BUILDING THE ULTIMATE WEAPONS

Lasers and particle beams are being assessed for military deployment

> *It is still a matter of wonder how the Martians are able to slay men so swiftly and so silently. Many think...they are able to generate an intense heat....This intense heat they project in a parallel beam against any object they choose by means of a polished parabolic mirror of unknown composition....Whatever is combustible flashes into flame at its touch, lead runs like water, it softens iron, cracks and melts glass, and when it falls upon water, incontinently that explodes into steam.*
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> — H.G. Wells, *The War of the Worlds,* 1898

Second of two articles

By JANET RALOFF

Science fiction has spellbound generations with fantastic tales of "death rays," like that prescient nineteenth-century account by Wells. What the Department of Defense (DOD) would like to do is give life to that fantasy. But as scores of physicists have been learning for the past quarter century, fashioning a directed-energy weapon is easier said than done.

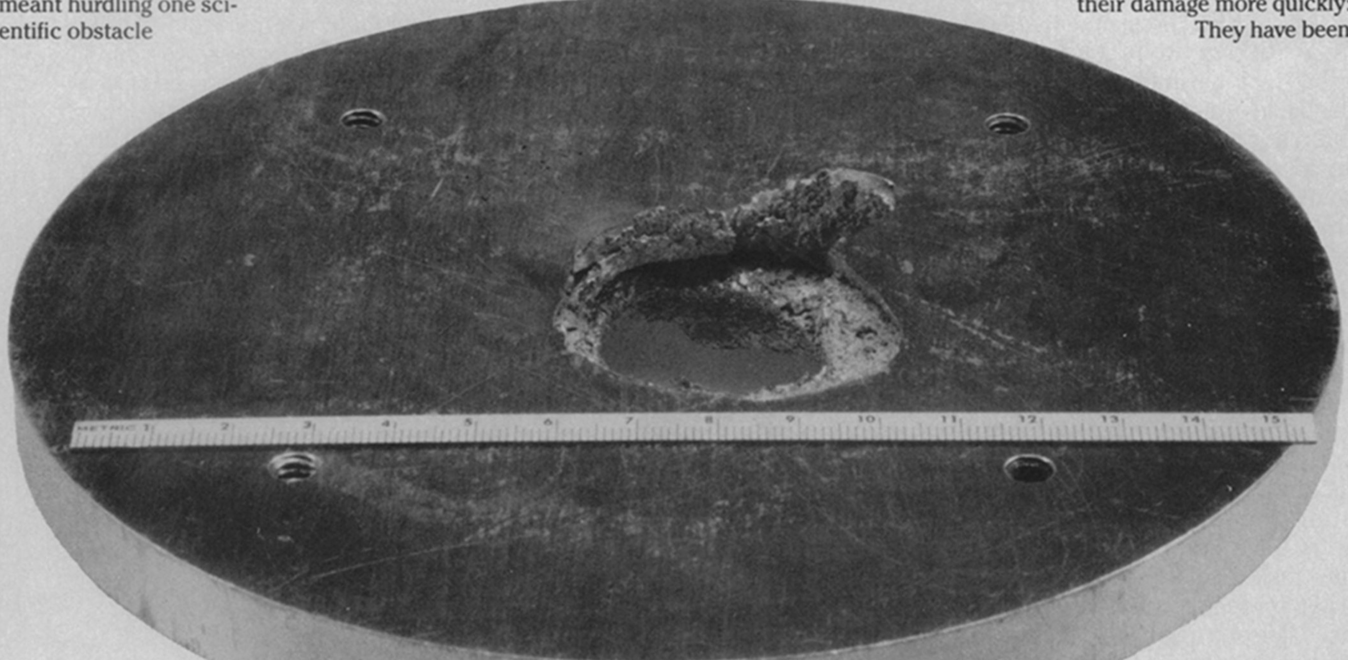
In fact, the term death ray is somewhat misleading, as these weapons are not being explored to stop troops dead in their tracks. In terms of their human lethality, beam weapons are just not as cost effective as bullets. However, mere cannon and bullets are a weak defense against intercontinental salvos flying fast and heavy—and packing a punch that could knock out cities. Able to travel at the speed of light, or close to it, beams of directed energy may be the only way of effectively routing such munitions semiautonomously at split-second speed, and from great distances—for example, before they cross into the nation's air space.

