

REFINEMENTS IN DESIGN

From the late 1940s, U.S. nuclear weapon designers developed and tested warheads to improve their ballistics, to standardize designs for mass production, to increase yields, to improve yield-to-weight and yield-to-volume ratios, and to study their effects. These improvements resulted in the creation of nuclear warheads for a wide variety of strategic and tactical delivery systems.

Fission. The first advances came through the test series Operation Sandstone, conducted in the spring of 1948. These three tests used implosion designs of a second generation, which incorporated composite and levitated cores. A composite core consisted of concentric shells of both uranium-235 and plutonium-239, permitting more efficient use of these fissile materials. Higher compression of the fissile material was achieved by levitating the core—that is, introducing an air gap into the weapon to obtain a higher yield for the same amount of fissile material.

Tests during Operation Ranger in early 1951 included implosion devices with cores containing a fraction of a critical mass—a concept originated in 1944 during the Manhattan Project. Unlike the original Fat Man design, these “fractional crit” weapons relied on compressing the fissile core to a higher density in order to achieve a supercritical mass. These designs could achieve appreciable yields with less material.

One technique for enhancing the yield of a fission explosion was called “boosting.” Boosting referred to a process whereby thermonuclear reactions were used as a source of neutrons for inducing fissions at a much higher rate than could be achieved with neutrons from fission chain reactions alone. The concept was invented by Teller by the middle of 1943. By incorporating deuterium and tritium into the core of the fissile material, a higher yield could be obtained from a given quantity of fissile material—or, alternatively, the same yield could be achieved with a smaller amount. The fourth test of Operation Greenhouse, on May 24, 1951, was the first proof test of a booster design. In subsequent decades approximately 90 percent of nuclear weapons in the U.S. stockpile relied on boosting.

Fusion. Refinements of the basic two-stage Teller-Ulam configuration resulted in thermonuclear weapons with a wide variety of characteristics and applications. Some high-yield deliverable weapons incorporated additional thermonuclear fuel (lithium deuteride) and fissionable material (uranium-235 and uranium-238) in a third stage. While there was no theoretical limit to the yield that could be achieved from a thermonuclear bomb (for example, by adding more stages), there were practical limits on the size and weight of weapons that could be carried by aircraft or missiles. The largest U.S. bombs had yields of from 10 to 20 megatons and weighed up to 20 tons. Beginning in the early 1960s, however, the United States built a variety of smaller, lighter weapons that exhibited steadily improving yield-to-weight and yield-to-volume ratios.

A nuclear explosion releases energy in a variety of forms, including blast, heat, and radiation (X rays, gamma rays, and neutrons). By varying a weapon’s design, these effects could be tailored for a specific military purpose. In an enhanced-radiation weapon, more commonly called a neutron bomb, the objective was to minimize the blast by reducing the fission yield and to enhance the neutron radiation. Such a weapon would prove lethal to invading troops without, it was hoped, destroying the defending country’s towns and countryside. It was actually a small (on the order of one kiloton), two-stage thermonuclear weapon that utilized deuterium and tritium, rather than lithium deuteride, to maximize the release of fast neutrons. The first U.S. application of this principle was an antiballistic missile warhead in the mid-1970s. Enhanced-radiation warheads were produced for the Lance short-range ballistic missile and for an eight-inch artillery shell.

(T.B.C./R.S.N.)

Chemical and biological weapons

CHEMICAL WARFARE

Chemical warfare agents are substances, whether gaseous, liquid, or solid, intended for use in warfare because of

their direct toxic effects on people, animals, or plants. Worldwide revulsion toward chemical weapons is embodied in the Geneva Protocol of 1925, prohibiting “the use in war of asphyxiating, poisonous or other gases, and of all analogous liquids, materials or devices.” More than 140 states, including all major nations, are parties to the Protocol of 1925.

History of use. Toxic smokes and other toxic substances were used occasionally in war from ancient times, but the earliest large-scale use of chemical warfare agents was in World War I. Preceded by both sides’ sporadic use of various tear gases in artillery and other projectiles starting in 1914, it was the German attack with chlorine released from thousands of cylinders along a four-mile (six-kilometre) front at Ypres on April 22, 1915, that initiated the massive use of chemicals in that conflict. The wind-borne cloud totally broke the lines of the unprepared French Territorial and Algerian units in its path, but the attackers failed to exploit the opportunity. Although numerous chlorine gas-cloud attacks were subsequently carried out by both sides, they accomplished little, owing to the introduction of gas masks and other protective measures.

