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Third-Generation Nuclear Weapons

During the early 1950's American weapon laboratories were exceptionally productive. They not only achieved dramatic improvements in the performance of fission bombs, which represent the first generation of nuclear weapons, but also succeeded in establishing a second generation of nuclear weapons by harnessing the explosive power of fusion in the form of the hydrogen bomb and its various derivatives. By the end of the 1950's the warheads in the U.S. nuclear armament bore little resemblance to the bombs that had ushered in the nuclear age over Hiroshima and Nagasaki.

Today a third generation of nuclear weapons is technologically feasible. By altering the shape of the nuclear explosive and manipulating other design features, weapons could be built that generate and direct beams of radiation or streams of metallic pellets or droplets at such targets as missile-launch facilities on the ground, missiles in the air and satellites in space. These weapons would be as removed from current nuclear weapons in terms of military effectiveness as a rifle is technologically distant from gunpowder.

The surge of technical creativity that produced the first two generations of nuclear weapons can be explained largely by the fact that the national laboratories had massive funding, a mandate to pursue new weapon possibilities and unqualified Government support. Yet speaking as one who worked at that time on the design of nuclear weapons, perhaps the most stimulating factor of all was simply the intense exhilaration that every scientist or engineer experiences when he or she has the freedom to explore completely new technical concepts and then to bring them into reality.

The Strategic Defense Initiative, under which a vigorous military research and development program is currently being carried out, could well generate conditions at the U.S. weapon laboratories similar to those in the 1950's. The daunting technical challenge implied in President Reagan's call to search for a way to defend the nation against ballistic missiles is likely to spur modern-day weaponeers to consider radically new types of nuclear weapons—quite apart from concurrent advances in delivery and command-and-control systems.

It would be logical for a weapon designer to build on the legacy of the first- and second-generation nuclear weapons, all of which transform mass into an abundance of energy that is then uniformly dissipated in a roughly spherical pattern. Such a new generation of nuclear weapons might selectively enhance or suppress certain types of energy from the vast energy source provided by a nuclear explosion. Moreover, the lethal effects of a selected energy carrier (such as electromagnetic radiation, subatomic particles or expelled material) might be increased by distorting its normal pattern of emission into a highly asymmetrical one—in essence concentrating the energy in a certain direction.

Indeed, nuclear weapons that deliver 1,000 or more times the energy per unit area on a target than does a conventional nuclear weapon are entirely plausible. Special components or materials attached to the exterior of a nuclear device could convert the energy released by its detonation into a different form; configuring the nuclear explosive and its casing in certain ways could channel most of the energy in certain directions. Alternatively, the energy released from a nuclear explosion could be converted and directed by exploiting the effect such an explosion has on natural surroundings. Regardless of their original intent, if such weapons are built, they will undoubtedly be modified for application in a wide variety of strategic and tactical missions—offensive as well as defensive—in all kinds of environments.

Like previous generations of nuclear weapons, members of the new generation would derive their enormous explosive energy from fission (the splitting of a nucleus by a neutron into two nuclei of comparable size) or a combination of fission and fusion (the joining of two light nuclei to form a heavier nucleus). Fission explosions are easier to produce and essentially amount to bringing together, in the space of about a microsecond (a millionth of a second), enough fissile material (such as uranium 235 or plutonium 239) in a sufficiently small volume so that a huge number of fission-inducing neutrons can be quickly generated in the material. The high-speed assembly of the fissile material is generally achieved by precisely detonating chemical-explosive charges in such a way as to propel subunits of the material together to form a single compressed mass.

Initiating a fusion explosion is a much more complex affair, because extremely high temperatures (on the order of hundreds of millions of degrees Kelvin) are required. In fact, the only practical mechanism by which to generate such temperatures in a transportable device is a fission explosive. A pure-fusion explosive—without a fission trigger—reportedly still eludes weapon designers.

Fusion reactions not only release substantially more energy per unit weight than fission reactions but also produce more high-energy neutrons. The additional neutrons can in fact “boost” the yield of a fission weapon if they are allowed to interact with uranium or plutonium in the weapon’s core. Hence placing small quantities of thermonuclear fuel such as tritium or deuterium (both are isotopes of hydrogen) in a fission weapon increases the overall yield-to-weight ratio of the weapon, since the added weight needed for boosting is insignificant.