However, progress towards this or any simpler beam-weapons application has meant hurdling one scientific obstacle after another. The problem has been to identify a technology able to deliver the destructive power a weapon would require in a package that's practical and affordable. Having already knocked planes and missiles (SN: 8/6/83, p. 85) from the sky with lasers, it might seem DOD was well on its way to achieving that. Not necessarily. In fact, it's unlikely a fully integrated weapons system could even be tested before the turn of the century. As new missions, new physics and new candidate technologies present themselves, researchers have to start all over, because in the beginning it's often hard to guess how well candidates will survive the practical constraints of making a reliable, portable weapon.

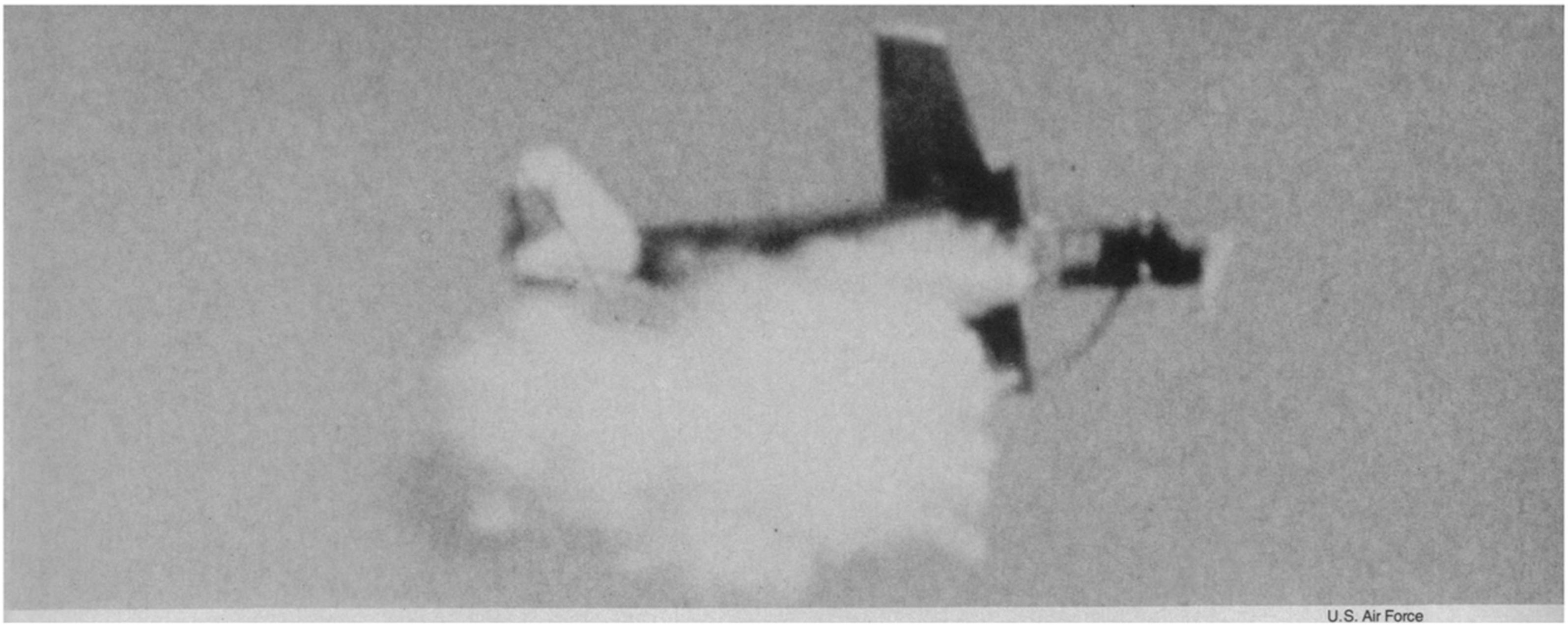
Consider, for example, an early technology that suggested promise and yielded disenchantment: the carbon-dioxide gas laser. In his book *Beam Weapons: The Next Arms Race* (Plenum Press, 1984) laser-research analyst Jeff Hecht recalls the problem researchers had scaling it up from a laboratory curiosity. "To increase power, developers often resorted to the brute-force approach of enlarging the laser," he says. But that wasn't good enough here because the device reached "monstrous proportions" before it yielded beam power sufficient to be useful. Hecht observes, "This was the sort of laser that prompted someone whose name is lost to history to crack that 'a laser big enough to inflict militarily significant damage wouldn't even have to work—just *drop* it on the enemy.'"

