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Introducing the Particle-Beam Weapon

Dr. Richard M. Roberds

It is not that the generals and admirals are incompetent, but that the task has passed beyond their competence. Their limitations are due not to a congenital stupidity--as a disillusioned public is so apt to assume--but to the growth of science.

Captain B. H. Liddell Hart, speaking
on weapon-development decisions, 1935

CONSIDERABLE debate has been stirred Cby President Reagan's recent suggestion that the United States embark on a program that would use advanced-technology weaponry to produce an effective defense against Soviet ICBMS. On the one hand, critics argue that the idea of a defensive system that would neutralize the ICBM threat is naive and, at best, would require large expenditures in the development of a very "high-risk" technology. Furthermore, they suggest, even if such a system could be developed, it would be too costly and would also be vulnerable to simple and cheap countermeasures. On the other hand, others argue that we *must* continue to explore such high-technology options until they have been either proved scientifically unachievable or developed into effective systems. If it were possible to build and effectively deploy such weapons, the payoff in terms of national security would be tremendous. And certainly, if this weaponry is achievable, it must be the United States, not the Soviet Union, that first develops it.

The advanced technology that has raised the possibility of defeating an ICBM attack is referred to collectively as directed-energy weapons, which gain their unprecedented lethality from several fundamental characteristics. Among their more important features are their ability to fire their "bullets" at or near the speed of light (186,000 miles a second), which would effectively freeze even high-speed targets in their motion; their ability to redirect their fire toward multiple targets very rapidly; their very long range (thousands of kilometers in space); and their ability to transmit lethal doses of energy in seconds or even a fraction of a second. No conventional ammunition is required; only fuel for the power generator is needed.

There are three principal forms of directed-energy weapons: the directed microwave-energy weapon, the high-energy laser, and the particle-beam. Only the last two types have received substantial government support.

Much has been written on the high-energy laser (HEL), and this category of directed energy weapon appears to be well understood by members of the defense community. Laser weapons have been under active development for twenty years and easily constitute the most advanced of the directed-energy devices.

In contrast, the particle-beam weapon (PBW) has been the "sleeper" among directed-energy weapons until very recently. Enshrouded in secrecy, it began as a project sponsored by the Advanced Research Projects Agency (now called Defense Advanced Research Projects Agency better known as DARPA) as early as 1958, two years before the first scientific laser demonstration in 1960. Code-named Seesaw, the project was designed to study the possible use of particle beams for ballistic missile defense. Today while its development lags that of the high energy laser, the particle-beam weapon is viewed by some military technicians as the follow-on weapon to the laser, because of its higher potential lethality.

The successful development of a particle beam weapon would require significant technology gains across several difficult areas. But even though the technical understanding to support the full-scale development of a PBW will not be available for several years, the technology issues that pace its development are no difficult to understand. The purpose of this article is to provide a basis for understanding the fundamental technology connected with particle-beam weapon, with the hope of assisting DOD leaders and other members of the defense community in making sound decision about the development and possible deployment of PBWs in the days ahead.

What Is a Particle-Beam Weapon?

The characteristic that distinguishes the particle-beam weapon from other directed energy weapons is the form of energy it propagates. While there are several operating concepts for particle-beam weapons, all such devices generate their destructive power by accelerating sufficient quantities of subatomic particles or atoms to velocities near the speed of light and focusing these particles into a very high-energy beam. The total energy within the beam is the aggregate energy of the rapidly moving particles, each particle having kinetic energy due to its own mass and motion.

Currently, the particles being used to form the beam are electrons, protons, or hydrogen atoms. Each of these particles can be illustrated through a schematic of the hydrogen atom, the smallest and simplest of all atoms. (See Figure 1.) The nucleus of the hydrogen atom is a proton, which weighs some 2000 times as much as the electron that orbits the single-proton nucleus. Each proton has an electric charge of a positive one, while each electron carries a charge of a negative one. In the case of hydrogen, the single electron and proton combine to form a neutrally charged atom.