Unlike boosted weapons, in which the energy released by fusion does not significantly contribute to the overall weapon yield, so-called thermonuclear weapons derive a substantial part of their explosive energy from fusion reactions. The relative amounts of energy attributable to fusion and fission depend on the design of the weapon. If a considerable amount of lithium deuteride (which, when it is irradiated with neutrons, produces tritium) is compressed and heated by the energy released from a small fission-explosive trigger, the fraction of the total yield due to fusion in relation to the fraction due to fission can become very large. Such weapons are sometimes called “clean” thermonuclear weapons, because they release relatively few radioactive fission products. At the other extreme are weapons in which the thermonuclear fuel is enclosed in a substantial quantity of ordinary uranium (uranium 238). The high-energy neutrons produced by fusion in the thermonuclear fuel can induce fission in the surrounding uranium, multiplying the total fission yield considerably.

The yield-to-weight ratios of pure fission warheads have ranged from a low of about .0005 kiloton per kilogram to a high of about .1 kiloton per kilogram. (One kiloton is equivalent to the detonation of about 1,000 tons of TNT.) The overall yield-to-weight ratio of strategic thermonuclear warheads has been as high as about six kilotons per kilogram. Although the maximum theoretical ratios are 17 and 50 kilotons per kilogram respectively for fission and fusion reactions, the maximum yield-to-weight ratio for U.S. weapons has probably come close to the practical limit owing to various unavoidable inefficiencies in nuclear weapon design (primarily arising from the fact that it is impossible to keep the weapon from disintegrating before complete fission or fusion of the nuclear explosive has taken place). Yet even the lowest yield-to-weight ratio of a pure fission weapon is orders of magnitude higher than the ratio of chemical explosives. Indeed, the discharge of energy from a detonated nuclear weapon is so massive and violent that it immediately vaporizes and ionizes the weapon itself, converting it into plasma: an extremely hot gas of positively charged ions and negatively charged electrons. In addition substantial quantities of gamma rays and neutrons are emitted as by-products of the fission and fusion reactions. The kinetic energy of the weapon-debris plasma as well as the nuclear emanations constitute what

could be called the primary effects of a nuclear explosion; they arise in any nuclear burst, regardless of the environment in which it takes place.

Plasma at the temperatures prevailing just after a nuclear explosion radiates X rays. Indeed, about 70 percent of the energy emitted in the first few microseconds after an explosion consists of this radiation. The exact fraction of the total explosive energy released in the form of primary X rays tends to increase with the yield-to-weight ratio, since the ratio determines the overall temperature of the weapon-debris plasma. The greater the amount of energy dissipated in the form of X rays, the less the kinetic energy of the expanding weapon-debris plasma. A typical plasma velocity for a thermonuclear weapon with a high yield-to-weight ratio would be about 1,000 kilometers per second, representing some 10 percent of the total explosive energy.

Gamma rays that are emitted within a second or so of the explosion (so-called prompt gamma rays) account for about 3.5 percent of the total energy released by fission and for as much as 20 percent of the energy released from some cycles of thermonuclear reactions. In current types of nuclear explosives all but a few percent of these gamma rays are absorbed within the weapon. The kinetic energy of excess neutrons accounts for about another 1.8 percent of the energy released by fission and, depending on the type of thermonuclear fuel, between 40 and 80 percent of the energy released by fusion. High-energy neutrons, however, tend to be slowed down by inelastic scattering or collision with light elements in the materials of implosion systems. The average energy of the neutrons that actually escape capture in the weapon materials and are released into the environment is therefore typically much lower. This effect is particularly pronounced in thermonuclear weapons, since the fuel consists of light elements. Indeed, in such weapons the energy of the neutrons is deliberately deposited within the thermonuclear fuel, since neutrons play a vital role in maintaining the elevated temperatures needed to achieve high reaction rates. Most nuclear-weapon development for the past 40 years has not had the aim of significantly enhancing or suppressing particular forms of energy other than by adjusting the relative amounts of fission and fusion taking place in the warhead. One exception is the so-called neutron bomb [see "Enhanced-Radiation Weapons," by Fred M. Kaplan; *SCIENTIFIC AMERICAN*, May, 1978]. A neutron bomb is a low-yield thermonuclear explosive specifically designed for an increased output of high-energy neutrons per kiloton of total yield. It is intended to be a nuclear antipersonnel weapon that produces minimal concomitant blast damage and radioactive fallout.