Though DOD has studied particle-beam technologies even longer than it has funded laser work, the particle-beam program still has not established what the Pentagon terms "proof of concept." So this program doesn't focus on weapons, per se, but instead on demonstrating characteristics — such as firing rate, "bolt" velocity and beam control — that would be needed in a weapon.

Spurring interest in these beams of accelerated atomic particles — usually electrons and hydrogen nuclei — is not only their potential for inflicting more damage than lasers, but also their ability to wreak their damage more quickly: They have been



Air Force Weapons Laboratory, Kirtland AFB



U.S. Air Force

called "the ultimate weapon." Keith Taggart is Assistant to the Deputy Associate Director for strategic defense research at Los Alamos National Laboratory, in New Mexico, where work is underway exploring beams of uncharged particles for use in space. According to Taggart, particle beams today are at least on a par with lasers in terms of having suggested a weapons potential, and may in fact lead lasers in engineering. That such a statement would not have been accepted five years ago, let alone 10, points to the magnitude of reshuffling that has occurred among leading technology candidates in recent years.

In fact, the cast of available candidates is still evolving, the result of a continuing stream of new developments in the applicable physics. Similarly, new missions being considered for directed-energy weapons are changing the criteria — such as allowable size, weight and "kill" reliability — by which the ultimate front-running candidates will be chosen.

For instance, since the President's "Star Wars" speech last year, the beam-weapons program has focused increasingly on assessing its potential for strategic-defense missions (SN: 7/14/84, p. 26). Chief among these new missions is one known as "boost-phase intercept." The most profitable time to kill an intercontinental ballistic missile (ICBM) is in its boost phase, before its many warheads and decoys have been deployed. Though boost-phase intercept is today virtually impossible, beam weapons could change that.

Left: Aluminum hit by a single 60 billionth or 70 billionth of a second pulse from a charged particle beam. The 100-kiloamp pulse delivered 30,000 joules of energy in a beam roughly 2 inches in diameter – 30 percent smaller than the hole it caused. Above: Laser-initiated fire downs unmanned plane in 1980 test. Laser beams are far more susceptible than particle beams to thwarting. For example, countermeasures such as spinning a target or shielding it with oblative material could slow or prevent absorption of beam energy.

In addition to particle beams, the technologies now appearing to offer the most promise for directed-energy weapons belong to three classes of lasers able to generate short-wavelength beams. As one Pentagon official put it, in the area of lasers "you want as short a wavelength as possible."

And that's why the hydrogen-fluoride chemical laser is falling from favor. Still the best-developed laser technology of military interest, hydrogen-fluoride's infrared wavelength is drawing too much heat from program critics for DOD to comfortably count on it as much more than an understudy to more immature, but promising shorter-wavelength alternatives.

Several factors are driving this push to smaller wavelengths. Among these is concern over beam spread. Since beam spread reduces the energy deposited per unit area on target, it's important to limit it as much as possible by making the ratio of mirror size to beam wavelength very large. Taggart puts it another way: For any energy flux per unit area on target that is chosen, the smaller the wavelength of light beamed, the smaller the mirror needed to direct that beam. "The effect is substantial," he notes. To deliver a 1.2-meter spot onto a target 1,000 kilometers away, he says, a laser with a 10-micron (infrared) wavelength would need a 10-meter mirror, while a laser with a one-micron wavelength (approaching the ultraviolet) would need only a one-meter-diameter mirror. "And there's a big difference between building a one-meter mirror and a 10-meter mirror," he adds.

