4 What does it take to make a WMD?

The facilities and resources needed to produce WMDs, and to produce and deploy the munitions to deliver them, vary according to the type of WMD; a program to produce and deploy a nuclear-weapon force is a much larger undertaking than one to produce a biological- or chemical-weapon one. The acquisition of a nuclear force, large enough to be strategically significant within the region, requires the investment of a huge sum of money and the employment of a very large group of specialists. Nevertheless, a number of developing countries—Israel, India, and Pakistan—have made the investment and deployed a nuclear force; North Korea has a nuclear-weapon program, Iran may be planning one, and Iraq was developing nuclear weapons before the 2003 war.

all but the least developed countries could afford the resources to deploy chemical weapons

A program to deploy a chemical-weapon force requires the investment of the least amount of resources and is the least demanding of the three; all but the least developed countries could afford the resources to deploy chemical weapons.

What is a nuclear-weapon program?

A country that does not have nuclear weapons but does have advanced nuclear technology and security concerns in its region is often called a "latent nuclear-weapon state" or a "virtual nuclear state." Japan is an example of such a country. A country without such advanced nuclear technology may decide for reasons of security or prestige to acquire nuclear weapons. Iraq, Iran, and North Korea are suspected of doing so. What materials, facilities, and personnel would such countries need to become actual nuclear-weapon powers?

A country with a civil nuclear program will have little difficulty in designing, developing and fabricating nuclear weapons. If it is, for example, using nuclear-power reactors to generate electricity, it will already have the skilled physicists, chemists, technologists, engineers, and technicians and the capability to produce plutonium suitable for use in nuclear weapons. The "peaceful atom" and the "military atom" are intimately linked—"Siamese twins" in the words of Nobel Prize winning Swedish physicist, Hannes Alven.

Thirty countries are operating 438 nuclear-power reactors for the generation of electricity today. They include developing countries, such as Argentina, Brazil, India, Mexico, Pakistan, and South Africa. Countries also operate reactors, called research and test reactors, to produce radioisotopes for medical, industrial, and agricultural use and for training physicists and engineers. (Radioisotopes are used in medicine to diagnose and treat diseases; in industry to radiograph large structures; and in agriculture to kill pests and sterilize male insects to reduce their numbers.) A country with this type of reactor also has a group of skilled people who could be diverted to a nuclear-weapon program.

Military scientists in any industrialized country will, it can be assumed, be collecting information on nuclear weapon design—by searching the scientific and technical literature, attending relevant meetings and conferences, engaging in espionage, and so on. Perhaps only a small number of people working in a military research establishment will be involved in this preliminary stage. A team may be set up actually to design nuclear fission weapons, boosted weapons, and perhaps thermonuclear weapons. Computer simulations of weapon design and the effects of a nuclear explosion may well be performed. The computer codes needed for these activities are available commercially. This preliminary work may be said to be "for defensive purposes." There is unlikely to be a specific political decision to undertake this work.

The move to an active nuclear-weapon program will almost certainly require a political decision, which may be taken by the country's political leader, perhaps with discussion with a small number of colleagues, but need not involve the whole cabinet. In the United Kingdom, for example, the decision to acquire nuclear weapons was taken by Prime Minister Clement Attlee, Foreign Secretary Ernest Bevin and the Minister of Supply, whose department was responsible for the program. In France, it was taken by President de Gaulle.

In the United Kingdom, the decision to acquire nuclear weapons was taken by Prime Minister Clement Attlee

The first step of the program will be to acquire nuclear material—plutonium and highly enriched uranium. Industrialized countries will want to produce these indigenously so that they are not dependent on others for them. Indigenous production will require the acquisition of special materials—such as a specially strong steel (called maraging steel), and special tubing, for the construction of gas centrifuges to produce highly enriched uranium from natural uranium—or materials to construct a nuclear reactor for the production of plutonium from the uranium. If the country has a civil nuclear program, it will already have a team of nuclear physicists and engineers, some of whom can be used in a nuclear-weapon program.

At this stage there will be experiments to develop implosion technology to compress a sphere of fissile material into a supercritical mass, including the development of pure conventional high explosives. Experiments will be carried out, probably in an establishment run by the defense ministry, to implode spheres made from non-fissile material, such as natural or depleted uranium.

