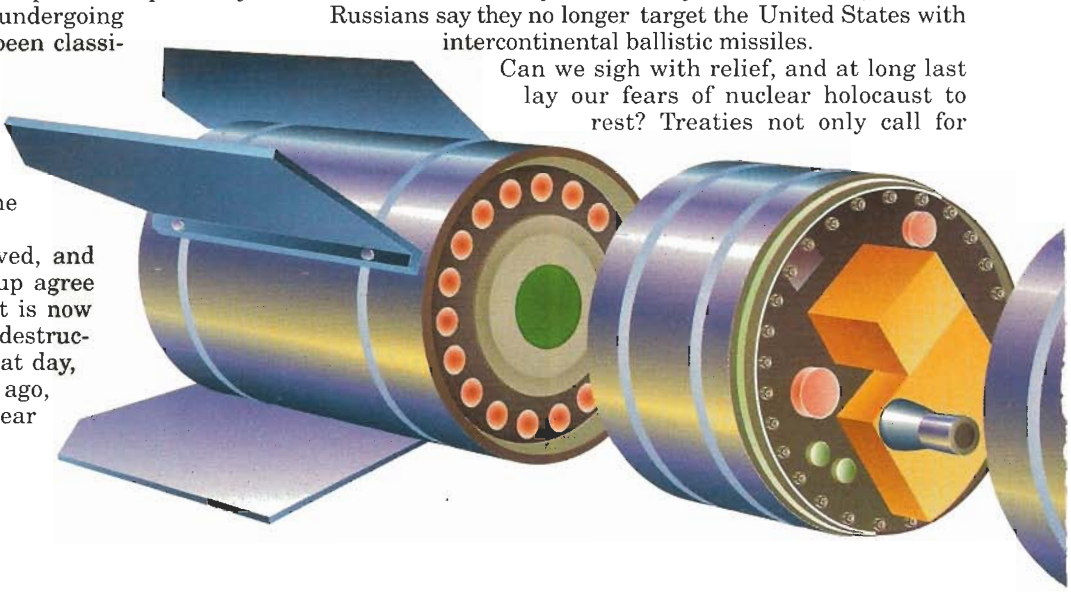
Pantex is a high-security Department of Energy facility named for its location in the Texas panhandle. It is protected by gun-toting guards wearing spit-shined combat boots. "Some of the guys say that if we just took down a couple of fences, it would look like a prison," says administrative program manager Jerry Hemphill, one of nearly 3,000 employees.

In January, Pantex officials allowed POPULAR SCIENCE inside the complex's razor-wire fences for an unprecedented tour. Building 104, a new $30 million structure officially known as the Weapons Special Purpose Bay Replacement Complex, was still undergoing safety tests and had not yet been classified. Since our visit, it has gone "behind the fence," according to Tom W. Walton, public affairs officer at Pantex. It is here that the next chapter in the epilogue of the Cold War is being written.

The Soviet Union is dissolved, and the nations born of its breakup agree with the United States that it is now time to reduce the stockpile of destructive energy stored up since that day, a little more than 50 years ago, when the first controlled nuclear chain reaction took place at Stagg Field on the University of Chicago campus.

Just a few years ago, the United States and the Soviet Union had a total of about 50,000 nuclear weapons in their stockpiles. Some of these weapons have already been dismantled. The Strategic Arms Reduction Treaty (START) calls for cutting the nuclear warhead count from around 9,000 per side to 6,000 per side. START II—designed to eliminate multiple-warhead, land-based missiles—would further reduce the strategic-weapons arsenals to 3,500 per side. The United States has already withdrawn all short-range and naval nuclear weapons formerly stored abroad, and the Russians say they no longer target the United States with intercontinental ballistic missiles.

Can we sigh with relief, and at long last lay our fears of nuclear holocaust to rest? Treaties not only call for



Popular Science
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TAKING APART THE