A second advantage to shorter wavelengths is that they tend to be absorbed better by the target. And a target can only sustain damage if the laser radiation incident upon it is absorbed. Kosta Tsipis is director of the Program in Science and Technology for International Security at the Massachusetts Institute of Technology in Cambridge. In his book *Arsenal: Understanding Weapons in the Nuclear Age* (Simon and Schuster, 1983) he explains: "Only four percent of the light from an infrared laser illuminating a shiny aluminum target would be absorbed by it. The other 96 percent would be reflected and cause no damage to the target. On the other hand, ultraviolet radiation is largely absorbed by metallic surfaces [like those on a missile], so more than half of the energy of an ultraviolet laser that reached a target would cause damage."

There is a tradeoff in moving to shorter wavelengths, though. The degree to which the atmosphere absorbs some of the beam's energy is also a function of wavelength. The shorter the wavelength, the more susceptible a high-energy beam is to experiencing jitter and defocusing, also known as "thermal blooming." Since lasers in the vacuum above earth's atmosphere don't have to confront the problems of beam degradations caused by air, space has been called the laser's natural environment. And in fact, for the very-short-wavelength lasers, it is the *only* environment in which they have any value.

Of these newer, short-wavelength alternatives, the excimer is most similar to chemical lasers in that its energy is also derived from the reaction between two types of atoms. A stream of electrons is used to create the "excited dimers," or excimers; these molecules can only form when their constituent atoms have been chemically excited and stripped of some electrons.

Two excimers, the xenon-fluoride and krypton-fluoride, have been identified as having weapons potential. However, the excimer molecule's short lifetime means "the laser tends to produce only short pulses, which may not be useful for weaponry," according to Hecht. What's more, pulsed operation creates acoustic waves that can disrupt a laser's beam. Excimer lasers are particularly susceptible to that, Hecht points out, "because their short wavelength makes small aberrations more significant." Then there is the problem of scaling up to high power; the best excimer today has an average power less than one tenth of a percent of what is possible with the best chemical lasers.

The free-electron laser could offer the best hope for harnessing high power at short wavelengths. Conceived in 1971 and demonstrated for the first time five years later, this system uses a particle accelerator to bring a beam of electrons up to high velocity. The beam is then passed through an array of permanent magnets, known as a "wiggler" (for the way its tailored variations in magnetic-field strength and direction deform the beam path). As electrons pass each of the wiggler's component magnets, their paths bend, a process that causes them to emit and absorb light. With the right magnetic-field design, the electrons will emit more light than they absorb. One only has to put mirrors at the right places to have a free-electron laser.

Though the initial free-electron experiment produced a beam having an infrared wavelength, in fact the laser is "tunable"—able to yield shorter wavelengths well into the ultraviolet—by changing magnet spacing and the electrons' input energy. Among its other advantages is a theoretical efficiency (percentage of energy entering the laser that is emitted in its beam) of between 30 and 50 percent — more than tenfold better than with chemical lasers. Its disadvantage, relative to excimers and chemical lasers, is the size and weight of its particle accelerator/wiggler package: Hoisting them into orbit could prove not only difficult but also costly.

By far the most exotic and controversial of the short-wavelength lasers is the nuclear-powered X-ray. Having a small nuclear explosion as its energy source, its development and physics have, not surprisingly, been kept quite secret.

This laser concept, rejected seven years ago for having little apparent military value, is again under serious investigation by DOD's Advanced Research Projects Agency (DARPA). Much of DARPA's renewed interest is being credited to Edward Teller, a senior research fellow at the Hoover Institute (on Stanford University's campus), and the physicist largely responsible for development of the hydrogen bomb. Teller has posited that an X-ray laser could be packed aboard a missile and "popped up," or fired into space, at the first siting of preparations for a Soviet ICBM launch. A single device would have up to 50 separate lasing rods—each able to independently target a separate missile or satellite.

Because its X-ray emissions are so efficiently absorbed by earth's atmosphere, it has utility only in space. On the other hand, because its wavelength is so extremely short—on the order of one angstrom—any targets hit would absorb the beam's energy with devastating efficiency. The X-ray laser is also a one-shot device; the bomb that generates the energy to excite atoms in the device's lasing material will eventually vaporize the works. However, because X-rays travel at the speed of light, they will get out before the device self-destructs.

