EIR Special Report
EXECUTIVE INTELLIGENCE REVIEW July 1982

Beam Weapons: The Science to Prevent Nuclear War

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The Present Strategic Situation

For the past 25 years, humanity has been held hostage to the threat of nuclear war. The strategic military policy of the United States—a policy called mutually assured destruction, or MAD—has been based on the premise that nuclear war can be prevented only if each nuclear power arrays its forces in such a way that the consequence of nuclear war is the complete destruction of both sides.

Yet, the Soviet Union has followed a policy of rapid technological development, premised on the conviction that a nuclear war might occur and that such a war, as destructive as it might be, can be won if the proper defensive measures are taken.

Underlying this asymmetry in strategic thinking are three fundamental facts:

(1) The existence in large numbers of nuclear weapons with such large destructive power that one explosion is sufficient to destroy any single military or civilian target (a city, for example).

(2) The development of intercontinental ballistic missiles (ICBMs) that allow many nuclear weapons to be delivered at distances of more than 7,000 miles, aimed at their targets with an accuracy of less than 1 mile. Thus, there is no objective that cannot be destroyed within approximately 30 minutes, the flight time of a nuclear-armed ballistic missile.

(3) There is no technology in the United States today capable of preventing a ballistic missile from reaching its target once that missile has been launched.

The result of the conjunction of these three facts is a military situation without precedent in modern times: An offensive weapon exists (nuclear-armed ICBMs) of incredible destructive power for which one of the major powers conceives no defense possible. Such a situation is inherently unstable and pushes the United States toward the consideration of a nuclear first strike, on the one hand, and toward utopian fantasies of "limited nuclear war" on the other. Long-term peace in the face of such a military situation is almost impossible.

The instability characteristic of an offensive weapon against which we have prepared no defense is compounded many times over by the development of nuclear weapons capability by states other than the United States and the Soviet Union, notably Israel, Pakistan, and South Africa. The question of deterrence against nuclear war can no longer be decided on the basis of superpower relations, but must include the consideration of small, unstable states acquiring not only nuclear weapons but also ballistic missiles for their delivery.

As the Soviet Union has recognized, but the mainstream of U.S. policymakers has not, scientific and technological developments have occurred in the past several years that promise an end to this threat of uncontrollable holocaust. Scientific and engineering data, available up until now only in highly technical publications or obscured under the cover of military classification, show that a weapon can be built capable of finding, tracking, and destroying nuclear armed ballistic missiles in flight. This research and its implications are the subject of this white paper.

The importance of such a ballistic missile defense system can hardly be overstated: Commenting on one component of this system, Edward Teller called it the most important military development since the atomic bomb; and military professionals concur.

The political economist Lyndon H. LaRouche, Jr., in his book on U.S. military policy, put it this way:

> There is no solution to continued balance of thermonuclear terror which is not premised on the ability of at least one of the superpowers to destroy a proverbial "ninety-nine and forty-four one-hundredths percent" of the incoming and thermonuclear armed aircraft deployed against its national homeland.
>
> We go further. We propose that the adoption of such a high-technology answer to the thermonuclear balance of terror become the central reference point for a comprehensive reform of United States military doctrine and organization of the Defense Department.[1]

Such a reform would include a comprehensive nuclear defense policy with both "conventional" ballistic missile defense systems and beam weapon systems. The conventional technologies, taking advantage of spectacular advances in guidance and propulsion technologies over the past five years, can be used to build an "antimissile missile." According to authoritative studies, such a system of both low altitude missiles and higher altitude interception techniques, could be deployed within five years, with substantial protection available within as little as three years.[2] These systems by themselves are not sufficient, but as part of a comprehensive defensive strategy, they acquire a significance and effectiveness that alone they lack.

A Complete Defense

The keystone of effective ballistic missile defense is the development of a beam weapon. As little as three years ago, even the phrase "directed energy beam weapon" was classified, and yet this family of technologies is the centerpiece of ballistic missile defense. There are four branches of this family of defensive weapons:

(1) *Laser antimissile systems.* Using intense, highly focused light energy produced by a laser, this beam weapon would use its ability to project large energies at the speed of light to burn through an incoming ballistic missile. Laser weapons stationed both in space and on the earth have been studied for application to the destruction of ICBMs. Lasers such as those proposed for antiballistic missile systems have been used by both the United States and the Soviet Union to destroy airplanes and helicopters in flight, and, according to authoritative sources, the Soviet Union has downed a ballistic missile with such a laser.[3] The United States does not even plan such a test for another 18 months.

(2) *Particle beam antimissile systems.* In this version of a beam weapon, a high energy stream of atomic or subatomic particles is used to create a shock wave that destroys the target. These particles, traveling near the speed of light, cause intense mechanical stresses and pulses of radiation that can disable a ballistic missile. Such devices have been tested at Soviet weapons laboratories on a weapons scale;[4] the United States does not plan such tests for several years.