When it has been demonstrated that fissile materials can be successfully produced, a political decision will be needed to go ahead and produce and deploy nuclear weapons. The initial size of the nuclear force will be also discussed. At this stage decisions will be required about delivery systems—combat aircraft or, more likely, surface-to-surface missiles. New systems will be developed or existing ones modified. Groups will be established in the Ministry of Defense to monitor and develop the various military activities.

The military will need to integrate nuclear weapons into tactics and strategy, which will mean evolving these processes for nuclear use and developing and setting up an effective command, control and communications system. War games and military maneuvers will be undertaken and textbooks will be prepared for use in military colleges. Aircrew will practice the air delivery of nuclear weapons. The pilot will be trained to maneuver the aircraft after dropping the nuclear weapon to avoid being damaged by the effects of the explosion.

A nuclear-weapon program involves decisions and activities by the country's military scientists and engineers, the political leaders, the military leaders, defense bureaucrats, industry, and academics. A separate military-political-industrial-bureaucratic-academic complex will evolve devoted to the production and deployment of nuclear weapons and the development of tactics and a strategy for their use.

What do you need to make a nuclear weapon?

Both civil and military nuclear programs depend on uranium. Uranium was discovered in 1789 by the German chemist H. M. Klaproth but was used for only minor purposes—in, for example, chemistry and metallurgical research—until the Second World War when large quantities began to be used in nuclear-weapon programs. Since the 1950s large amounts have been and are being used to fuel nuclear-power reactors.

Uranium is a very widely distributed element found, as an oxide, in a large variety of minerals and in seawater. Most of the uranium is dispersed through the rocks of the Earth's crust; only a small fraction is found in concentrated ores. Deposits that can be mined economically occur in sandstones, shales, granites, phosphates, lignites, and quartz-pebble conglomerates and veins.

Uranium is mined in open-pit and underground mines. Uranium mines are operated in about twenty-four countries. The biggest ones are in Australia, Canada, Namibia, Niger, Russia, South Africa, and the USA. In addition, China, the Czech Republic, France, Kazakhstan, Tajikistan, and Uzbekistan mine significant amounts. There is a world glut of uranium, so any country intent on doing so could readily get its hands on supplies.

A country running a clandestine nuclear-weapon program will, if it can, mine its own uranium. Israel, for example, mines uranium in the Negev desert with phosphate deposits. India mines uranium at Jaduguda and Pakistan mines it at Dera Ghazi Khan. Iran has recently opened a uranium mine about 200 kilometers from the city of Yazd.

Uranium mining is a hazardous activity. There are not only the usual dangers of mining, but also radioactive decay products which accompany the uranium to contend with. Both uranium-235 and uranium-238 are radioactive and both have a family of daughter products. Uranium-238, for example, has fourteen radioactive daughter products, one of which is the gas radon. If a uranium miner breathes a radioactive dust particle or radon he or she could get lung cancer. People living in badly ventilated houses built on granite or containing granite are also exposed to radon and run a risk of a similar kind.