SANDIA NATIONAL LABORATORIES

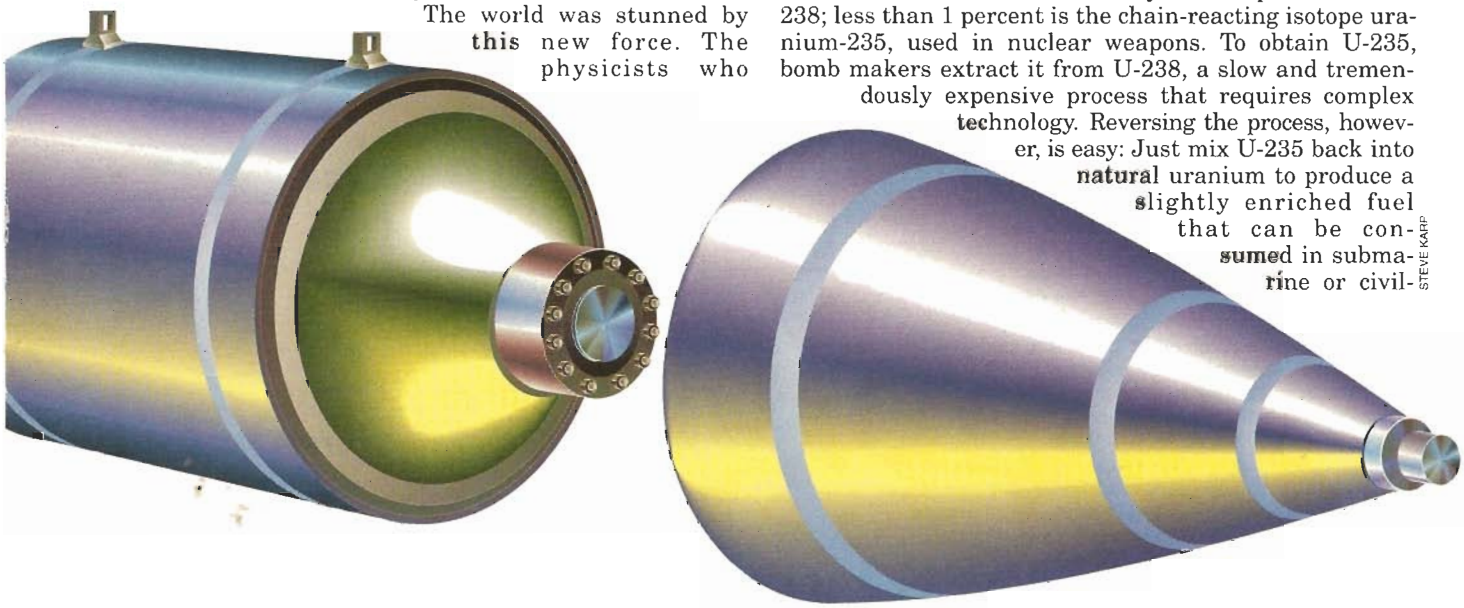
A B-61 nuclear bomb (rear) is broken down into four major subassemblies (center), which are dismantled separately. The bomb has about 6,000 parts, some of which are displayed on this table.

the dismantling of warheads, but also for the destruction of missiles and other delivery systems. And the production plants for fissionable materials—the plutonium and uranium that power nuclear weapons—stand idle. But despite all these changes, no government has any plans to destroy or make totally inaccessible its inventory of fissionable materials. Nuclear firepower is not going out of existence—merely into storage.

The atomic bomb was developed by the United States in the fear that Nazi Germany's scientists would be first to implement a concept known to all physicists since the 1930s—nuclear fission. That concept inflated physics, once a concern only of theoreticians and tabletop experimenters, into a huge industry and a major instrument of national power. Despite Germany's defeat in the spring of 1945, the bomb program hastened to its conclusion: Two atomic bombs were dropped on Japan in August of that same year.

The world was stunned by this new force. The physicists who had created it foresaw the future—that the Soviets would have the bomb soon (they did, by 1949) and that an arms race would follow. Now that race has finally ended, and the competitors—who together spent more than a trillion dollars to create their nuclear weapons complexes—are making plans for the dismantling of their arsenals. This is a positive step, but not one that will soon bring an end to the mess caused by nuclear weapons. In their race to produce weapons, the cold-warring nations contaminated land, air, and water with radioactive materials and toxic chemicals. As much as 15 percent of the former Soviet Union's territory is now estimated to be unfit for human habitation. In the United States, the cleanup is expected to take decades and will cost at least $200 billion. Weapons dismantling in the next few years will add to this legacy an estimated 25 tons of highly enriched uranium and ten tons of plutonium.

Natural uranium ore is mostly made up of uranium-238; less than 1 percent is the chain-reacting isotope uranium-235, used in nuclear weapons. To obtain U-235, bomb makers extract it from U-238, a slow and tremendously expensive process that requires complex technology. Reversing the process, however, is easy: Just mix U-235 back into natural uranium to produce a slightly enriched fuel that can be consumed in submarine or civil-



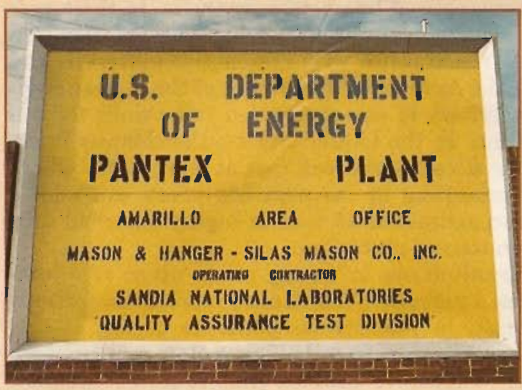
STEVE KARP

BOMB

Disassembling a nuclear weapon is easy. The hard part: Getting rid of its radioactive innards.

