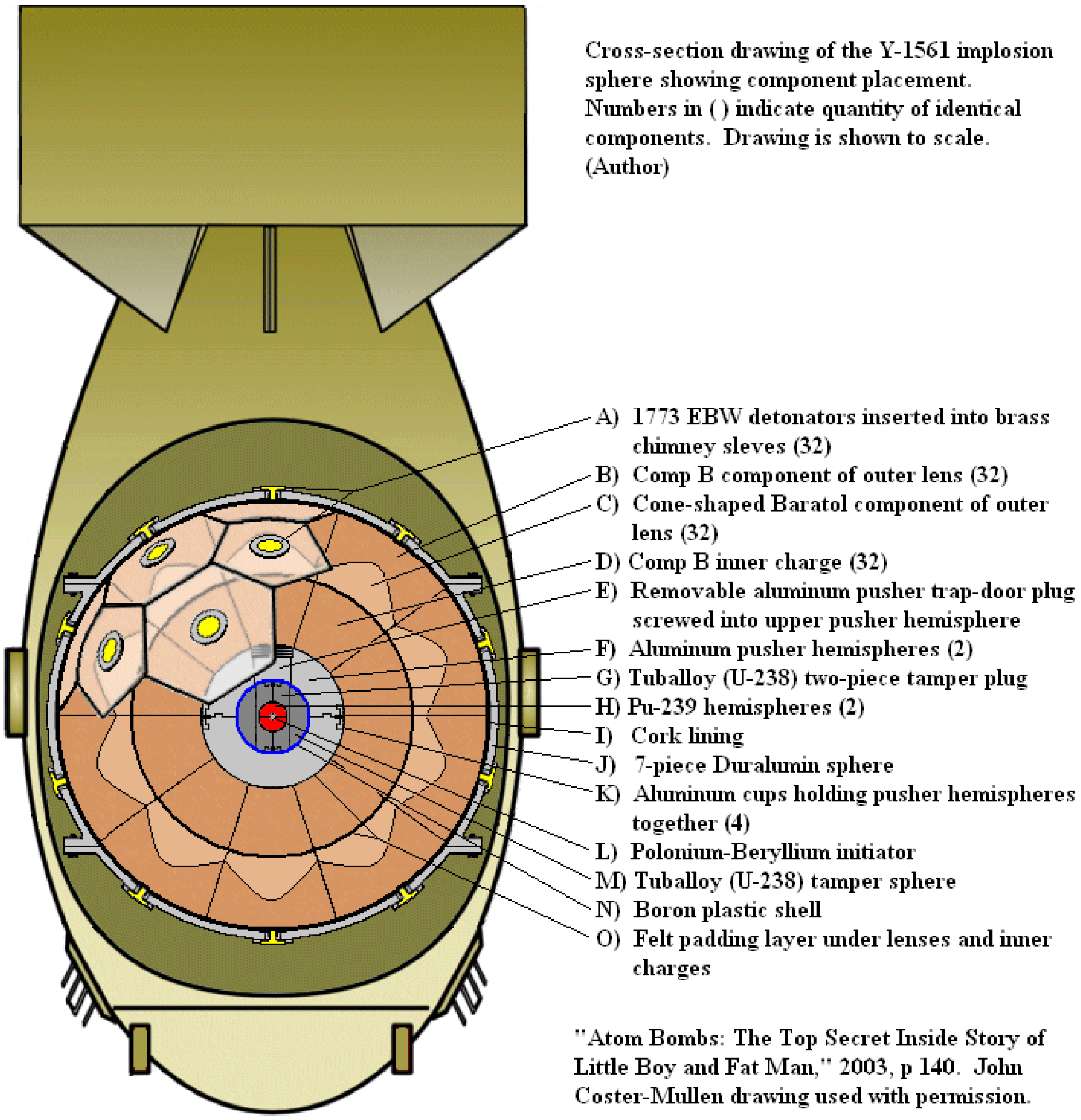
Another idea that had been “kicking around” for some time was to bring a subcritical mass to a supercritical one by compressing it, the so-called *implosion* method.

Below is a diagram of the main parts of the "Fat Man" device itself, followed by a more detailed look at the different materials used in the physics package of the device (the part responsible for the nuclear initiation).