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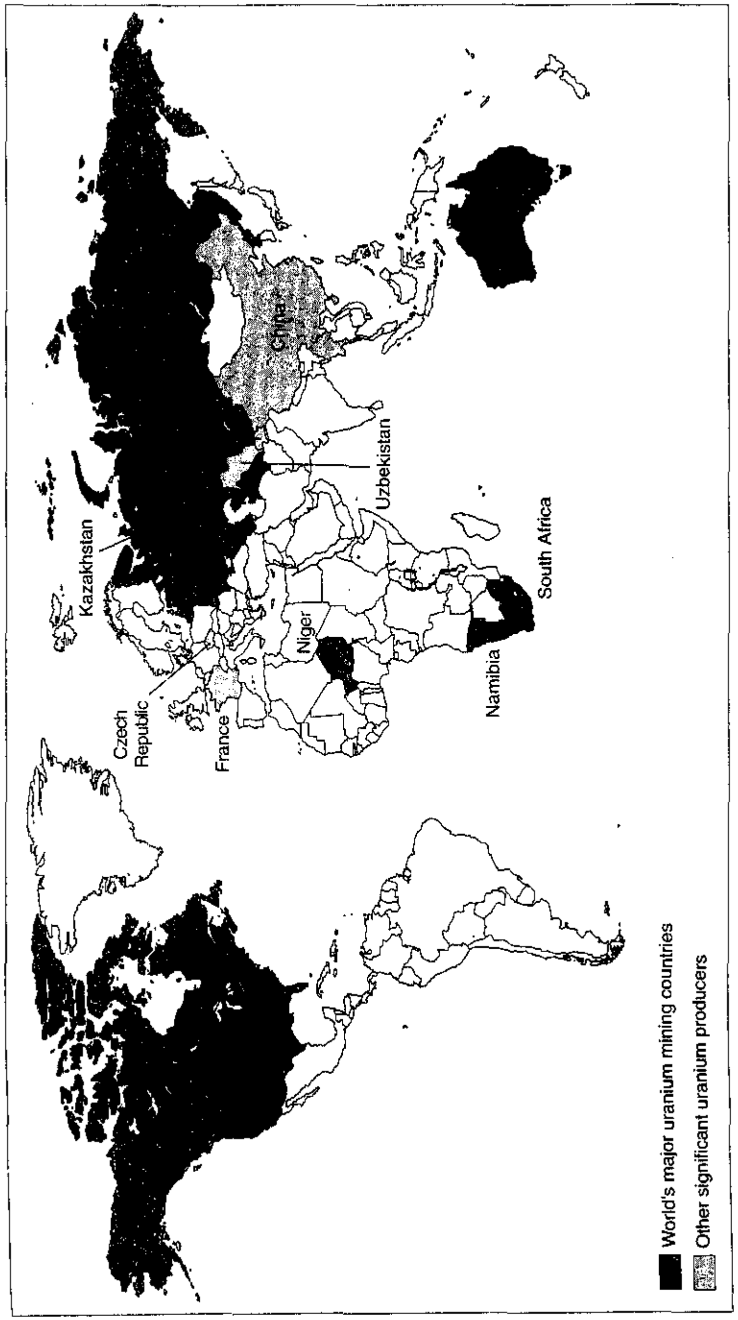
Once mined, the uranium ore, often still in rock, is taken to a



The world's top uranium-producing countries

uranium mill. The amount of uranium in typical ore is only one or two parts per thousand. The uranium mills are, therefore, usually close to the mine. The ore is crushed, mixed with water, and ground into fine particles. The mixture is put through a chemical procedure to purify it. This produces a uranium oxide, U_3O_8, a yellow compound called yellow cake, which is sold in this form for about 22 US dollars per kilogram.

Every thousand atoms of naturally occurring uranium contains only seven atoms of uranium-235; the other 993 are atoms of uranium-238. This concentration of uranium-235 is too low to produce the supercritical mass needed to generate a fission chain reaction in a nuclear weapon. Therefore, the concentration of uranium-235 in uranium is increased in a process called enrichment.

The extent of the enrichment depends on the purpose for which the uranium is required. Some military reactors used to produce plutonium for use in nuclear weapons are fueled with natural uranium and use no enriched uranium. Commercial nuclear-power reactors use uranium enriched to about 4 percent in uranium-235. For use in a fission nuclear weapon, uranium is enriched to more than 90 percent.

Uranium-235 and uranium-238 are chemically identical and so it is necessary to use a physical method to separate and enrich them. The difference between the two isotopes is that the nucleus of a uranium-238 atom contains three more neutrons than the nucleus of a uranium-235 atom, giving a minute difference in the weight of the atoms. There are two main methods of using this difference to separate the isotopes, using a gaseous diffusion method or gas centrifuges. Both methods use a uranium gas, uranium hexafluoride, which is a solid at room temperature. It is converted into a gas by heating it to a temperature of about 64 degrees Celsius. Pure uranium hexafluoride is obtained by converting yellow cake in a chemical plant, called a conversion plant.