Yet just as a nuclear weapon can be designed to enhance its output of primary neutrons at the expense of blast and radioactive fallout, virtually any other primary energy released by a nuclear explosive could similarly be enhanced by placing appropriate materials in suitable geometries close to the explosive. Significant control over the amount and energy of X-radiation, for example, could be achieved by changing the average molecular weight of the materials in the weapon, the weapon's exterior surface area and the way the energy generated in its core is distributed over the expanding front of weapon debris after detonation.

Changes in the design of thermonuclear weapons could also substantially increase the energy accounted for by prompt gamma rays. One possibility is to encase the weapon with an isotope that, when it is bombarded with neutrons, emits gamma rays. In this way excess fission or fusion neutrons escaping from the weapon's core could induce the emission of gamma rays, nearly half of which would leave the expanding explosion debris. (The other half would radiate inward and be absorbed by the debris material.)

The quantities of radioactive fission products (the main component of fallout) among the weapon debris could similarly be controlled over very wide ranges, particularly for thermonuclear weapons with yields greater than a few hundred kilotons. Furthermore, by blanketing the weapon with

isotopes that, when they are irradiated with neutrons, produce radioactive nuclei having selected half-lives and decay modes, the lethality of the radioactive fallout could be increased.

The effects of a nuclear explosion could also be made directional in the same way high-explosive devices such as conventional shaped charges can produce armor-penetrating jets of molten metal or directional shrapnel. By considering how explosive charges of nonspherical shape release their energy some insight can be gained on how this could be done [see illustration on next page].

Detonating a disk of high explosive all at once, for example, causes the explosion products to be flung out in a characteristic double-cone pattern. The reason is that the velocity of the explosion products in a direction perpendicular to the disk's two surfaces will be higher than their radial velocity. The apex angle of the cones will direction perpbly the ratio of the thickness of the disk to its diameter. The average total kinetic-energy flux (energy per unit area per unit time) of the explosion products crossing a plane perpendicular to the axis of the double cone could therefore be considerably greater than it would be if the same mass of high explosive expels its products spherically. If the average velocity of the explosion products in the direction of the cone's axis is 40 times their average radial velocity (corresponding to a cone angle of about three degrees), the enhancement factor would be about 3,000.

Another example is the detonation of a long, thin cylinder of high explosive. In this case the highest explosion-product velocities would be perpendicular to the axis of the cylinder. Hence the explosion products would tend to preserve a cylindrical pattern; the energy-flux enhancement factor in this example tends to be smaller than the factor in the preceding one.

A final example is a charge of high explosive that is tamped, or restricted, by dense material in all directions except forward. In such a case the explosion products would be projected primarily forward. The additional weight entailed by the inert mass around the explosive is more than balanced by the concentration of the energy through the opening in the tamper. That is why a rifle bullet can produce much greater damage to a target than the detonation of a mass of high explosive having the same weight as the rifle.

Of course, nuclear reactions release many more forms of energy at much higher intensities than chemical high explosives, including gamma rays, X rays, neutrons and a wide variety of radioactive nuclei. It is clear that even nuclear explosives of very low yield offer many more opportunities than chemical explosives to produce such directional effects.

Most of a nuclear explosion's lethal effects are actually secondary effects resulting from the interaction of the kinetic energy of the weapon debris plasma and the initial radiation (namely X-radiation) with the medium in which the detonation takes place. Hence many nuclear-explosion phenomena of military interest are determined by properties of the medium such as its pressure, density and composition. It is the variations in these properties that account for the widely divergent responses associated with nuclear bursts in space, in the atmosphere, on the surface of the earth and below the earth's surface. By choosing the appropriate primary effects to be enhanced or suppressed, depending on the prevailing environmental conditions, the secondary effects of the weapon can be more efficiently transmitted to targets.

Because space is essentially empty, there is no medium with which to interact, and the primary products of a nuclear explosion (X rays, weapon debris plasma and nuclear radiation) continue to travel in the same directions in which they were released until they hit something or are deflected by the earth's magnetic or gravitational field (depending on whether they have respectively electric charge or mass). That is why initial asymmetries in the distribution of mass in an explosive set off in space tend to be preserved out to great distances in the pattern of the energy radiated.