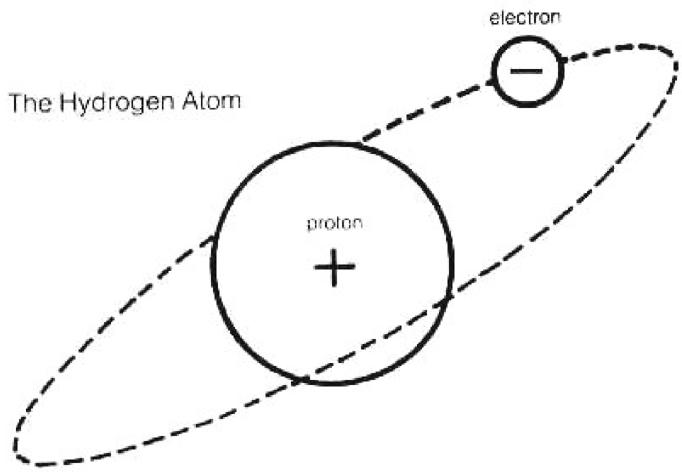


Figure 1. The hydrogen atom consists of a proton or positive charge, orbited by an electron of equal but opposite (negative) charge. Together, they form a neutrally charged atom, which can serve as the "bullet" of a particle-beam weapon in space. Also, the proton and the electron themselves are both viable candidates as the ammunition for an endoatmospheric weapon.

The particle beam itself is analogous to a natural phenomenon with which we are all familiar--the lightning bolt. The analogy is so close that particle-beam pulses are referred to as "bolts." The particles in a lightning bolt are electrons (an electric current) flowing from a negatively charged cloud to a positively charged cloud or section of the earth. While the electric field in lightning that accelerates the electrons is typically 500,000 volts per meter, these electron velocities are still less than that desired in a particle-beam weapon. But the number of electrons (electric current) in the lightning bolt is nominally much greater. In any case, the phenomenon and its destructive results are very much the same.

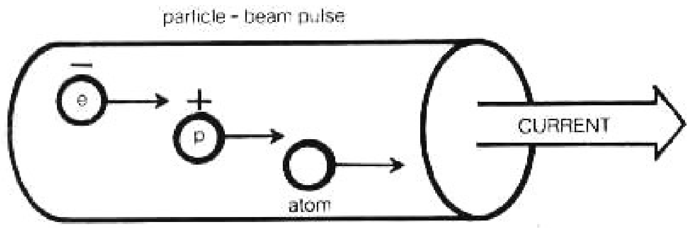
Neither the proton nor the electron show any conclusive advantage over the other in their use as the appropriate "ammunition" of a PBW. The determining factor of whether to use electrons or protons so far has been simply the specific particle *accelerator* concept planned for use in a beam weapon. Some accelerating schemes call for the acceleration of electrons, while others use protons.

The use of a hydrogen-atom beam, however, is not based on the choice of a particular acceleration scheme. Because it is neutrally charged, the hydrogen atom has been selected specifically as the likely particle to be used in the initial space weapon. Neutral atoms would not be susceptible to bending by the earth's magnetic field as would a charged-particle beam. Neither would the beam tend to spread due to the mutually repulsive force between particles of like-charge in the beam. (In the atmosphere, a charged-particle beam will neutralize itself by colliding with air molecules, effectively creating enough ions of the opposite charge to neutralize the beam.)

The mechanism by which a particle beam destroys a target is a depositing of beam energy into the material of the target, which might be any material object. As the particles of the beam collide with the atoms, protons, and electrons of the material composing the target, the energy of the particles in the beam is passed on to the atoms of the target much like a cue ball breaks apart a racked group of billiard balls. The result is that the target is heated rapidly to very high temperatures--which is exactly the effect that one observes in an explosion. Thus, a particle beam of sufficient energy can destroy a target by exploding it (although that is not the only means of destruction).