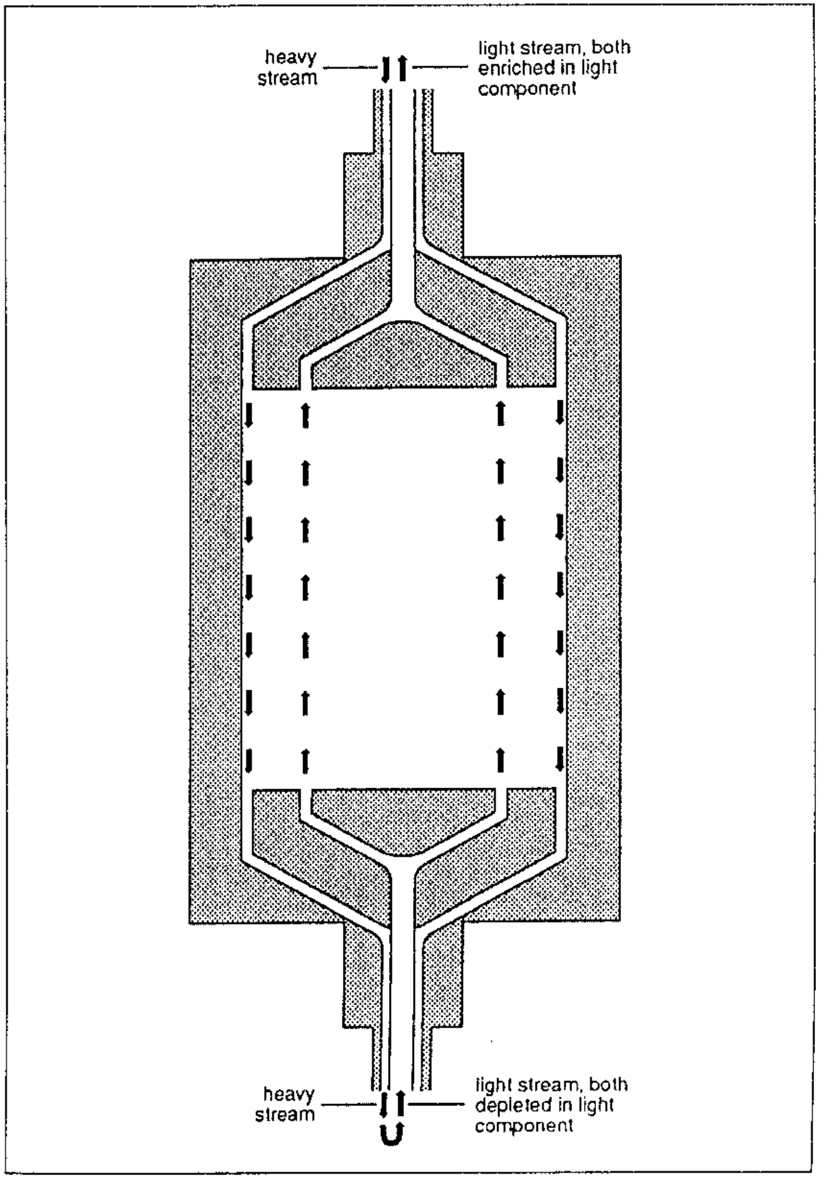
Gaseous diffusion relies on the fact that in a gaseous mixture of the two isotopes, the molecules of uranium-235, the lighter one, will diffuse more rapidly through a porous barrier than the molecules of uranium-238, the heavier one. Uranium hexafluoride is extremely corrosive and reactive, so much so that special materials, such as nickel and aluminium alloys, have to be used for the construction of the pipes and pumps used in a diffusion plant, and the entire installation must be kept free of grease and oil so as not to produce undesirable chemical reactions with the hexafluoride.

The proportion of uranium-235 in the gaseous mixture is increased by only a small fraction in each diffusion stage. Numerous stages are required to give a significant enrichment. A commercial diffusion plant uses an enormous amount of electrical power, usually requiring the construction of an independent power station. A large diffusion plant is operating in each of China, France, and Russia; two are operating in the USA. These plants were all originally built for military purposes, to produce highly enriched uranium for use in nuclear weapons. They are now mainly used to produce enriched uranium to fuel nuclear-power reactors. Argentina operates a small pilot diffusion plant but has not yet taken a decision to construct a commercial plant.