BY KEVIN CAMERON

THE INSIDE STORY OF PANTEX: THE UNITED STATES'



JOHN B. CARNETT

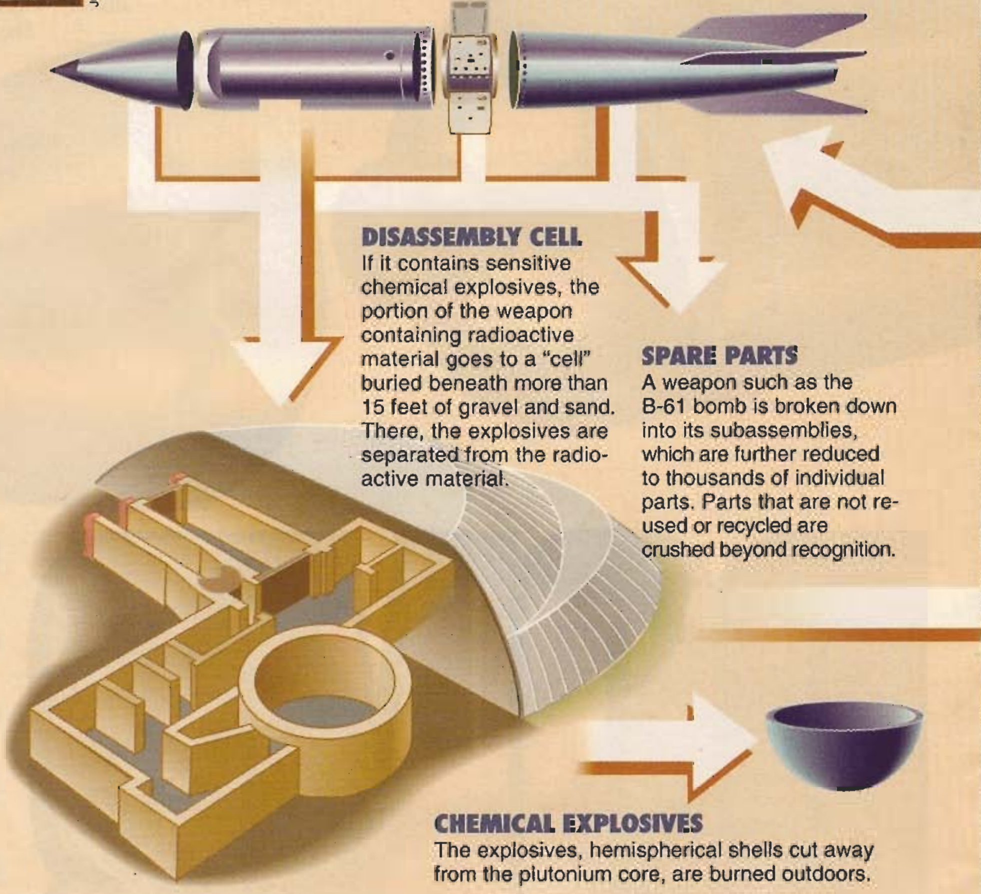
Pantex was once responsible for assembling weapons, but its more important mission now is disassembly. Employees work on about four nuclear weapons types in a year, out of about 30 in the U.S. arsenal. During the past 40-plus years, the Department of Energy has disassembled close to 50,000 weapons. Not all of the weapons, however, have been retired. Some were taken apart for testing, and were then reassembled. Others were retrofitted to create new weapons.

Weapons arrive at Pantex in armored, guarded trucks and are stored in bunkers (see illustrations at right). The weapons are inspected, separated into subassemblies, and finally broken down into individual parts for recycling or disposal. Workers separate the chemical explosives and radioactive materials, then store the weapons' plutonium pits.

Pantex has the capacity to disassemble about 2,000 weapons per year. But at that rate, the plant will soon run out of storage space for plutonium pits, which are no longer sent away to be made into new bomb cores. Proposals now on the table would allow Pantex to expand the storage space for pits, which would remain at the plant for an "interim" period of six to ten years. After that, the pits could be moved to another storage site.—*Dawn Stover*

IAN WORPOLE

SPECIAL DELIVERY
Weapons arrive at Pantex in armored, guarded trucks known as Safe Secure Tractor-trailers, or SSTs. Radio and satellite equipment enables government officials to track trucks' whereabouts at all times.



DISASSEMBLY CELL
If it contains sensitive chemical explosives, the portion of the weapon containing radioactive material goes to a "cell" buried beneath more than 15 feet of gravel and sand. There, the explosives are separated from the radioactive material.

SPARE PARTS
A weapon such as the B-61 bomb is broken down into its subassemblies, which are further reduced to thousands of individual parts. Parts that are not reused or recycled are crushed beyond recognition.

CHEMICAL EXPLOSIVES
The explosives, hemispherical shells cut away from the plutonium core, are burned outdoors.

ian power reactors. Without the extraction technology, the mixture is useless for bomb production.