In describing a particle beam, it is conventional to speak of the energy of the beam (in electron-volts), the beam current (in amperes), and the power of the beam (in watts). (See Figure 2.) The specific meaning of these terms as they pertain to a particle beam is derived from the close analogy between a particle beam and an electric current.

Particle Beam Descriptors



particle energy = E (electron volts)
current = I (amperes)
power = $E \times I$ (watts)

Figure 2. A particle beam consists of a stream of electrons, protons, or neutral atoms flowing with a real or imagined electric current. The particle energies are expressed in electron-volts, while the current is stated in amperes. The product of the two yields the power of the beam in watts.

The electron-volt is a unit of measure for energy. It is the kinetic energy of an electron that has been accelerated by one volt of electric potential. Nominally, all the particles in a beam will have been accelerated to the same velocity, or energy, so it is possible to characterize the energy of a particle beam in terms of the energy of a typical particle of the beam, usually millions of electron-volts (MeV). Hence, a 20-MeV particle beam would be a beam of particles, each with a nominal energy of 20 million electron-volts.

A measure of the number of particles in the beam (beam intensity) may be made from the magnitude of the electric current (amperes) in the beam. To be able to assign a current to the beam, it is necessary to assume that each particle has an amount of electric charge equivalent to an electron (even if it is a neutral atom). This assumption enables an electric current to be ascribed to the particle beam, and an indication of the number of particles in the beam is inferred by the current magnitude expressed in amperes.

The power of a particle beam is the rate at which it transports its energy, which is also an indication of the rate at which it can deposit energy into a target. Again, the analogy with an electric circuit serves us well. The power developed in an electric circuit is the mathematical product of the voltage (E) and the current (I); its unit of measure is the watt. Since the unit of energy for a particle in a beam is the electron-volt (E), and the beam has an electric current(I)ascribed to it, the power of the particle beam in watts is simply the energy in electron-volts multiplied by the beam current in amperes.

Types of Particle-Beam Weapons

There are two broad types of particle-beam weapons: the charged-particle beam weapon and the neutral-particle beam weapon. The charged-particle variety would be developed for use within the atmosphere (endoatmospheric) and has a set of technological characteristics that are entirely different from the neutral particle beam weapon that would be used in space (exoatmospheric). Primarily, the extremely high power and precisely defined beam characteristics required for a particle beam to propagate through the atmosphere distinguish an endoatmospheric device from a beam weapon designed to operate in space. The development of a power supply and particle accelerator with sufficient power and appropriately shaped pulses for endoatmospheric weapons depends on very "high-risk" technology and is likely years away.[1]