The gas centrifuge method of enriching uranium also relies on the minute difference in mass between uranium-235 and uranium-238 atoms. It uses a rapidly spinning centrifuge to separate the isotopes. The centrifuge consists of a cylindrical drum that rotates at very high speeds. The heavier uranium-238 concentrates at the outer radius of the drum and is made to flow in one direction, while the uranium-235 is enriched near the central axis of the drum and is made to flow the opposite way. The enriched uranium-235 is collected through an exit orifice.

Although the separation of the uranium isotopes is much greater per stage in a centrifuge plant than in a diffusion plant, it is still very small. A centrifuge plant, therefore, contains a great number of centrifuges in a cascade to achieve a useful output of enriched uranium. The slightly enriched uranium-235 from the first centrifuge in the cascade is fed into the input nozzle of the next centrifuge, the slightly more enriched uranium-235 from the second centrifuge is fed into the third, and so on.

The requirements for the materials used in the construction of



Gas centrifuge

gas centrifuges are very demanding. The outer casing of the drum and the rotor bearings, in particular, must be made from a material with a high tensile strength, the most suitable of which is carbon fiber.

Gas centrifuge plants are cheaper to run than diffusion plants. The amount of electricity required to operate a centrifuge plant is typically about one tenth of that required for a diffusion plant. Another advantage with a centrifuge plant is that it can be built up in stages, step by step, as demand for enriched uranium increases. Large gas centrifuge plants for uranium enrichment operate in China, Germany, Japan, the Netherlands, Pakistan, Russia, and the UK.

Electromagnetic separation has been used to enrich uranium on a significant scale, in machines called calutrons. It was used in the Manhattan project in the Second World War to produce the highly enriched uranium for the Hiroshima bomb. The USA stopped using calutrons in 1946 because they were very expensive to operate. More recently, Iraq experimented with the technique but soon abandoned it in favor of gas centrifuges.

In a calutron, atoms of uranium are ionized—that is, one or more electrons in the atom are removed—and injected into a magnetic field. The particles bend as they travel in the magnetic field with the lighter particles, the uranium-235 particles, bending more than the heavier uranium-238 particles. Separation can thus be achieved.

The South Africans are using the helicon or jet nozzle method of separating uranium isotopes at a plant at Valindaba. The process, developed at Karlsruhe in Germany, is an aerodynamic one, using pressure diffusion in a gaseous mixture of uranium hexafluoride and a light gas, such as helium or hydrogen, flowing at high speed through a nozzle along sharply curved walls. The heavier molecules are less deflected in the stream with the largest curvature, allowing separation to take place.

For the enrichment of uranium to the extent needed to produce nuclear weapons, normally uranium containing more than 90 percent of uranium-235 is used. To produce 1 kilogram of this uranium requires about 180 kilograms of natural uranium. Each nuclear weapon typically contains about 15 kilograms of highly enriched uranium, requiring the mining of about 1,500 tons of uranium ore.

Plutonium

If a country decides to produce plutonium to use as the fissile material in its nuclear weapons, it will need to construct two key facilities, a plutonium-production reactor and a chemical plant to separate, or reprocess, the plutonium from other materials in the fuel elements when they are removed from the reactor.

All reactors produce plutonium; military plutonium-production reactors do so very efficiently. Unlike nuclear-power reactors, they produce no usable power or energy.

Plutonium results when uranium-238 absorbs some of the neutrons produced in the fission process, to become the isotope uranium-239. Uranium-239 is radioactive and decays to plutonium-239. This plutonium isotope can be used as the fissile material in nuclear weapons.

The uranium fuel elements are removed from a plutonium-production reactor after a short time, typically three months or so. At this time, the plutonium is of the type best suited for use in nuclear weapons. If the fuel elements are left much longer the plutonium-239 itself absorbs neutrons, producing plutonium-240 and plutonium-241. These other isotopes contaminate the plutonium-239 and the fewer there are of them the better.

When the fuel elements are removed from the plutonium-production reactor they contain, in addition to the plutonium -239 and a small amount of plutonium-240 and -241, unused uranium and fission products. The reprocessing plant chemically separates the plutonium from the uranium and the fission products. The method used in reprocessing plants is

A reprocessing plant is an essential facility for the production of plutonium for nuclear weapons generally the PUREX process in which tributyl phosphate and kerosene are used to separate the fission products from the uranium and plutonium.