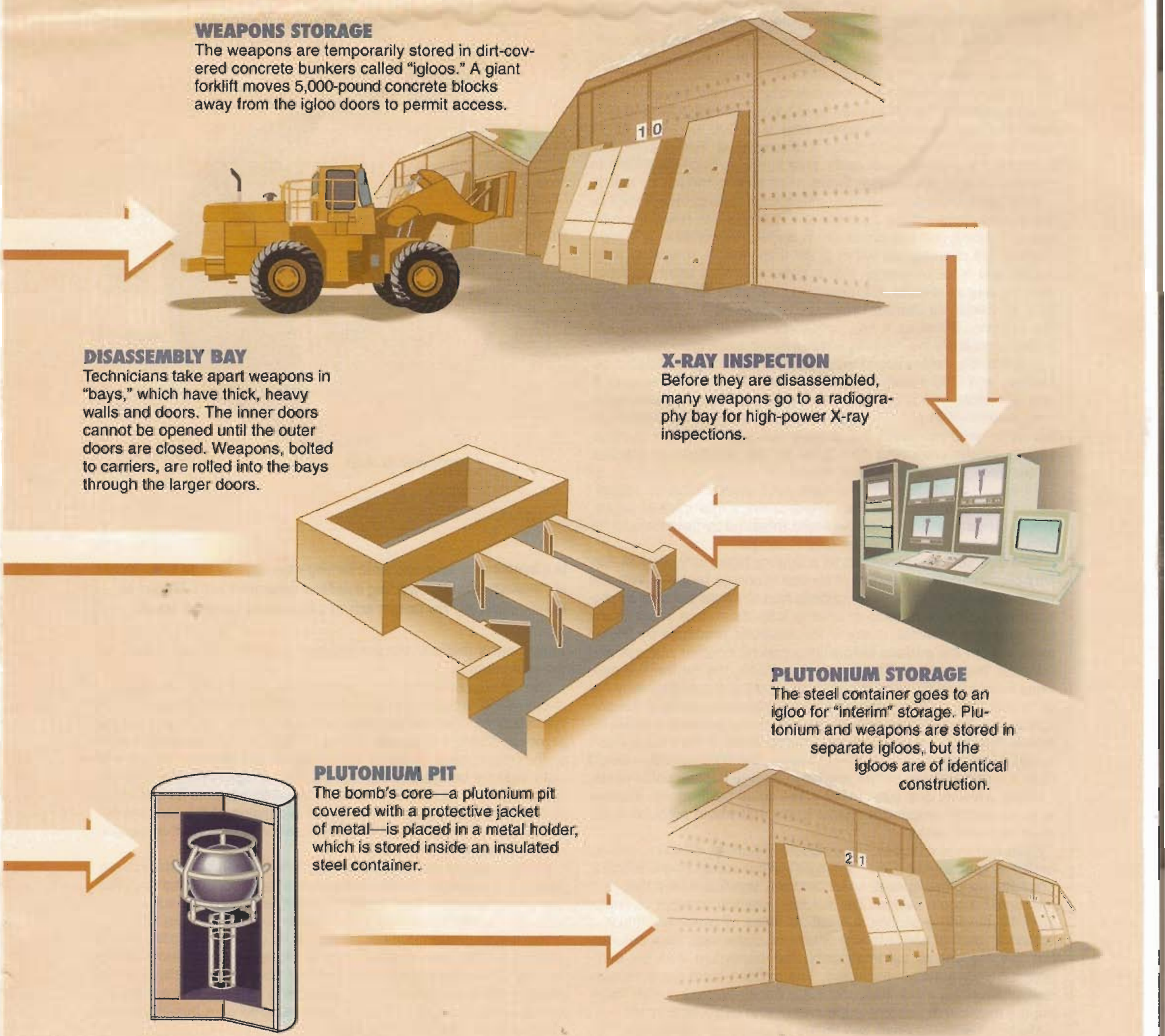
Plutonium, however, is a problem. Nonexistent in nature, plutonium is created in nuclear reactors by irradiating natural uranium with neutrons. Unlike U-235, plutonium can be chemically extracted from any mixture with ease.

Arms control experts believe plutonium is relatively safe in fixed storage at military bases or dismantlement centers. The cost of such storage is estimated at $1 to $2 per gram, or between $300 million and $600 million per year worldwide—not too much to pay for protection against the unauthorized use of this dangerous, cancer-causing material.

Greater risk occurs in transit. A special armored "white train" was once used to convey U.S. nuclear weapons to Pantex, the nation's only dismantlement center. Now a fleet of 70 special armored trucks, escorted by heavily armed guards, transports weapons to the 16,000-acre plant, located east of Amarillo, Texas.