If a nuclear explosive is detonated above the atmosphere but within the earth's magnetic field, the plasma expanding in directions more or less perpendicular to the magnetic field lines will distort the field. When this happens, a large fraction of the kinetic energy in the weapon debris is converted into electromagnetic energy, resulting in the emission of a sudden burst of radiation with a broad range of wavelengths—from a few meters to hundreds of kilometers or more. Such an electromagnetic pulse (EMP) can represent a substantial fraction of the total energy of the explosion and can propagate with little attenuation through the atmosphere to the earth's surface. Nuclear explosions in space or in the high-altitude regions of the atmosphere can produce another type of EMP. In this case gamma or high-energy X rays striking the upper part of the atmosphere cause electrons to be ejected from air molecules. Such a sudden cascade of electrons is equivalent to a huge surge of electric current. Since the current would not be spherically symmetrical (it would flow predominantly in the direction of higher air density, namely downward) and would vary with time, it would generate transient magnetic fields that in turn would produce electromagnetic radiation in the form of an EMP.

As a result of the approximately exponential increase in the density of the atmosphere with decreasing altitude, much of the energy radiated downward by a nuclear explosion above the atmosphere is deposited in the atmosphere's upper reaches. Deposition of this energy can sometimes produce severe secondary effects that then propagate to the surface of the earth. X rays and weapon debris at sufficiently high fluences (total energy per unit area) can, for example, heat the atmosphere to such high temperatures that it radiates visible light and infrared radiation.

Gamma rays, neutrons and X rays released by the weapon, as well as the decay products of radionuclides, can directly or indirectly generate electric currents in the layer of the atmosphere where they deposit their energy. These currents can then generate other EMP's whose wavelengths and instantaneous power levels extend over a very wide range. Heating of the atmosphere can also initiate complex chemical reactions that affect its transmission and reflection of radio waves.

In the lower atmosphere, underground or underwater the primary X-radiation leaving an exploding nuclear weapon is absorbed by the atoms and molecules of the surrounding medium within a few meters of the point of detonation. Consequently the medium is quickly heated, forming a fireball, which in turn reemits electromagnetic radiation of lower frequencies. Most of this radiation is in the visible and infrared regions of the spectrum and can travel considerable distances through the air.

The radiative energy also combines with the kinetic energy of the outwardly expanding plasma to produce a pressure impulse of tremendous force on the surrounding medium. Such an impulse forms a shock, or blast, wave that propagates through the medium. The denser the medium, the greater the amount of energy transformed into the shock wave. Hence for explosions in water or earth a larger percentage of the explosion's energy is converted into a shock wave than is the case for explosions in air.

Surface, subsurface or very-low-altitude explosions can also fling huge quantities of dust, crater debris, manmade structures or water into the air that can directly or indirectly cause considerable destruction. Moreover, much of this material is likely to be rendered radioactive, thereby severely contaminating extensive areas through fallout.

Forms of energy that are not normally released as primary or secondary effects can also be generated from the vast energy supply provided by a nuclear burst. Furthermore, such energy can be channeled into small emission angles. The key question about such weapons (which cannot be answered in detail here because the subject is classified) is how to convert a substantial fraction of the energy of a nuclear explosion into a particular energy that can be emitted with high directional

enhancement. Suffice it to say that electromagnetic energy with wavelengths typical of gamma rays, X rays, visible light and microwaves can be focused by the equivalent of lasers: devices that cause the atoms or molecules of a material to radiate in phase. Longer-wavelength radiation can be emitted directionally if such weapons are equipped with the equivalent of antennas. The problem in either case is how to channel the torrential flow of energy from a nuclear explosion into an energy-conversion and -direction device in the few microseconds before the entire weapon assembly disintegrates. Another option, which may simplify the problem somewhat, is to set off nuclear devices in a reusable containment structure from which the explosive energy could then be tapped. Such structures, designed to withstand explosions with yields of up to perhaps one kiloton, have in fact been under study for several decades. The Lawrence Livermore National Laboratory has recently considered a proposal to construct such a chamber in which a variety of nuclear effects could be studied.

For ground-based weapons intended to attack targets in space the weight of the needed equipment is not critical; for space-based weapons it is, however. It is therefore to be expected that the technical approaches for developing ground-based directed-energy nuclear weapons will be different from those required for similar weapons in space. Some advantages that ground-based weapons have over weapons placed in space include avoidance of treaties banning nuclear weapons in space, accessibility to large and heavy conversion equipment (with associated higher directivity and greater efficiency of conversion of the explosion energy into the form radiated), much lower cost and possible reusability of the equipment.