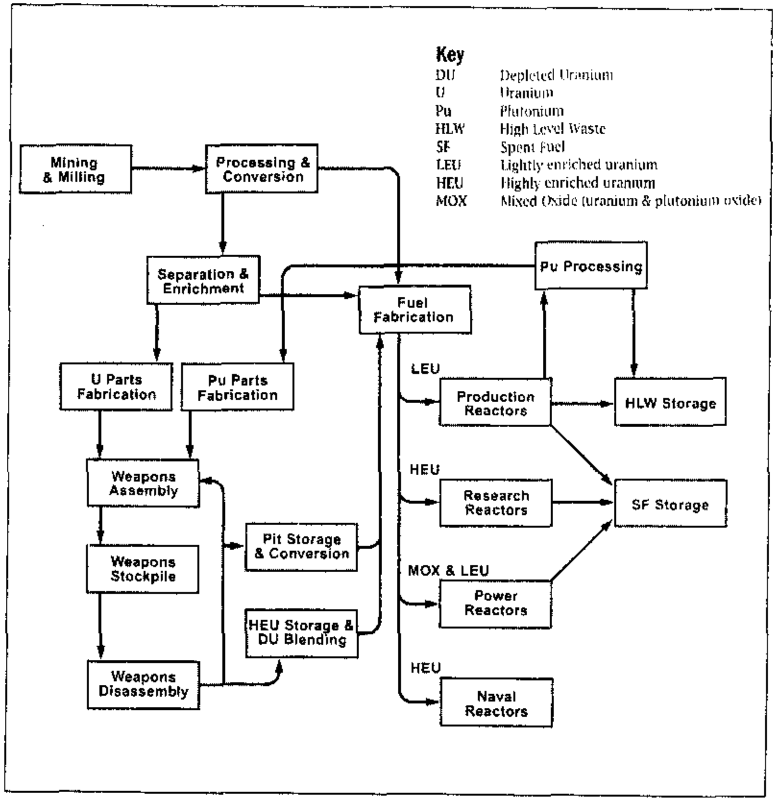
A reprocessing plant is an essential facility for the production of plutonium for nuclear weapons. The existence of one suggests that a country intends to use plutonium to produce nuclear weapons. All countries with significant reprocessing facilities are, therefore, actual or potential nuclear-weapon powers.

A nuclear weapon normally contains about 4 kilograms of plutonium. A country wanting to produce, say, three nuclear weapons a year will need a reprocessing facility able to separate about 12 kilograms of plutonium a year. A facility of this capacity is small enough in physical size to be easily hidden, and so is a small plutonium-production reactor able to produce 12 kilograms of plutonium a year. Either facility could be constructed in a moderately sized two-story building. A country which has decided to use plutonium rather than highly enriched uranium could, therefore, do so clandestinely. It would be more difficult to conceal a gas centrifuge plant able to produce enough highly enriched uranium to produce three nuclear weapons a year, as satellite photographs would be able to spot the construction and operation of such a plant.

The fuel elements removed from a plutonium-production reactor are very radioactive and have to be handled with remote equipment. Also, parts of the reprocessing plant have to be heavily shielded to prevent the workers becoming exposed to too much radiation.

The production of the components for nuclear weapons

The plutonium will leave the reprocessing facility as plutonium dioxide. This will be converted into plutonium metal. The metal is then rolled, formed and heat treated to produce small plutonium ingots, each weighing less than a kilogram. These operations require special equipment such as furnaces and lathes. The ingots are shaped in a foundry into the solid or hollow spherical form of a weight, of about 5 or 6 kilograms, suitable for use in the core of nuclear weapons.



These operations will be performed in an atmosphere of an inert gas. Because of its high toxicity, no plutonium will be allowed to escape into the human environment. Care in handling toxic materials is required during the production of other components for a nuclear weapon, such as the manufacture of the beryllium shell used as a neutron reflector.