The bombs, warheads, and artillery shells that the trucks transport to Pantex are delivered to an area called Zone 4 and temporarily stored in "igloos," bunkers made of reinforced concrete covered with at least three feet of soil. From the igloos, weapons are moved to buildings that are designed for inspection, assembly, and disassembly tasks. Building 104, one such facility, contains eight

NUCLEAR WEAPONS DISMANTLEMENT CENTER



"bays"—large, heavily shielded rooms. The walls consist of 15 feet of earth sandwiched between a pair of two-foot-thick layers of concrete, and the entrances are protected by 1,100-pound doors. The floors are made from paint chips that are mixed with polyurethane to form a spongy material deemed unlikely to set off explosives. While there is little danger of a nuclear detonation, it's possible that the chemical explosive of a weapon could blow up during the disassembly process. If that were to happen, the room's shielding would help contain the blast.

In one of the bays, technicians operate a powerful X-ray machine that can penetrate 15 inches of steel. "You want to know what the weapon system's condition is before you dismantle it," explains Randall L. Hodges, production supervisor for nondestructive evaluation.

Technicians place a weapon on a large turntable. Film is attached to a screen behind the turntable; pointed at the weapon is a linear accelerator suspended from a gantry—a jumbo version of the X-ray machine your dentist points at your cheek. A computer automatically controls the movement of the turntable and linear accelerator, and the technicians can watch the X-ray image as it's being made. Then they can add false-color enhancement to detect flaws.

After the X-ray inspection, the weapon goes to an assembly/disassembly bay. "You use essentially the same

THE BIRTH OF THE BOMB: FROM THEORETICAL PHYSICS TO THERMO

Familiar fuels like coal and gasoline derive their energy from the electrical forces that bind one atom to another in chemical compounds. These forces are mediated by the negatively charged electrons orbiting every atom's tiny nucleus. Nuclear energy exists in the far stronger, short-range forces that hold the atomic nucleus together. The nucleus is made up of positively charged protons and uncharged neutrons—and is 2,000 or more times heavier than the electron cloud surrounding it. Being positively charged, the protons repel each other strongly. To confine them in the tiny nucleus, the nuclear forces must be enormously powerful.

Most atomic nuclei are stable—the forces holding them together are substantially greater than the forces tending to make them fly apart. A few types are unstable; in a given population, a known fraction will disintegrate within a set time period, releasing fragments and a lot of energy. For a time, scientists believed there was no way to release this energy on demand. But in 1932, English physicist Sir James Chadwick discovered the existence of the neutron. Because it has no charge, a free neutron can approach and enter the nucleus without being electrically repelled.

Just months before World War II began, German physicists Lise Meitner and Otto Frisch discovered that hitting the nucleus of a uranium atom with a neutron causes the nucleus to break apart —to fission—with considerable release of energy. Absorption of the extra neutron makes the already oversized uranium nucleus slightly bigger, reducing the "grip" of the short-range nuclear forces enough to allow nuclear fission.

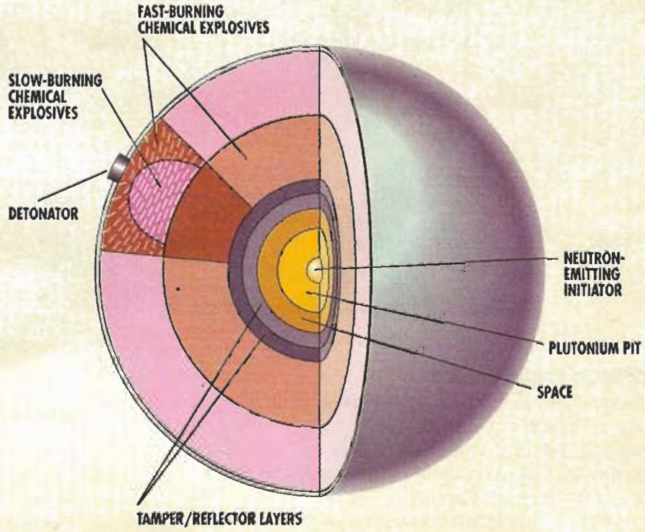
When physicists learned that each such uranium fission releases two or more neutrons, they knew at once that nuclear explosives were a possibility. The neutrons released by fission could hit other nuclei, causing a prompt chain reaction.

Scientists developed methods for preparing high-purity uranium and plutonium in quantities sufficient for use in bombs by 1945. With the bomb ingredients in hand, physicists had to figure out how to produce an explosive release of energy from them. In a small chunk of fissionable material, many of the neutrons produced by fission escape from the surface before they can hit another nucleus and continue the reaction. The bigger the chunk, the farther the neutrons must travel to reach the surface, and the more likely they are to hit and fission other nuclei. At a particular size—termed the critical mass—enough neutrons hit other nuclei to produce a chain reaction. The problem was to build a bomb in which the critical mass would come together quickly—otherwise, the chain reaction would blow the device apart before any large energy release could occur.