Conversion of the explosion energy into more tractable electrical-energy pulses can be accomplished by magnetohydrodynamic generators: devices that convert a plasma's kinetic energy directly into electricity. (Such devices have been proposed for converting fusion energy in a power reactor into electricity.) The pulses of electrical energy could then drive devices for conversion of the electricity into electromagnetic radiation (with or without an attendant self-destruction of the device) that could be tightly focused toward targets in space. In most cases the low efficiency of such energy conversion can be more than compensated for by a high degree of focusing in the direction of a target.

An extremer possibility is the use of a relatively small nuclear explosion deep underground to accelerate very large projectiles through the equivalent of a cannon barrel. These so-called hypervelocity projectiles would reach velocities close to earth-escape velocity (about 10 kilometers per second). Appropriately shaped, compact projectiles can thus penetrate the atmosphere in a way that is somewhat analogous to penetration of the atmosphere by large meteorites. Such proposals were studied as long ago as the late 1950's as a method for placing massive loads of materials in space at relatively low cost.

The kinetic energy of, say, 10 tons of material moving at 10 kilometers per second is the equivalent of about 100 tons of TNT. This suggests that reasonably efficient use of a nuclear explosion with a yield in the vicinity of one kiloton could provide more than enough propulsive energy. If the "cannon barrel" were a few hundred meters long, the average acceleration of the projectile would be on the order of 10,000 times the acceleration of the earth's gravity, which is not beyond the strain-bearing capacity of a compact, high-density projectile. Subsequent fragmentation of such a projectile into solid chunks or liquid droplets could make it a highly effective weapon for destroying satellites or ballistic missile warheads in space.

Another possibility is to design nuclear weapons so that the act of detonation itself directly accelerates material on the weapon that immediately fragments into small pellets or droplets moving at velocities substantially greater than 10 kilometers per second. Such weapons could

readily focus the hypervelocity fragments into a conical volume, but they would have to have a mechanism to control the acceleration process in order to avoid vaporizing the fragments. In addition they would probably be limited to attacking targets in space or in the upper atmosphere, since at low altitudes the ranges of such fragments are much less than the distances at which the detonation's air blast causes severe damage.

The damage an object is likely to suffer when it is exposed to the gamut of energy types emanating from a nuclear explosion can be roughly calculated by estimating the type of energy likely to reach the object, the way in which damage could be done and in many cases the rate of deposition of the energy. This aspect of the effects of nuclear explosions is extremely complex and often not well understood.

Ranges of total energy fluence that can cause temporary malfunction or permanent damage in military or civilian targets vary over nine orders of magnitude [see illustration below]. The effects of the longer-wavelength radiation (such as that produced by an EMP) at the low end of the energy-fluence scale are the subtlest and the most difficult to assess and are therefore the most uncertain.

A fluence of .1 joule per square meter is one million times greater than an easily detectable one-second radio signal emitted by a 10-kilowatt spherically symmetrical radio transmitter 100 kilometers away. Yet commercial and military communications and radar transmissions producing smaller fluences have been known to cause accidental firings of high-explosive detonators and malfunctions in computers and other electronic and electrical equipment. These effects would be similar to those produced by the EMP from nuclear explosions. Indeed, the effects of electromagnetic radiation on military ordnance have prompted efforts to protect against it. Some measures include enclosure in conducting shields and avoidance of components that can be sensitive to even small pulses of current induced by electromagnetic radiation that has leaked in. Yet these measures have not always been entirely successful.

Some components of electronic systems, such as transistors, can be very sensitive to small currents and other effects resulting from gamma-ray and neutron bombardment. These effects can be minimized by shielding or by avoidance of highly sensitive components. Yet the general lack of protective measures in nonmilitary space systems makes them particularly vulnerable to such nuclear radiation.

Gamma rays, neutrons, high-energy X rays or radionuclides impinging on targets in space can also cause the target to become charged to a potential that is on the order of the maximum energy of ejected charged particles. It is possible that the electric field strength near the surface could reach values on the order of one million volts per meter, sufficient to induce malfunctions or permanent damage in some types of internal electrical systems that are not well shielded.

Unlike neutrons or gamma rays, hypervelocity fragments would pit the surface of a target.

Exceedingly rapid ejection of the material during the pit formation drives a strong shock wave into the target. Because of their high velocities, which are up to about 100 times faster than a high-speed rifle bullet, hypervelocity fragments weighing much less than one gram can do considerable damage when they are aimed at targets in space.