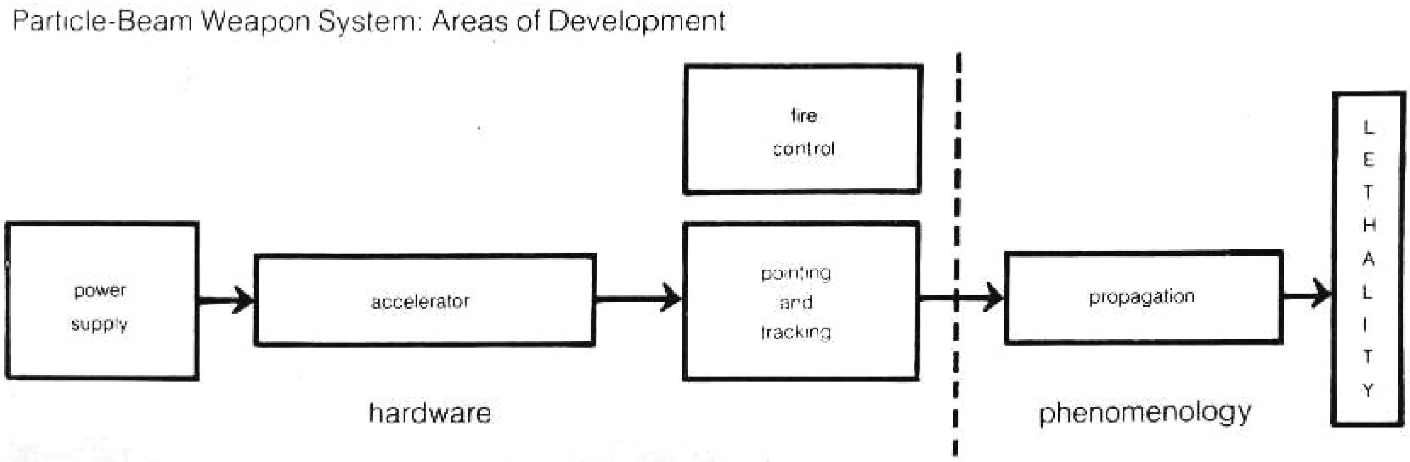
The technological problems associated with exoatmospheric weapons are considerable also, but they are not as difficult as those associated with endoatmospheric weapons. Here, the greatest challenge is in the area of directing the beam: the weapon must be able to focus its energy to strike a target that may be thousands of kilometers away. There are two aspects to this challenge. First, the weapon must create a high-intensity, neutral beam with negligible divergence as it leaves the accelerator. Second, the weapon must have a system for aiming its beam at the target. This system must be able to detect pointing errors in a beam (which is itself very difficult to detect because of its lack of an electric charge) and, when necessary, redirect a missed "shot" toward the target.

Because of these two different sets of demands, the endo- and exoatmospheric devices represent two different types of weapon systems in appearance and operation. Nevertheless, there are certain fundamental areas of development that are common to both types of PBWS.

Development Areas for PBWs

The realization of an effective particle-beam weapon depends upon technology developments in five areas. Three of these concern hardware developments, while two others are related to advances in the understanding of beam weapon phenomena. (See Figure 3.)

Figure 3. Any particle-beam weapon system may be broken into five major areas. Three of these areas are hardware-related, and two concern the understanding of the associated phenomena. The current DOD particle-beam program aims to develop each area sufficiently to determine the feasibility of a particle-beam weapon.



lethality

One of the phenomenological aspects under study is lethality. Lethality refers to the general effectiveness of a weapon in engaging and destroying a target. There is no doubt that a particle beam is capable of destroying a military target. However, a knowledge is needed of the precise effect that a particle beam would have when it impinges upon various-type targets composed of different materials and components. The problem is made more difficult from the fact that the particle beam can vary according to particle type, particle energy, and beam power. To gain such an understanding, beam/target interaction is the subject of continuing technological investigations and studies.

In assessing the unique value of a particle beam as a potential weapon system, it is important to consider six characteristics that would give the beam weapon a high degree of lethality.

Beam velocity. The particles "fired" by a PBW will travel at nearly the speed of light (186,000 miles per second). The advantage of such a high-velocity beam is that computing the aim point for a moving target is greatly simplified. The effect of this extremely high velocity is essentially to fix a target, even if the target attempts evasive action. For example, if the weapon were required to shoot at a reentry vehicle (RV) some 50 kilometers distant and traveling at the high speed of 20,000 feet per second, the RV would travel only about 5 feet from the time the weapon fired until it was struck by the beam. It is this aspect of PBWs that makes feasible the task of "shooting a bullet with a bullet," as the ABM targeting problem is sometimes characterized.

Beam dwell time. Beam dwell time refers to the time that a beam remains fixed on a target. In an endoatmospheric weapon, the power of the beam would be sufficient to destroy the target instantaneously (in millionths of a second) upon impact, and no beam dwell time would be required. In space, where the required power of the beam is considerably less, some very short beam dwell time may be necessary.[2]

Rapid-aim capability. The particle beam may be redirected very rapidly from one target to another by means of a magnetic field. This field would itself be generated by an electric current. Varying the current would change the magnetic field intensity, which would deflect the charged particles in the desired direction. Within certain limits, no physical motion of the weapon would be required as it engages enemy targets. This capability to very rapidly aim and redirect the beam would enhance significantly the weapon's capability to engage multiple targets.