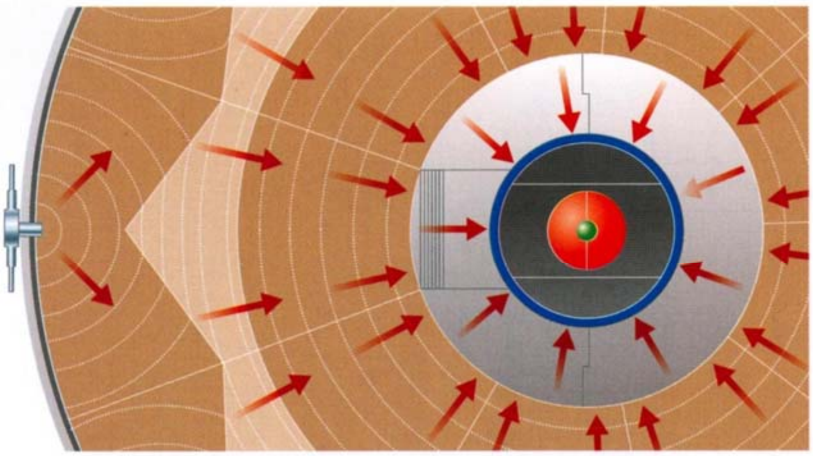
1. AN 219 contact fuze (four)
2. *Archie* radar antenna
3. Plate with batteries (to detonate charge surrounding nuclear components)
4. *X-Unit*, a firing set placed near the charge
5. Hinge fixing the two ellipsoidal parts of the bomb
6. Physics package (see details below)
7. Plate with instruments (radars, baroswitches and timers)
8. Barotube collector
9. *California Parachute* tail assembly (0.20-inch (5.1 mm) aluminium sheet)

Physics package

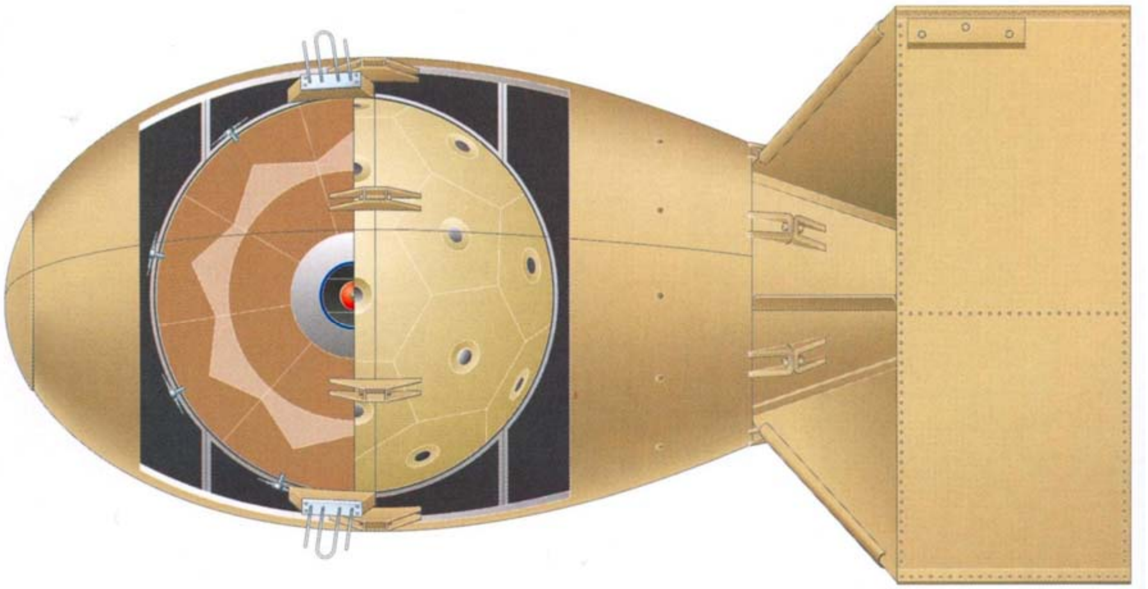


Cross-section drawing of the Y-1561 implosion sphere showing component placement. Numbers in ( ) indicate quantity of identical components. Drawing is shown to scale. (Author)

"Atom Bombs: The Top Secret Inside Story of Little Boy and Fat Man," 2003, p 140. John Coster-Mullen drawing used with permission.



To detonate the plutonium core "Fat Man," shaped charges of fast and slow explosives focused a spherical shock wave to compress the inner components - a beryllium–polonium-210 "initiator" known as the "urchin" and a "pit" of plutonium-239/240. As the metals came into contact, they fissioned and a chain reaction that was controlled and focused by a uranium tamper. About 20% of the pit fissioned, and released energy in the form of a nuclear explosion.