Visible light or infrared radiation released as a secondary effect from the heating of the atmosphere primarily causes damage by igniting combustible materials on the surface of targets. Even if the target surface is not combustible, nonuniform heating of the surface can nonetheless cause damage from the resulting thermal stresses.

Incident high-energy X-radiation or weapon-debris plasma damages a target in space principally by the rapid blowoff of vaporized material from the target's surface. If X rays are the agent, the

resulting shock can be transmitted through the outer layers of the object, causing the inside surfaces to shatter, presuming the time necessary to deposit the incident energy is short compared with the time required for the shock to reach the inner surface. Such a process is called spalling. For incident weapon-debris plasma, however, spalling does not generally occur. The reason is that it takes too long for the weapon-debris plasma to deposit its kinetic energy. In any case, the overall momentum transferred inward from the surface blowoff can result in incapacitating damage even if there is no interior spalling.

To help make these estimates more accessible, one can consider the range within which a particular energy carrier can produce destructive effects [see illustration on this page]. Potentially huge damage ranges (or, equivalently, large fluences at a given distance) can be readily achieved by emitting energy within a narrow angle. Microwaves that have wavelengths between three centimeters and one meter are particularly suited for such directional enhancement because the atmosphere is essentially transparent over this range, making it possible to use the radiation for ground-to-space, space-to-ground and space-to-space applications. Also, the ranges of the microwave-energy fluence needed to cause damage to many types of military and civilian targets are the lowest of all forms of electromagnetic radiation.

The military potential of directed microwave beams is therefore awesome. Suppose, for example, it should become possible to convert 5 percent of the energy released by a one-kiloton explosion into three-centimeter radiation that is emitted by a 50-meter-diameter antenna or an equivalent microwave laser. The explosion of such a device in a 30,000-kilometer geosynchronous orbit would deposit about 800 joules per square meter over an area of 250 square kilometers on the earth's surface (larger than the area of Washington, D.C.). This estimated energy fluence is greater than the level known to cause severe damage to many types of electrical equipment—computers, antennas, relays and power lines. Of course, at much shorter distances the energy fluence would be much larger, about five million joules per square meter at a distance of 400 kilometers.

The development and deployment of such a microwave weapon would greatly complicate both offensive and defensive military tactics and strategy. It could, for example, cause temporary malfunctions or permanent damage in the complex electronic and electrical equipment that is typically found in military systems for surveillance, tracking, communications, navigation and other command-and-control functions. Because the atmosphere is virtually transparent to microwaves, either the beam-generating device or the intended target could be based in space, in the atmosphere or on the earth's surface. In any event, the deployment of such weapons is likely to undermine confidence in the wartime reliability of strategic and tactical forces, including those forces that constitute the ultimate deterrent to nuclear war.

How likely is it that these third-generation nuclear weapons will actually be developed and deployed? The answer depends largely on the character and extent of support provided by both the U.S.S.R. and the U.S. to their respective national weapon laboratories. Since developments in the military realm of one country invariably elicit emulative responses from the other, the likelihood strongly depends on what is perceived to be the pace of the adversary's research and development in this area.

One key indicator of the extent of a country's effort is the frequency of nuclear testing. If the U.S. continues and the U.S.S.R. resumes underground nuclear testing even at levels substantially lower than the 150-kiloton limit stipulated in the Threshold Test Ban Treaty, it will probably be just a matter of time before these new types of offensive and defensive nuclear weapons are developed. Photo: PATTERN of energy emission distinguishes current nuclear warheads from those likely to be developed in the near future. Current warheads (top) release their explosive energy in many

forms, each of which is radiated uniformly outward. Hence the region in which military equipment would be destroyed or incapacitated for each of the major energy types (color key above) can be roughly represented as spheres. In contrast, warheads of future nuclear weapons could be equipped with devices that suppress, convert and direct energy, enabling a significant fraction of the explosive energy to be transformed into microwaves that are then concentrated on targets (bottom). Photo: ARRAY OF EFFECTS listed in the key at the left could be militarily exploited by the next generation of nuclear weapons, which would suppress certain effects, heighten others and perhaps channel them in certain directions as well. In space (top row) nuclear weapons could radiate incoherent X rays in all directions