The chemically pure conventional high explosives, normally HMX, used to produce the symmetrical shock wave to compress the plutonium (or highly enriched uranium) in the core of the weapon will be fabricated in a special establishment with facilities to test and perfect the implosion system.

If highly enriched uranium is used as the fissile material in nuclear weapons, the enriched hexafluoride will be first converted into uranium oxide and the oxide will then be converted into uranium metal, procedures that are straightforward chemistry. Ingots of highly enriched uranium metal will be produced using processes similar to those used to produce plutonium ingots.

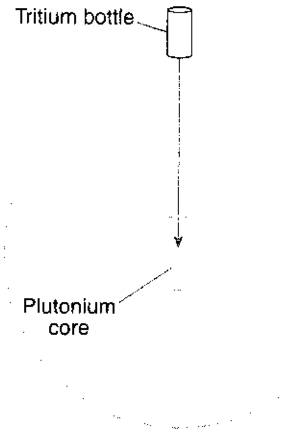
If the "gun" design is used in the nuclear weapon, two masses of highly enriched uranium, each less than a critical mass but together making a supercritical mass, are produced. When the two masses are assembled together, a nuclear explosion will occur.

If the implosion technique is used, the highly enriched uranium is machined into components that can be put together to produce either a solid or a hollow sphere. The total mass of highly enriched uranium will be less than the critical mass. This core is surrounded by conventional high explosive to compress the highly enriched uranium to produce a supercritical mass and a nuclear explosion.

The critical mass of a bare sphere of highly enriched uranium is much greater than the critical mass of a bare sphere of plutonium-239; the former is about 52 kilograms, the latter is about 11 kilograms. These critical masses can be reduced by more than half by surrounding the core of fissile material with a thick neutron reflector made from, for example, beryllium.

Because of the relatively small amount of plutonium-239 needed in a nuclear weapon, it is normally the material of choice in nuclear-weapon programs. Of the current nuclear-weapon powers, only Pakistan uses highly enriched uranium in its weapons. South Africa also used highly enriched uranium to produce six nuclear weapons, based on the gun technique. The weapons were built and deployed in the late 1970s. Following a decision in 1989, taken by former President F. W. de Klerk, the weapons, all based on the gun technique, were dismantled, making South Africa the only country to deploy nuclear weapons and then dismantle them.

> *plutonium-239 is normally the material of choice in nuclear-weapon programs*

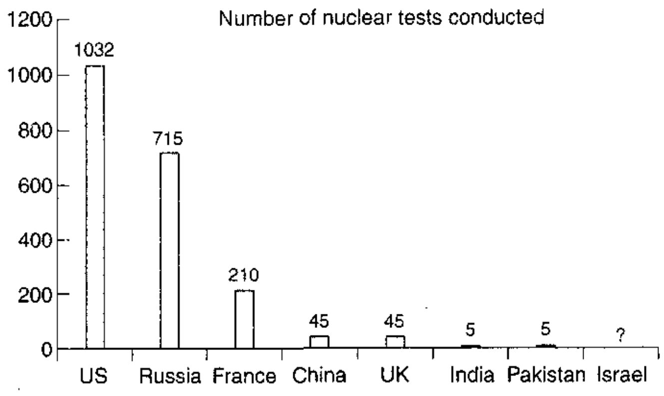


The Tritium bottle is an external component, for ease of change

If a country decides to boost its nuclear weapons to increase their explosive power, it will also need a facility to produce tritium. Tritium is the radioactive isotope of hydrogen; each tritium atom contains a proton and two neutrons in its nucleus. It can be used to produce nuclear fusion (see diagram). Tritium is produced in a suitable nuclear reactor. Its production is another reason why a country planning nuclear-weapon force will acquire a nuclear reactor. Israel, for example, uses its reactor at Dimona to produce both plutonium and tritium for use in its nuclear weapons.

Nuclear testing

A nuclear weapon using just nuclear fission to produce the energy for a nuclear explosion does not need testing. The design is so straightforward and well tried that the scientists and technologists who produce the weapons can be confident that they will work without testing. Countries having a very competent nuclear community, like Israel, will probably not need to test boosted nuclear weapons but would need to test thermonuclear ones.