To develop a working X-ray laser battle station would be a truly awesome engineering marvel. The most detailed and accessible account of what would be involved appears as a 25-page chapter in Hecht's *Beam Weapons*. For instance, the typical battle station now being discussed would have 50 individual lasing rods, each a hairlike carbon fiber roughly one centimeter long and one ten-thousandth that in diameter. To identify targets and direct each laser's energy to them, each rod would need a separate pointing and tracking system. Not only could the alignment of each end of the hairlike rods be off no more than one-tenth of one percent, but this precise alignment would have to be able to withstand vibrations set up when the bomb detonates. They would be substantial vibrations too; this fragile system could unleash trillions of watts of power during just a trillionth of a second.

Such intense energy bursts could shatter a target. Lasers that deliver a continuous lower-power flux of energy could, if their beams were focused onto a small region of a target's surface, literally burn a hole through it and into the vulnerable electronic guidance components and fuel. Lasers that deliver their energy in short, discrete pulses may be even more effective "killers" if they can heat the target enough to generate a plasma (ionized gas) in front of it. Laboratory tests have already demonstrated that subsequent heating of this plasma can produce shock waves destructive enough to rip open a target's skin.

Explains Herbert Flicker at Los Alamos: "The plasma has a higher absorption for the laser energy," so it absorbs more of the initial laser energy, and then reradiates it to the metal surface of the target using a shorter wavelength. "The net effect is a more efficient coupling [absorption of laser energy]," he says, "because you've destroyed the good reflectivity of the metal and replaced it with the reflectivity of the plasma, which is fairly low."

When it comes to potent devastation, however, nothing can hold a candle to particle beams. DOD's research is focusing on two varieties: *charged* beams of energetic electrons and *neutral* beams of hydrogen atoms.

Charged particle beams are for travel through earth's atmosphere. Though like-charged particles, such as electrons, normally repel each other, the large electric currents in a beam moving though the atmosphere actually set up a strong magnetic field about the beam. This field effectively pinches the electrons into a tight, self-focusing beam.

This self-focusing works only within the atmosphere, however. In space, a charged beam would quickly disperse. Moreover, charged beams traveling long distances in space — something most space-based missions would require—would be bent by earth's magnetic field in ways that would be almost impossible to predict. Finally, propagating charged beams in space would cause what's known as a "space charge" to build up on the particle accelerator itself, explains a DOD official: The result is that one would "need more and more energy to overcome that space charge that's not satisfied by a return current of ions and electrons created in the atmosphere."

This also explains why particles beamed in space must be electrically neutral. However, because particles must carry a charge to be accelerated to the high velocity and energy needed of a weapon, neutral beams are created by stripping electrons off an already accelerated beam of negatively charged particles. (Currently, DOD is planning tests of neutral beams made from accelerated negatively charged hydrogen atoms.) Not only are neutral beams in space immune to earth's magnetic field, but they also keep their tight focus without magnetic pinching. That tight beam control would break down, of course, if the beam strayed into the atmosphere.