- (a) or coherent X rays in a particular direction
- (b). Microwaves can readily penetrate the atmosphere and could therefore reach the surface of the earth from space, particularly if they were concentrated
- (c). Gamma rays also travel a certain distance through the air and could be directed to targets in the upper atmosphere
- (d). The ionized weapon debris produced by a nuclear explosion above the atmosphere but within the earth's magnetic field could produce a powerful pulse of long-wavelength electromagnetic radiation as it distorts the field
- (e). A similar effect can be achieved in the atmosphere (middle row): X rays can knock electrons loose from air molecules to create a sudden current surge through the air, which results in the emission of the radio-wave pulse (f). The more familiar neutron-emission (g), air-blast
- (h) and incendiary
- (i) effects of nuclear weapons could also be enhanced. Targets in space could be engaged by microwaves beamed upward
- (j). The energy of subsurface bursts (bottom row) could interact strongly with the surrounding medium to produce enhanced ground
- (k) or water
- (l) shock waves. The amount and distribution of radioactive fallout from nuclear weapons could be controlled, depending on the materials chosen to encase the weapon as well as on whether the weapon is detonated underground
- (m) or underwater
- (n). Finally, the blast of a subterranean explosion could conceivably propel projectiles through a "cannon barrel" and into space (o).

Photo: FOUR TYPES OF NUCLEAR EXPLOSIVES are depicted schematically; all but one rely on fission (the splitting of a nucleus by a neutron into two lighter nuclei). A weapon relying solely on fusion for its explosive energy

- (a) consists of a core of fissile material (uranium 235 or plutonium 239) surrounded by chemical-explosive charges and inert structures that focus the charges' blast energy inward, causing the core to implode and thereby initiate a runaway fission reaction. The yield of fission explosives can be "boosted
- (b) by placing deuterium and tritium (isotopes of hydrogen) in them. The temperatures produced on detonation of a fission explosive cause the hydrogen isotopes to undergo fusion (the joining of nuclei), releasing substantial quantities of neutrons, which induce more fission reactions. In boosted weapons the fusion reaction does not contribute significantly to the total yield of the weapon. Fusion reactions can account for most of a nuclear weapon's yield,

however, if a substantial amount of such a thermonuclear fuel as lithium deuteride is exposed to the energy released by fission

(c). An outer shell of normal uranium (uranium 238) serves to hold the warhead together just a fraction of a microsecond longer before it blows apart, enabling the nuclear reactions to produce more energy. Also, when it is irradiated with neutrons produced by fusion, the U-238 itself undergoes fission. A pure-fusion weapon

(d), which dispenses with a fission trigger by applying laser, electron or ion beams to implode thermonuclear fuel, reportedly eludes weapon designers.

Photo: ATMOSPHERIC PENETRATION of the energy emitted by a nuclear burst in space depends on the energy type. Radiation in the microwave, infrared and visible ranges of the electromagnetic spectrum could reach the ground with relatively little attenuation.

Photo: SHAPED CHEMICAL CHARGES can eject their explosion products (primarily blast and weapon debris) in markedly nonspherical patterns. A flat disk of chemical explosive, for example, emits its products in a characteristic double cone. Setting off a long, thin cylinder of explosive produces a cylindrical pattern of emission. Finally, by tamping, or restricting, the effects of the explosion with inert, dense material in all but one direction, the explosive products can be concentrated in that direction. Nuclear explosives could presumably apply such directional effects to control the pattern in which their explosive products are emitted.

Photo: DESTRUCTIVE EFFECTS of different types of energy are listed in this chart as well as the fluence (total energy per unit area) necessary to achieve such effects on military equipment. Since relatively small fluences of microwave or longer-wavelength radiation are sufficient to cause damage, such kinds of radiation may be the energy types emphasized in third-generation nuclear weapons.

Photo: MAXIMUM DISTANCE from the detonation of a nuclear weapon at which damage can be done to military targets in space depends on the type of energy causing the damage and how much of the total explosive energy it represents. Two cases are considered: a one-kiloton weapon (black) and a one-megaton weapon (color). (A kiloton is the energy equivalent of the detonation of 1,000 tons of TNT; a megaton is 1,000 kilotons.) The bars indicate the range of damage-radius estimates for plausible third-generation weapons, whose energies have been enhanced but not directed. The percentage of the total explosive energy funneled into each particular energy type is indicated next to each pair of bars. Much greater damage radii could be achieved if the weapons focus their energy.