As other gases and more effective delivery methods were introduced, so too were improved defenses. Notable among offensive improvements were respiratory agents more poisonous than chlorine, such as phosgene, and chemicals that blistered the skin and attacked the eyes, especially mustard gas. The defense kept pace, with the introduction of better gas masks, protective clothing, and battlefield tactics for minimizing exposure. More than 100,000 tons of various chemical warfare agents were used in World War I; but gas was an unimportant weapon in overall military terms, largely because of the effectiveness of defenses against it.

In World War II, chemical weapons were stockpiled by both sides, but they were not used and were not integrated into military planning. Records indicated various reasons for this: (1) military opinion that chemical weapons would be no more effective than conventional weapons and would complicate and delay operations, (2) fear of retaliation, especially against civilian centres, and (3) aversion to gas warfare by political and military leaders, reflecting the proscriptions of the Geneva Protocol.

Chemical weapons were used in only a few of the more than 200 wars fought after World War I. In each case—as in Ethiopia (1935–36), China (1938–42), the Yemen (1966–67), and Iraq–Iran (1984–88)—chemicals were used against forces initially lacking gas masks.

The weapons. Modern lethal chemical weapons employed the organophosphorus nerve agents first produced but not used by Germany during World War II. Related to certain insecticides but much more toxic to man, they would cause intense sweating, filling of the bronchial passages with mucus, dimming of vision, uncontrollable vomiting and defecation, convulsions, and finally paralysis and respiratory failure. Death would result from asphyxia, generally within a few minutes after respiratory exposure or within hours if exposure was through a liquid nerve agent on the skin.

The U.S. stockpile of chemical warfare agents, loaded into munitions or stored in bulk, included the nerve agents sarin and VX, while the Soviet Union stocked the nerve agents sarin, VX, and soman. Of these three nerve agents (all liquids), sarin would evaporate the most rapidly and would pose mainly a respiratory hazard. VX, the least volatile, would act primarily as a contact poison. Soman, with volatility intermediate between that of sarin and VX, would pose both respiratory and contact hazards.

In addition to nerve agents, both nations stocked mustard gas and the irritant CS, which was also used by police. The Soviets also stocked lewisite, a blister agent developed but not used by the United States during World War I. Mustard gas and lewisite would not be nearly so lethal as the nerve agents, causing casualties principally from incapacitating blisters and temporary blindness. Their full effects would take several hours to develop, although lewisite, in contrast to mustard gas, would cause immediate pain to the skin and eyes.

Liquid chemical warfare agents, such as mustard gas,

Chlorine
in World
War I

U.S. and
Soviet
nerve
agents

Boosted
reactions

The
neutron
bomb

lewisite, and the nerve agents, could be loaded into artillery projectiles, bombs, or missile warheads, to be dispersed by an explosive charge as a vapour cloud or a liquid spray. Liquid agents might also be carried in tanks and sprayed from aircraft at low altitude. Greater persistence and more controlled dispersion might be obtained by the addition of thickeners. Solid agents, such as CS, might be dispersed explosively or aerosolized from pyrotechnic mixtures in various munitions.

An innovation put into quantity production by the United States in 1987 was the binary sarin artillery projectile, in which two relatively nontoxic precursors of sarin were held in separate canisters. Upon firing, the two chemicals would mix and react to form sarin. One of the canisters might be stored and shipped separately, to be inserted into the projectile at the ammunition depot or the gun site. This built-in safety feature was intended to provide greater operational flexibility in the storage and transport of the weapon. The binary principle could be applied to other types of chemical warfare agent.

The amount of a chemical warfare agent required to create a hazardous cloud over a target area would be highly dependent on air movements. The weight of sarin, for example, required to produce a lethal respiratory hazard to unprotected persons over most of an open mile-square area could be between 0.3 and 10 tons, depending on atmospheric conditions. As an illustration, the delivery of these amounts by 155-millimetre artillery would require the firing of approximately 100 to 3,000 projectiles.

For causing casualties to unprotected troops, chemicals could be more effective than an equivalent weight of conventional high-explosive fragmentation weapons. For troops with good protection, however, the reverse would be true; soldiers with modern antichemical protection would be far less vulnerable to chemicals than to conventional weapons.