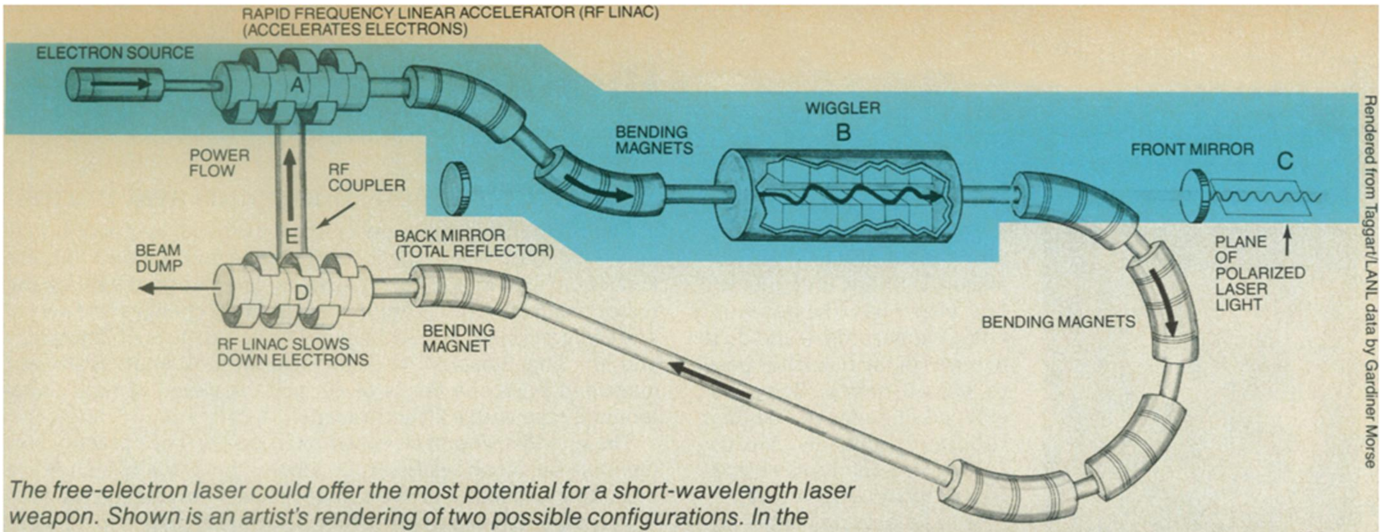
All this might suggest that propagating beams is easy, provided the right type of beam is used in the environment. Not so. Yet to be established in *any* environment is how to get a straight beam that travels distances "of military interest" without losing most of its energy, and one that can be "slewed" (swept from target to target like a flashlight's beam) with control.

At Lawrence Livermore National Laboratory (LLNL) in California, charged particle-beam studies using the new 50 million electron volt Advanced Test Accelerator (ATA) aim to acquire the first meaningful data on the possible range and stability of 10-kiloamp electron beams in air. ATA attained full power in June. Beam steering and lethality will also be studied.

Previous tests of charged beams in full atmosphere have been conducted at low energies. And under those conditions, "the beam sort of falls apart," explains William Barletta, program leader for LLNL's beam research. The problem is that as the beam attempts to tunnel its way through air, some of its electrons collide with air molecules and leave their energy behind as heat. Says Barletta, "Under normal conditions, the [beam] pulse will lose half of its energy after 300 meters" — hardly the range weapons planners envision. However, because the energy lost in heating causes the air to expand and become less dense, later electrons traveling down the beam path encounter fewer energy-robbing collisions. It's possible that propagation over miles may be possible by shooting off each large "bolt" of high energy particles as a string of tiny, discrete pulses, he says.

If these ATA tests prove successful, DOD may be on the road to developing a weapon with the ability to selectively strike and kill tens of targets a second. Charged particle beams might be used in defending battleships from cruise missiles, in defending U.S. missile silos from incoming Soviet ICBMs or in defending national command centers against bombers and air-launched short-range missiles.

Make no mistake: These would be potent weapons. Unlike laser beams, particles de-



Rendered from Taggart/LANL data by Gardiner Morse

The free-electron laser could offer the most potential for a short-wavelength laser weapon. Shown is an artist's rendering of two possible configurations. In the simplest (colored area), electrons are accelerated (A) in a radiofrequency linac and then routed through a wiggler magnet (B) where they radiate light. If the electron beam is "dumped" at this point, the collected light that reflects between the two mirrors — and eventually exits through the "partially silvered" surface of the front one (C) — will convert electron energy to light with an efficiency of between 4 and 5 percent. In the "racetrack" design, however, the electron beam is not dumped until it has been recycled back through an RF linac (D) the "wrong way." This last step permits much of the electrons' energy to be extracted and sent via an RF coupler (E), back to power the original linac (A). Though more complicated, the scheme's advantage is an amazing laser efficiency of between 30 and 50 percent.

posit their energy in a long, narrow cone throughout the target. High-energy electrons, for instance, can penetrate a few feet into solid aluminum. This penetrating ability makes the effective shielding of targets against them virtually impossible. A missile hit by a weapon beaming energetic electrons would undergo structural damage and experience nearly instantaneous detonation of any chemical explosives on board.