Nuclear tests by country

Seven nuclear-weapon powers (China, France, India, Pakistan, Russia/the Soviet Union, the United Kingdom and the United States) are known to have conducted a total of at least 2,052 nuclear tests since the first nuclear explosion in 1945. The USA carried out its first test of a nuclear fission weapon on 16 July 1945, the former Soviet Union did so on September 23, 1949, the UK on October 2, 1952, France on October 13, 1960, China on October 16, 1964, India on May 11, 1998, and Pakistan on May 28, 1998. The dates on which countries that have thermonuclear weapons made their first full-scale thermonuclear test explosion are: USA, November 1, 1952; the former Soviet Union, August 21, 1953; the UK, May 15, 1957; France, September 24, 1968; and China, June 17, 1967.

The USA carried out a total of 1,032 tests; the former Soviet Union made 715; France 210; China 45; the UK 45; India 5; and Pakistan 5. Israel, the eighth known nuclear-weapon power, has not, so far as is publicly known, tested a nuclear weapon although an explosion high in the atmosphere on September 22, 1979, off the eastern coast of South Africa, is widely believed to have been a clandestine Israeli nuclear test. There have been no known nuclear tests since the end of 1998.

American nuclear tests were performed at sites in Nevada and

in the Pacific; the former Soviet Union had test sites in Kazakhstan and Novaya Zemlya; the British had test sites in Australia, Christmas Island, and Nevada; the French in Algeria and Polynesia; the Chinese at Lop Nor, India at Pokhran in the Thar desert; and Pakistan at Chagai Hills.

Until 1981, many nuclear tests were carried out in the atmosphere; since 1981 they have all been performed underground. The total explosive yield of all the nuclear tests conducted so far is equivalent to that of roughly 510 megatonnes of TNT, or the explosion of about 40,000 Hiroshima bombs. The atmospheric tests are responsible for much radioactive contamination of the human environment, fifty times more than that released by the 1986 Chernobyl nuclear accident. It has been estimated that exposure to the radiation from the radioactivity produced by atmospheric nuclear tests will eventually cause the death of about 1.5 million people.

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Nuclear tests are performed to develop knowledge about nuclear fission weapons and the effects of nuclear explosions, and to conduct initial research into thermonuclear explosions. Operational nuclear and thermonuclear warheads were tested, including a variety of actual nuclear munitions such as artillery shells and aircraft bombs. Troops were exposed to nuclear explosions during some of the earlier tests to analyse the effects of the explosions on the battlefield.

Underground nuclear tests are normally conducted in an excavated chamber, deep enough to contain the radioactivity produced by the nuclear explosion. Scientific instruments and equipment to measure the effects of the nuclear explosion are placed in tunnels running off the chamber. In some cases, the blast from the explosion has broken through the surface and radioactivity has escaped into the atmosphere, a process called venting.

The making of chemical weapons

Just as biological-warfare agents are made in plants very similar in design to civilian plants used to produce high-grade pharmaceutical products, so nerve agents for use in chemical weapons can be made in plants very similar to industrial chemical plants used to manufacture herbicides. Both nerve agents and herbicides are organophosphorous compounds.

The military chemical plants will employ chemists, industrial chemists, physical chemists, and technicians. The plants will include measures to contain the toxic agents to prevent the workers becoming exposed to them, including the use of barriers to separate workers from the organophosphorous compounds and efficient methods of ventilation.

Biological and chemical munitions

The ordnance for the delivery of biological (and chemical) weapons, including artillery shells, mortar rounds, rockets, aircraft bombs, and missile warheads, is produced in special factories. Great care must be taken to prevent any leakage of biological and chemical agents into the human environment. The workers in the factories are protected by effective containment of the agents, the use of physical barriers to separate the workers from the agents, and effective ventilation.

Biological and chemical munitions normally disseminate liquid agents as aerosols. Both types of agents are most lethal if the aerosols produce drops of liquid that are of a consistent and appropriate size. The droplets should be about a micron (a millionth of a meter) in diameter, a size that makes it possible to breathe them deep into the lung. Larger droplets are filtered out by the nose and do not get into the lung. The munitions must, therefore, be carefully designed. Steps must be taken to enable the munitions to deliver the agent to the target with minimum degradation.