Using uranium, one sub-critical mass could be fired into another in a gun barrel, creating a critical mass that would produce a nuclear explosive yield.

Plutonium was different. Unavoidable impurities emitted so many neutrons that a plutonium "gun-type" bomb would begin reacting prematurely, blowing itself apart before a significant percentage of the material could fission. The solution was the concept of implosion. By placing a slightly sub-critical mass of plutonium inside a spherical shell of conventional chemical explosives, then detonating the explosives symmetrically, the plutonium can be compressed very quickly—imploded. The sudden increase in density makes neutrons more likely to hit the tighter-packed nuclei, causing the material to become supercritical and begin fissioning.

Modern bombs contain two layers of chemical explosives. The inner layer of fast-burning chemical explosives is covered by a composite layer of both fast- and slow-burning explosives (see illustration), arranged as multiple "explosive lenses." These lenses transform spherical detonation waves, originating from each detonator, into a uniform, inward-moving detonation wave focused on the plutonium pit.



In a bomb's core, fast- and slow-burning explosives form an outer layer of "explosive lenses," creating a uniform detonation wave focused on the plutonium pit. The tamper acts as a hammer to compress the pit.

IAN WORPOLE

The chemical explosives accelerate a spherical component —called the tamper/reflector—inward at high speed (several miles per second). The tamper/reflector, sometimes made in multiple layers of different materials, acts as a hammer to compress the pit to the critical stage. A space inside the tamper/reflector allows it to gain velocity before striking the pit. The tamper/reflector also reflects neutrons back into the plutonium pit to increase its rate of reaction, and it slows the initial rate of expansion of the reacting pit, keeping its density high as long as possible to prolong the reaction for a greater explosive yield.

A few neutrons are needed to trigger the fission process. In early designs, the hollow center of the plutonium pit contained an initiator, a device that emitted neutrons. In current designs, neutrons are injected into the bomb core by a special-purpose vacuum tube.

The first implosion bombs used 11 to 13 pounds of plutonium—a sphere a little over three inches in diameter—and about 2,000 pounds of chemical explosive. Refined computer models of bomb physics have permitted great reductions in size. Current implosion-type bombs can be built at least as small as a basketball and can weigh as little as 50 pounds.

Physicists knew in 1940 that even an atomic bomb would be a minor power source compared with the mechanism that drives the sun and other stars—nuclear fusion. At the pressure in the core of a star, pairs of hydrogen nuclei fuse to form helium nuclei, with a

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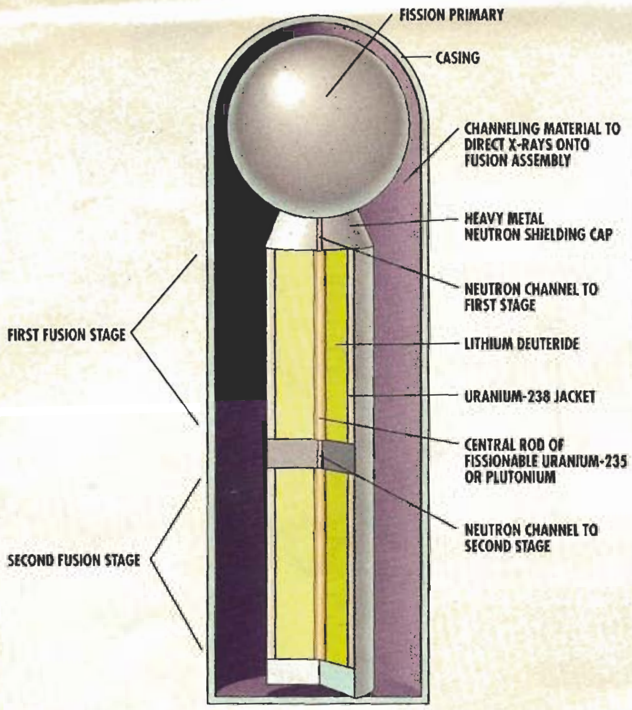
facilities for either production or dismantlement," says Gerald W. Johnson, the senior Department of Energy official at the plant. Inside the heavily reinforced bay, workers break down weapons into subassemblies. The versatile B-61 bomb that's carried by Air Force and Navy planes, for example, is broken into four sections: the nose cone, a center section containing radioactive materials, an arming section, and a tail section that contains a parachute. To learn how to take the weapon apart, workers train on a simulator that looks just like the real thing, but has mock radioactive components.