Beam penetration. The subatomic particles that constitute a beam have great penetrating power. Thus, interaction with the target is not restricted to surface effects, as it is with a laser. When impinging upon a target, a laser creates a blow-off of target material that tends to enshroud the target and shield it from the laser beam. Such beam/target interaction problems would not exist for the particle beam with its penetrating nature. Particle beams would be quite effective in damaging internal components or might even explode a target by transferring a massive amount of energy into it (the catastrophic kill mechanism). Furthermore, there would be no realistic means of defending a target against the beam; target hardening through shielding or materials selection would be impractical or ineffective.

Ancillary kill mechanisms. In addition to the direct kill mechanism of the beam, ancillary kill mechanisms would be available. Within the atmosphere, a secondary cone of radiation symmetrical about the beam, would be created by the beam particles as they collide with the atoms of the air. This cone would be comprised of practically every type of ionizing radiation known (i.e., x-rays, neutrons, alpha and beta particles, and so on). A tertiary effect from the beam would be the generation of an electromagnetic pulse (EMP) by the electric current pulse of the beam. This EMP would be very disruptive to any electronic components of a target. Thus, even if the main beam missed, the radiation cone and accompanying EMP could kill a target. While the EMP and the radiation cone would not be present in an exoatmospheric use of the weapon, there are other possible options in space that are not available in the atmosphere. Many intriguing possibilities come to mind. For example, using lower levels of beam power, the particle beam could expose photographic film in any satellite carrying photographic equipment, or it could damage sensitive electronic components in a satellite.

All-weather capability. Another advantage of a particle beam over the high-energy laser in an endoatmospheric application would be an all-weather capability. While a laser can be thwarted completely by such weather effects as clouds, fog, and rain, these atmospheric phenomena would have little effect on the penetrating power of a particle-beam weapon.

propagation of the beam

The successful development of a PBW depends on the ability of the beam to propagate directly and accurately to the target. As we ponder its similarity to lightning, we might consider the jagged, irregular path of a lightning bolt as it darts unpredictably through the sky. Such indeterminacy would never do for the particle beam of a weapon, which must have an extremely precise path of propagation as it traverses the kilometers to the enemy vehicle. This aspect, in fact, may be the Achilles' heel of the endoatmospheric weapon. However, the space weapon, which at this time is envisaged to be a neutral stream of hydrogen atoms, would not suffer from the beam instability problems that may possibly plague a beam of charged particles traveling through the air.

Another problem of propagation is possible beam spreading. An increase in beam diameter would result in a decrease of the energy density (intensity) of the beam as it travels toward the target. Over short ranges, a slight beam divergence can be tolerated, but the very long ranges that would be required of the space weapon place a tremendous restriction on the amount of beam divergence that is acceptable.

Use of a neutral beam in space would ensure that the beam would not spread due to mutual repulsion of the beam particles. Divergence would come strictly from that imparted by the accelerator. In the atmosphere, however, even if the beam particles were neutral, air molecules would strip the surrounding electrons quickly from the beam's neutral atoms, turning the beam into a charged-particle beam. The charged particles within the beam would then tend to repel one another, producing undesirable beam divergence. But as the beam propagates through the air, it would also strip electrons from the surrounding air molecules, creating a region of charged particles (ions) intermingling with the beam. The result of this phenomenon is to neutralize the overall charge of the beam, thereby reducing the undesired effect of mutual repulsion among the charged particles in the beam that is a cause of beam spreading. Another force that tends to prevent beam spreading is a surrounding magnetic field, created by the current of the charged particle beam. This field wraps itself around the beam and produces a conduit that inhibits beam divergence. (See Figure 4.)