Defense. The first and most important line of defense against chemical warfare agents (also needed for protection against radioactive fallout) was the individual protection provided by masks and protective clothing, and the collective protection of combat vehicles and mobile or fixed shelters. Filters for masks and shelters contained specially treated activated charcoal to remove vapours, and paper membranes or other materials to remove particles. Such filters typically could reduce the concentration of chemical (and biological) warfare agents by a factor of at least 100,000. Masks could be donned in less than 10 seconds and could be worn for long periods, even in sleep. Modern protective overgarments were made of fabric containing activated charcoal or other adsorptive forms of carbon. A complete suit typically weighed about four pounds (two kilograms). The fabric could breathe and pass water-vapour perspiration. In warm weather, periods of heavy exertion in full protective gear would have to be limited in order to avoid heat stress, or else protection would have to be partly relaxed, as by partially opening the protective jacket. Under common European conditions, military units routinely exercised at or near full protection for several days continuously.

Other items for chemical defense were detectors and alarms sensitive to nerve and blister agents, prophylactic and antidote drugs that would provide partial protection against nerve agents, and equipment for decontaminating people and equipment.

The effectiveness of chemical weapons against prepared forces would depend more on the interference with fighting performance imposed by wearing protective equipment and taking other precautions than on direct casualties. The extent of such interference, and hence the military value of chemicals in comparison with other weapons, was difficult to assess. Estimates, based on controlled field exercises, of the reduction in performance in military units under chemical attack ranged from near zero to more than 30 percent, depending on the mission and the conditions of the exercise.

BIOLOGICAL WARFARE

Biological warfare agents are infectious microbes, including viruses, bacteria, and fungi, intended for use in warfare

because of their pathogenic effects on people, animals, or plants. The development, production, and stockpiling of weapons based on them were outlawed by the 1972 Biological Weapons Convention, to which more than 100 states were party, including all five permanent members of the United Nations Security Council. The treaty also covered weapons based on naturally occurring poisons, known as toxins, however produced. As with chemical weapons, actual employment of biological weapons was outlawed by the 1925 Geneva Protocol.

At the time of their destruction in accordance with presidential directives of 1969 and 1970, the biological weapons of the United States (the only country for which authenticated information was available) included dry-powder or liquid-slurry formulations of the microbes that cause tularemia, Q fever, Venezuelan equine encephalitis, rice blast, and stem rust of wheat. They also included a number of toxins, such as paralytic shellfish poison. A variety of dispensers, both large and small, was also on hand.

Biological weapons designed to dispense airborne clouds of pathogenic microbes could in theory kill or incapacitate unprotected populations over very large areas. Such weapons were never used. (Ma.Me./J.P.P.R.)

Fortification

Fortifications are military positions that have been strengthened against attack. They are usually of two types: permanent and field. Permanent fortifications include elaborate forts and troop shelters; they are most often erected in times of peace or upon threat of war. Field fortifications are constructed when in contact with an enemy or when contact is imminent. They consist of entrenched positions for personnel and crew-served weapons, cleared fields of fire, and obstacles such as explosive mines, barbed-wire entanglements, felled trees, and antitank ditches. Both field and permanent fortifications often take advantage of natural obstacles, such as canals and rivers, and they are usually camouflaged or otherwise concealed. Both types are designed to assist the defender to obtain the greatest advantage from his own strength and weapons while preventing the enemy from using his resources to best advantage.

This section discusses military fortification since the introduction of rifled artillery and small arms. For discussions of fortification up to the modern era, see above *Military technology before the modern era: Antiquity and the classical age; The age of cavalry; and The gunpowder revolution.*

TRENCH WARFARE, 1860-1918

The American Civil War. In the American Civil War, field fortifications emerged as an essential of warfare, with both armies employing entrenchments to an extent never before seen. Troops learned to fortify newly won positions immediately; employing spades and axes carried in their packs, they first dug rifle pits and then expanded them into trenches. Early in the war, General Robert E. Lee adopted the frontier rifleman's breastwork composed of two logs on the parapet of the entrenchment, and many of Lee's victories were the result of his ability to use hasty entrenchments as a base for aggressive employment of fire and maneuver. Two notable sieges, that of Vicksburg, Miss., in the west, and Petersburg, Va., in the east, were characterized by the construction of extensive and continuous trench lines that foreshadowed those of World War I. In the Cold Harbor, Va., campaign, when General Ulysses S. Grant sent his troops against Confederate earthworks, he lost 14,000 men in 13 days. Field mines and booby traps were used extensively, and trench mortars were developed to lob shells into opposing trenches.

World War I. The lesson taught by accurate, long-range fire from entrenched positions in the American Civil War was lost on European commanders. Even the bitter experiences of appalling losses in the Crimean, Franco-German, and Boer wars failed to lessen an ardour for the theory of the offensive that was so fervent as to leave little concern for defensive tactics in the field. Few took notice of the immense casualties the Turks inflicted from behind

Banning of biological weapons

Effectiveness of masks and overgarments

The rifleman's breastwork