It takes workers as long as three weeks to disassemble some weapons, but a B-61 can be taken apart in about a day. After the bomb is broken down into its four subassemblies, the nose cone is sent to a Department of Energy plant in Kansas City. The segment containing the radioactive material and chemical explosives, known as the "physics package," usually goes to another building for special handling. The remaining parts are returned to other facilities for reuse, or "disfigured" to protect secret

NUCLEAR REALITY



In this thermonuclear device, X-rays from a fission bomb initiate fusion in an adjacent cylindrical assembly. The fusion fuel, lithium deuteride, is trapped between a U-238 "wrapper" and a "spark plug" of U-235 or plutonium.

huge energy release. If this process could be initiated on Earth, a hydrogen-fusion bomb—or H-bomb—was possible.

Mathematician Stanley Ulam and physicist Edward Teller devised a means of using an atomic explosion's generous output of soft X-rays to compress and initiate fusion in a cylindrical assembly *outside* the spherical atomic bomb, or primary (see illustration). A radiation channel conducts a fraction of the atomic primary's X-ray output onto the surface of the fusion assembly. The fusion fuel—a dry, ceramiclike salt, lithium deuteride—is confined between a "wrapper" of uranium-238 and a fissionable inner rod of plutonium or U-235, called the "spark plug."

Ignition of the fusion assembly begins when the radiation channel directs intense X-ray energy from the exploding primary onto the surface of the fusion assembly, causing it to vaporize explosively. This causes the fusion assembly to "recoil" inward, compressing itself to its ignition point. Simultaneously, neutrons enter the now-critical "spark plug," causing it to fission. Intense neutron flux converts the U-238 wrapper to fissionable form, and it too explodes. This triple reaction traps the fusion fuel for an extended time period at very high temperature and pressure, increasing the fusion yield. As a bonus, the lithium in the lithium deuteride is transmuted into tritium, which itself participates in the fusion reaction. Such a weapon is thus a fission-fusion-fission device. In this way, an imploding atomic primary of a few kilotons of energy can trigger a several-hundred-kiloton fusion secondary, which can in turn trigger a much larger second fusion stage.—*K. C.*

design information. Gold and other precious metals are recovered from the mangled parts, which are sent away for recycling or disposal. The total cost for disassembling a single weapon is between $10,000 and $25,000.

Some weapons, like the B-61 bomb, are two-stage thermonuclear arms. These types contain a fusion assembly known simply as the "secondary." Pantex sends secondaries to the Y-12 plant in Oak Ridge, Tenn., for storage or disassembly. Each secondary is shipped in a double-walled can called an MH-2800 Type B. There are 180 of these cans, and they must pass herculean tests: a 30-foot drop to a slab, a 40-inch drop to a spike, a 1,475°F fire for 30 minutes, immersion in water for eight hours, and a load of 6,500 pounds for 24 hours.

Inside the secondary is a "wrapper" of heavy uranium-238. The wrapper covers a sealed cylinder of lithium deuteride and a central plutonium rod. The lithium deuteride is pyrophoric—it ignites spontaneously if exposed to air—so it requires special care. The plutonium rod is removed, cased, and stored. Any other valuable materials are recovered, and the rest is ground to bits.

The B-61's "primary"—its fissionable core—is dismantled at Pantex in one of the plant's 12 "gravel gerties," semiburied structures in which a thick gravel-and-sand cap covers a "cell" with reinforced walls. In the event of an accidental chemical explosion that might disperse plutonium, "the gravel would rise a few feet and settle down, containing the radiation," explains Jerry Hemphill.

Working in the gravel-covered cells, gloved technicians wearing lead aprons and shielded face masks remove the primary's outer casing. Inside they may find an "electric blanket"—a heater designed to maintain the chemical explosives at an optimal temperature. Beneath the blanket is the spherical shell of explosives, protected by a close-fitting jacket.

Thirty-two or more exploding-wire detonators are bonded to the outside of the spherical primary; their job is to symmetrically ignite the chemical explosives. Each detonator is connected—through high-speed, solid-state switches—to its own capacitor. Like a car engine, an atomic bomb has a capacitor discharge ignition.

Located near the detonators are thermal batteries, devices that have a long shelf life and can deliver a lot of current on demand. During the arming sequence, the batteries charge the capacitors, which discharge across the detonators when the firing signal is given. While the bomb is being disassembled, the detonators and their capacitors are shorted, so that external electromagnetic fields cannot somehow induce a discharge.

The chemical explosives on the exterior of the spherical primary are high-density (almost twice that of water), high-energy stuff, far more energetic and fast-burning than dynamite, yet very resistant to unintended discharge from shock or heat. Workers use a water-jet saw to cut through the dark, waxy material, revealing the bomb's core. The hemispherical shells of high explosives that are removed are later burned on trays in an open field.

With the explosives removed, technicians can see a protective plating of gold or another inert material. Beneath it is steel-gray beryllium, or uranium-238—the spherical tamper. As the chemical explosive wave rushes inward, the tamper's mass acts as a hammer that strikes the plutonium pit—the bomb's fuel—from all directions simultaneously. The pit is suspended in the center of the hollow tamper's inner cavity.