The key to this method was the development of "explosive lenses" that would change the shape of the expanding shockwave as it moved through the explosive. As it happens, explosives are actually "set off" by the shock wave, initiated by a blasting cap, for example. As the shock wave moves through the explosive, it detonates. Thus the wave is propagated through the explosive just as light is passed through an optical lens. Light is bent, due to the shape of the lens and the change in the index of refraction of the glass. Now, the index of refraction is just the ratio of the speed of light in one medium compared to the speed of light in the other. So if we combined two different explosive materials, in which the propagation speed was different, we could shape them in such a way as to "focus" the detonation wave unto the central plutonium pit.

How is the explosive lens designed?

The actual design is accomplished in much the same way as optical lenses are designed. There are only two significant factors: the velocity of the detonation wave through the material, and the shape of how they’re joined.

The two explosives were Composition B (fast) and Baratol (slow). Of course, fast and slow are relative terms: the detonation velocity of Baratol was 4,900 m/s. (Comp B was a 60/40 mix of RDX, with a detonation velocity of 8,750 m/s, and TNT, with a detonation velocity of 6,900 m/s.)

Both these explosives used paraffin to bind them together. Molds were created in which the molten explosive was poured and allowed to slowly cool. The Baratol was poured first, and after cooling the surface machined to the precise shape. (The machining tools were made from a non-sparking alloy, to avoid the obvious.) An extention was bolted unto the top of the mold, and the Composition B was poured on top. Casting these High Explosive (HE) blocks was a major difficulty; some 100 blocks were required for each complete weapon.

Cooling too quickly could leave to the formation of cavities — bubbles — in the finished block. X-rays were used to image the interiors, and many blocks were rejected. With the Trinity test rapidly approaching, George Kistiakowsky — the head of the division — sat down with dental tools, drilled holes into the casing to reach the cavities, and filled them with molten explosive from a syringe. Only in this way were enough casing available for the various tests.

Of course, the shape of the lens is all important. These were determined by laborious computations, using electro-mechanical calculators. Initially, wives of the scientists were doing most of these computations — after all, there wasn’t a whole lot else to do! — but as the project dragged on, WACS were called in and took over much of the work.

(This Marchant calculator is on display in the museum in Los Alamos. Dick Feynman was in charge of the group performing these calculations.)

While the blasting caps detonated the high explosives, how was the nuclear reaction initiated?

The plutonium sphere could be crushed to sufficient densities by the HE, but would remain in the critical geometry for only a ten millionth of a second. You couldn't count on a stray neutron, even from ^{240}Pu contaminated plutonium, being available to initiate the nuclear chain reaction.

Early on, the idea of an *initiator* had been floating about. It wasn't really needed for the uranium bomb, although one was eventually added, but it was critical for the implosion weapon. Its basic design is simple enough: Serber had pointed out in the *Los Alamos Primer* that radium could be used to supply alpha particles that would knock neutrons out of beryllium. However, radium emitted hazardous gamma rays, so polonium was a better choice. The challenge was to design a source of sufficient neutron intensity that released those neutrons only at the precise moment they were needed.

The beryllium initiator used was called the "Urchin" or "screwball" design. It was a sphere consisting of a hollow beryllium shell, with a solid beryllium pellet inside, the whole initiator weighing about 7 grams. The outer shell was 2 cm wide and 0.6 cm thick, the solid inner sphere was 0.8 cm wide. 15 parallel wedge-shaped grooves, each 2.09 mm deep, were cut into the inner surface of the shell. Like the pit, the shell was formed in two halves by hot pressing in a nickel carbonyl atmosphere. The surfaces of the shell and central sphere were coated with 0.1 mm of gold, and also a nickel layer deposited by the nickel carbonyl atmosphere. 50 curies polonium-210 (11 mg) was deposited on the grooves inside the shell and on the central sphere. The gold and nickel layers protected the beryllium from alpha particles emitted by the polonium or surrounding plutonium. The Urchin was attached to a mounting bracket inside the central cavity of the pit, which was probably 2.5 cm wide.

The Urchin was activated by the arrival of the implosion shock wave at the center of the pit. When the shock wave reached the walls of the cavity, they vaporized and the plutonium gas shock wave then struck the initiator, collapsing the grooves and creating Munroe-effect jets that rapidly mixed the polonium and beryllium of the inner and outer spheres together. The alpha particles emitted by the Po-210 then struck beryllium atoms, periodically knocking loose neutrons, perhaps one every 5-10 nanoseconds.

Where can I learn more about building an implosion-type nuclear weapon?

http://ioannis.virtualcomposer2000.com/math/papers/Nukey.pdf