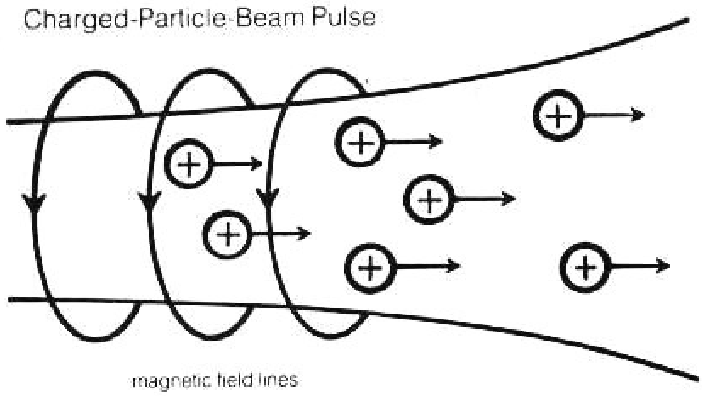


Figure 4. A charged-particle beam will tend naturally to spread apart, due to the mutually repulsive forces between the like-charged particles constituting the beam. The electric current created by the moving charges will generate a surrounding magnetic field, which will tend to bind the beam together. However, unless there is some neutralization of the charge, the mutually repulsive force will always be the stronger force and the beam will blow itself apart.

The propagation of a charged-particle beam through the atmosphere is, in fact, the pacing issue for the endoatmospheric weapon. It has been theoretically calculated that specific threshold values of the beam parameters (beam current, particle energy, beam pulse length, etc.) are required for a beam to propagate through air with reliability. While the values of these parameters are classified, no particle-beam accelerator is currently capable of creating a beam with the required parameters.

Two crucially important experimental programs are exploring the phenomena of atmospheric beam propagation. The first program, underway at the Lawrence Livermore National Laboratory, involves experiments with an accelerator called the Advanced Test Accelerator (ATA), the construction of which was completed in the fall of 1982. The second program, a joint Air Force/Sandia National Laboratories program, similarly is aimed at investigating beam propagation through the use of a radial-pulse-line accelerator (RADLAC). Continuation of the U.S. program to explore the development of an endoatmospheric weapon will depend on a positive prognosis from these two experimental studies of atmospheric beam propagation.

fire-control/pointing-and-tracking technology

The fire-control/pointing-and-tracking system of a PBW must acquire and track the target, point the weapon at the target, fire the beam at the proper time, and assess target damage. If the beam misses the target, the system must sense the error, repoint the weapon, and fire again. Much of the technology for this part of the weapon is not unique to a PBW, and its development has benefited considerably from the HEL weapon program, which has involved study of this problem for several years. Moreover, recent advances in radar technology and electro-optics, combined with projected developments in next-generation computers, portend a heretofore unimagined capability in this area of technology.

This is not to say that serious development problems do not remain in the area of the fire-control system. Many of the pointing and tracking problems will be entirely unique to a particle-beam weapon and cannot be solved by a transfer of technology from the laser program. Nevertheless, none of these problems are such that they will demand exploration of basic issues in physics and the advancement of the state of the art, as will some other aspects of the beam weapon's development.

accelerator technology

The accelerator is the part of the weapon system that creates the high-energy particle beam. It is composed of a source of ions (electrons, protons, or charged atoms), a device for injecting the particles into the accelerating section, and the accelerating section itself. The accelerating section of all conventional linear accelerators is made up of a series of segments (modules) that sequentially apply an accelerating electric field to the charged particles. While the voltage in each segment may be relatively low, the repeated application of an accelerating voltage by the large number of modules ultimately produces very high particle energies.

The first subatomic particle accelerators were constructed in the 1930s for scientific investigations in the field of elementaryparticle physics. The accelerators used for the first-generation PBW system will be embellished variations of the present-day, linear accelerators (linacs), such as the two-mile-long Stanford Linear Accelerator Center (SLAC), which is a state-of-the-art device capable of producing electrons with an energy of 30 GeV (30 billion electron-volts).