This insignificant-looking, grapefruit-size lump contains energy that can level cities. Heavier than a lead ball of the same size, the sphere is perpetually warm from its steady release of energy. Plutonium is highly reactive, so the pit is hermetically sealed in a jacket of stainless steel or a similar metal. "If you can picture a grapefruit skin with the fruit removed," says Tom Walton, "the steel is like the yellow part of the skin, and the plutonium is the white part just under the yellow. The inside is hollow."

The steel jacket prevents the pit from giving off particles that could be inhaled or ingested, but it does not block the carcinogenic gamma radiation emitted by the

[*Continued on page 102*]

Taking apart the bomb

[*Continued from page 69*]

plutonium. The amount of radiation that workers receive depends on how close to the plutonium they are, how long they are exposed, and how well they are shielded. Pantex permits workers to receive up to one rem of radiation per year, one-fifth of the government's limit for radiation workers. The average person who does not work around radiation receives a little more than a third of a rem per year from natural radiation, medical X-rays, and other sources.

Overcrowded igloos

The plutonium pits removed from weapons are placed in holders that fit inside steel containers. The containers are stored in 18 of the 60 igloos on the Pantex property (the others are reserved for weapons).

"We have always [stored] pits here, but only temporarily," says Hemphill. Until recently, the pits were sent to the Rocky Flats plant outside Denver to be made into new bomb cores, but that plant is now inactive. Pantex currently has the capacity to dismantle approximately 2,000 warheads per year, but at that rate, the plant will run out of storage space for the plutonium pits around the end of this summer.

There are two proposed solutions: Convert more igloos to pit storage or begin stacking the pit containers on top of each other inside the igloos. Current regulations prohibit both of these strategies, but if Texas approves an environmental impact assessment prepared by the DOE, the rules could be changed to permit "interim" storage.

What will be the ultimate fate of the plutonium piling up at Pantex? Theodore Taylor, a former bomb designer now concerned about weapons proliferation, suggests using the space shuttle or heavy booster rockets to shoot the world's supply of plutonium into the sun. The problem with this idea is that a *Challenger*-type accident could have catastrophic consequences.

A Russian entrepreneurial corporation, Chetek, proposed using underground nuclear explosions to mix and vitrify plutonium into millions of tons of miles-deep rock—making a highly diluted and inaccessible ore. But again, if anything went wrong, the consequences could be severe.

Another proposal is to create a new, mixed-oxide plutonium-uranium fuel cycle for nuclear power generation. There is some support in Congress for this idea, and some Russian authorities back it as well, but the technology would take a decade or more to implement.

Guarded storage may be the best solution. Now kept in "interim" storage, plutonium could eventually be deposited in sealed, deep geologic formations, as is now proposed to store reactor waste. The land above such a site would have to be guarded for millennia; only half of the plutonium will have decayed after 24,000 years.

But the Pentagon and the Department of Energy are in no hurry to find a final resting place for their stockpile of plutonium. Because public protest will likely limit the government's ability to reactivate the plants that manufactured fissionable materials, the pits created at great expense are being hoarded carefully, and there are no plans to make them permanently inaccessible for weapons use. The government is simply storing the materials, which could later be "recycled." The making of fresh bombs from old is a long-established practice.

Like their American counterpart, the former Soviet republics have not yet developed firm plans for permanent disposal. Ukraine, Kazakhstan, and Belarus initially agreed to return their arms to Russia for dismantlement, but they are now balking at giving up these powerful bargaining chips. Ukraine, in particular, wants a guarantee of military protection before it surrenders its weapons to Russia. The former republic also wants Russia to promise that it will permanently dispose of the weapons, rather than simply store them.

The U.S. Congress approved a $400 million loan to Russia to aid the transport and disposal process. The United States also offered Russia 25 specially fitted railcars that could be used to transport weapons to dismantlement areas.

Farewell to arms

How can U.S. officials be sure that the Russians are really taking apart their bombs? What goes on inside a dismantlement facility is the business of the nation that owns it, but inspectors at the gates will be able to monitor everything that goes in and out. It is hoped that, in this way, each nation can confidently scale down its warhead count step by step, knowing that the other is doing the same.

Scientists say that measurements of the types and intensities of emitted radiation can be used to identify weapons components, and that each unit can then be sealed with a coded fiber-optic cable that is inspectable and tamper-resistant. No sensitive design information will thus be revealed, and the only intrusion into national sovereignty that will be required is periodic seal inspection.

But these are really administrative matters. The end of the Cold War raises larger issues. Now that we have created nuclear weapons, how can we ever get rid of them? What do we do with the radioactive materials that cannot be destroyed or recycled? The best plans call for nothing more than the sequestering of these materials. Like garbage placed at the curb to be thrown "away," plutonium will merely be moved to another place and stored. Although that has ominous implications, it's a step in the right direction—toward the day when we will no longer be just a phone call away from nuclear disaster. PS