In addition to the destruction inflicted by the particles' transfer of kinetic energy to any material attempting to slow them, there is the generation of potent secondary radiation. Army Major Charles Kinney described this phenomenon in the February 1983 Military Electronics/Countermeasures: "Surrounding the beam during its transit to the target is a cone of lethal gamma radiation... produced through the interaction of the relativistic electrons with molecules of air in the path of the beam. [Relativistic electrons are those traveling at almost the speed of light.] This radiation is extremely penetrating and could cause radiation sickness and death to crew members inside combat vehicles. Additionally, very strong electromagnetic pulses [SN: 5/9/81, p. 300] would be induced because of the electron current passage through the atmosphere ..." And that electromagnetic pulse (EMP) radiation — which might even occur as electrons are knocked from atoms in the target's structural materials — is particularly lethal to electronic components.

Researchers working on the White Horse experiment at Los Alamos National Laboratory are focusing on propagation of a high-intensity neutral beam. Experimentally, all components of the system have been demonstrated to work. The goal of this project is therefore to verify that the integrated system performs; "You never *know* it works until you turn it on and try it out," Taggart explains. Moreover, he adds, it will test whether the hydrogen-ion source and particle-injector components — now "with a size that can be put into space"—perform as expected.

Asked whether there were any fundamental questions as to why this system might not work, Taggart answered: "None whatsoever. If it doesn't, it means we screwed something up" in the engineering. And it's because its success is dependent only on engineering, Taggart says, that "the particle beam is out in front of the pack." When it comes to what still needs to be demonstrated, he says, "We're talking about engineering, where the other directed-energy-weapons concepts [such as lasers] are still thinking about physics."

He points out, for example, that accelerator technology, already more than a half-century old, is relatively mature. "Accelerators already operate at particle energies that are clearly useful for a weapon," he notes. What's more, there also exist high-current machines (current is a function of the particle density in the beam). What's needed to demonstrate the particle beam's weapons potential is high energy and high current in the same machine.

Not everyone share's Taggart's assessment, however. The Pentagon still describes DOD's particle-beam as lagging considerably behind that for lasers (by 10 years or so, one usually hears). Moreover, one DOD official told Science News, unlike lasers, particle beams have never "shot things down"; all of their targets have been immobile and in the laboratory. Nonetheless, it's Taggart's belief that "the Pentagon is slowly changing its mind" and coming to "acknowledge that particle beams are on the same developmental time scale as lasers."

Even among those vocal critics of Reagan's "Star Wars" policy, there is generally strong support for some level of continuing DOD investigation of directed-energy technologies. But criticism has exploded over the following:

- spending on these and related "Star Wars" technologies. The Pentagon has proposed spending $1.78 billion in the upcoming fiscal year and would like to see $22 billion more devoted to that through 1989 — just to assess the technical feasibility of a ballistic-missile defense (BMD) that pivots about the availability of exotic directed-energy technologies. If a commitment to proceed with full-scale BMD were made, upwards of $300 billion, perhaps $500 billion, might be necessary.
- whether to develop such antisatellite and antiballistic-missile weapons, the testing of which might violate existing arms-control treaties.
- whether rendering Soviet ICBMs and satellites impotent would be more militarily destabilizing or less.
- whether the Strategic Defense Initiative's (SDI's) vision of BMD is even technologically credible. Sen. William Proxmire (D-Wis.) summed up this argument on June 13 in floor debate on SDI's proposed budget: "Even Gen. James Abrahamson, the new chief of SDI, testified before the Senate ... that the [Star Wars] defense system would be 'highly effective' — not perfect." Said Proxmire, experts have testified that even if the "Star Wars" comprehensive defense "were 99 percent effective, enough Soviet warheads would get through to destroy every major city in the United States with a population over 500,000."
- and finally, whether as Sen. Charles McC. Mathias (R-Md.) has suggested, that by advocating development of a "Star Wars" defense, the administration might risk raising false hopes and perpetuating the myth that America might be spared devastation in any nuclear exchange.

Jeff Hecht speaks for many when he says, "The best we can hope is not that beam weapons will end the arms race, but that they will buy us the time we need to end it." □