The SLAC represents a class of accelerators known as radio frequency (rf) linear accelerators. The great majority of linacs in operation today are rf linacs. Although such devices can accelerate particles to energies high enough for use as a weapon, they are limited severely in their current-carrying capability and would not be candidates for the endoatmospheric weapon system, since beam power is a product of current and voltage.

The space weapon, however, does not call for the tremendously high beam power required for the endoatmospheric weapon. Its accelerator could be based on the design of a state-of the-art rf linac.[3] The major demand for a space weapon is to create a high-intensity (high "brightness") beam of neutral atoms with very precise collimation as it exits the accelerator. It is in this area of divergence that the greatest technical problems exist. If the beam were to diverge from a pencil point to only the diameter of a penny after twelve miles of travel, this would represent a divergence of one part in a million (one meter for each 1000 kilometers traveled). A divergence much greater than this would not be acceptable for a space weapon that is to have a range of thousands of kilometers.

A second type of linear accelerator is called the induction linac. The world's first induction linac, the Astron I accelerator, was built at the Lawrence Livermore Laboratory in 1963. It was designed to produce high electron-beam currents that could be used in a magnetic-confinement scheme for controlled thermonuclear fusion. The Advanced Test Accelerator is art induction linac that grew out of this early accelerator technology. The ATA is designed to generate a 50-MeV beam with 10,000 amperes of current in pulses of 50 nanosecond (50 billionths of a second) duration.[4]

The fundamental principle of operation (applying successively high voltage across a series of accelerating segments) is the same for both the rf and induction linacs. However, the mechanism for generating the electric voltage within the segments of the two types of linacs is quite different. Compared to the rf linac, the induction linac does not impart as much instability to the beam when a modest current limit is exceeded. Therefore, of the two types of accelerators, the induction linac is the more likely candidate for an endoatmospheric beam weapon (which will require very high beam currents).

In examining the Air Force charged-particle-beam technology program, we find that its main thrust is the exploration of nonconventional acceleration techniques (neither rf nor induction linacs), with two main purposes in mind. The first is to develop a means of producing a particle beam with parameters closely resembling those that would be required for successful propagation through the atmosphere, so that beam propagation can be studied in depth and propagation theory refined. To date, a RADLAC I accelerator that has been developed has produced a 10-MeV beam of electrons with a 30,000-ampere current.[5] A more powerful RADLAC II is under construction.

The second purpose is to develop an accelerator with higher accelerating fields that would permit the building of a shorter device. The nominal accelerating gradient in conventional accelerators is about 5 to 10 MeV per meter of accelerator length. Thus, to produce a 1-GeV beam, a linear accelerator would need to be 100 to 500 meters in length--far too long and cumbersome, particularly if the device were to be carried aboard an aircraft. The Air Force hopes to build a device eventually that will generate a very powerful particle beam with an accelerator of more reasonable length.

power supply technology

Possibly the most difficult technical problem in developing an atmospheric particle-beam weapon is the development of its electrical power supply. To operate an endoatmospheric PBW requires that a tremendous amount of electrical energy be supplied over very short periods of time. Since power is energy divided by time, large amounts of energy over short spans of time translate into extremely high power levels. Building a power supply to produce high power in short bursts involves a very advanced field of technology known as pulsed-power technology.

Basically, a pulsed-power device can be divided into three component areas: the primary power source that provides electrical energy over the full operating time of the weapon (prime power source), the intermediate storage of the electrical energy as it is generated (energy storage), and the "conditioning" of the electrical power bursts or pulses of suitable intensity and duration (pulse-forming network) to fire the weapon. Each of these three areas represents a technological challenge.

Any electricity-producing device, such as a battery or generator, is a primary power source. The requirement of the particle-beam weapon, however, is for a prime power source that can produce millions to billions of watts of electrical power, yet be as lightweight and compact as possible. A conventional power station could provide the needed power levels, but it would be neither small nor lightweight. There is also a need for mobility in many of the envisaged applications; a power station would not meet this requirement. Some typical prime-power candidates are advanced-technology batteries, turbine-powered generators, or an advanced magnetohydrodynamic (MHD) generator using superconducting circuitry. Whatever the primary source might be, a sizable advance in the present power-generating state of the art will be required, particularly for the endoatmospheric weapon.

Once electrical energy is generated for the weapon, it will likely have to be stored in some fashion. A typical storage method involves charging a series of large capacitors (often called a capacitor bank). Other more exotic methods are possible, e.g., spinning a huge mechanical flywheel or simply storing the energy in the form of a high-energy explosive that is released in a contained explosion. Actually, there are numerous schemes for storing and releasing the required energy; their advantages and disadvantages depend on their particular application (i.e., the type of accelerator that is used and whether the weapon is endo- or exoatmospheric).

The pulse-forming network would be designed to release the stored energy in the desired form. In the atmospheric weapon, a single shot or "bolt" would most likely be comprised of a very short-duration pulse, repeated thousands of times per second. Hopefully, the prime power source would be able to generate energy at least at the same rate as energy was dispatched. If not, the weapon would be required to remain quiescent while its generator rebuilt a charge for another series of bolts.

THE development of a particle-beam weapon by the United States is a logical follow-on to the current high-energy laser development program. The weapon's potential lethality against high-speed, multiple targets, coupled with its capacity for selective destruction, would make the PBW particularly suitable for the space defense role. While some of the technological and operational issues to be resolved appear formidable at this time, it is far too early to discount the eventual operational effectiveness of such a weapon. Several scientists have argued that the PBW cannot be built or effectively deployed, creating or exacerbating doubts in other individuals. Yet those so concerned might do well to recall that in 1949, Vannevar Bush--a highly respected national leader with a Ph.D. in electrical engineering who had served as head of the U.S. Office of Scientific Research and Development during World War II--argued that technical problems made the development of an effective ICBM virtually impossible without astronomical costs.[6] Nine years later, in 1958, the United States had its first operational ICBM, the Atlas.

The PBW offers a possibility for defending effectively against a launched ICBM, and even a glimmer of hope toward this end is worthy of pursuit. Should the United States terminate its exploration of particle-beam technology, we would be opening the door for the Soviets to proceed at their own pace toward building such a weapon. We can ill afford technological surprise in an area as crucial as beam weapons.

The current pace of the U.S. program in PBW development is both logical and orderly. Funding levels remain relatively low, as DARPA and the three services continue to focus on the pacing technologies that must be understood if such a weapon is to be built. Since the potential payoff of such activity is tremendous, it seems imperative that the United States continue to pursue the development of PBWs at least at the present level of funding.

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Notes

1. The major technological problems of the endoatmospheric weapon are twofold: to understand and demonstrate the propagation of the particle beam through the air and to create an electrical pulsed-power source capable of generating billions of watts of power in extremely short, repetitive pulses.

2. For a different reason, all high-energy lasers (with the exception of the envisioned x-ray laser) require beam dwell time also. A laser needs such time to burn through the surface of the target.

3. The question of how a beam of neutral atoms might be accelerated in a conventional rf linac may arise in the mind of the perceptive reader. A present approach is to attach an extra electron to a hydrogen atom, accelerate the charged atom in conventional fashion, and then strip off the extra electron by passing the beam through a tenuous gas as it exits the accelerator. This stripping causes the beam to spread slightly and must be controlled if the divergence specifications of a space weapon are to be met.

4. B. M. Schwarzchild. "ATA: 10-kA Pulses of 50 MeV Electrons," *Physics Today*, February 1982, p. 20.

5. Private communication, Lieutenant Colonel James H. Head, High-Energy Physics Technology Program Manager, Air Force Weapons Laboratory, 6 February 1984.

6. Vannevar Bush, *Modern Arms and Free Men: A Discussion of the Role of Science in Preserving Democracy* (New York. 1949), pp. 84-87.

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