(3) *Electromagnetic wave beam weapons.* These weapons use intense beams of microwaves or radio waves to destroy their target. The intense heating and electrical fields caused by the intense radiation are known to be effective means for disabling the delicate electronics on a ballistic missile as well as for disabling the satellites used to guide and target the ICBMs. The Soviet Union is recognized to be many years ahead of the United States in the experimental development of intense, directed microwave sources.[5] The extent of the Soviet deployment of these microwaves is not publicly known.

(4) *Plasma beam weapons.* It has been known for many years that discrete pulses of highly ionized gas (plasmas) could be generated and accelerated. In a phenomenon closely resembling ball lightning, a self-contained structure of magnetic fields and charged particles can travel long

distances with large amounts of energy stored in the plasma-field structure. Studies show that the energy equivalent of 5 pounds of dynamite (10 megajoules) could be stored in a plasma ball about ½ inch across, traveling at velocities in excess of 1,000 miles per second. This energy, in the highly concentrated form of a plasma-field configuration, would completely destroy an ICBM. The Soviet Union has been conducting active research on this phenomenon since at least the middle 1950s and has recently experimented with large-scale plasma acceleration in the atmosphere.[6]

Combining these components in the U.S. military posture would, for the first time in 25 years, remove in an actual and practical sense the threat of nuclear incineration. We would no longer have to rely on the good will or rationality of all the world's nuclear powers for our defense. We would no longer be hostage to the threat of intercontinental nuclear war.

The greatest irony of the world's nuclear dilemma is that the perfection of a defense against nuclear weapons not merely would break the balance of nuclear terror, but also would begin a process of economic and technological progress sufficient to remove the most deeply rooted causes of war today.

The technologies required for the development of a beam weapon for ballistic missile defense are the same required for the development of controlled thermonuclear fusion energy—mankind's ultimate energy source, which has unlimited, cheap fuel, little waste, and very high energy densities. The ability to control high temperature plasmas, to generate intense magnetic fields, to master pulsed power sources, to generate intense laser beams, to understand the generation and propagation of shock waves, and to guide high density particle beams are the same capabilities required to solve the chief problems that arise in the various forms of controlled fusion research for energy production.

A Revolution in Science and Technology

As has often happened historically, military research on the most advanced technologies would have a revolutionary impact on civilian industrial and energy technologies. Much like the role of the military in the perfection of nuclear energy for propulsion—which resulted in a nuclear reactor safe and reliable enough for civilian electricity production—the development of a beam weapon will open up a new chapter in man's history: the age of plasma technologies. These new technologies used for energy production (fusion), materials processing (plasma torches), propulsion (fusion rockets), and industry (plasma furnaces and magnetic separation) will have a more revolutionary impact on society than the introduction of electricity had 100 years ago.

Without any practical limits to the energy and raw materials freed by plasma technologies, the age-old problems of starvation, plague, drought, and inadequate housing and health care can realistically be scheduled for solution; no *material* barriers to their solution would remain. There would be no limits to mankind's potential for growth.

The real source of the revolutionary impact of these technologies is the scientific challenge they present. The development of a beam weapon would require the resolution of the most profound problems of theoretical physics of the past several centuries. At the present time, all productive scientific research, whether in the United States or the Soviet Union, is based upon a method and set of fundamental breakthroughs of the Riemannian school of mathematical physics. This tradition, largely unconscious and misunderstood in the West, must be resurrected and elaborated if the physics of high energy density systems is to be mastered. The brute force computational techniques that dominate U.S. physical science today reflect the theoretical vacuum left by the virtual disappearance of the Riemannian tradition in the West. This theoretical deficiency appears in several forms (although usually misidentified): the apparent superiority of analytic and conceptual tools among Soviet scientists; the dependence on numerical calculation among Western scientists; the insistence on atomic or particle-based theoretical axioms in the West; the lack of fundamental developments in any field of continuum mechanics.

In the Soviet Union the Riemannian tradition is much stronger and applied much more systematically to the problems of high energy density systems, especially in the areas of plasma and beam physics. Through a line stretching back to the St. Petersburg Academy set up by Leibniz, Russian scientists have concentrated on the hydrodynamic methods necessary for a competent treatment of shock wave phenomena, continuum mechanics, and plasma physics.

The Newtonian opposition to this Riemannian method is the basis for opposition to beam weapon development. In both scientific and policy terms, the British empiricist school now dominates Western science and is almost uniformly opposed to the development of beam weapons and plasma technologies.

The apparent success of the Soviet Union in the application of the Riemannian method poses the scientific problem in stark terms: Either the United States must commit itself to the scientific and technological revolution implied by the development of a directed energy beam weapon for ballistic missile defense, or it must face an adversary prepared for nuclear war, having armed itself with too few of the wrong kind of weapons, for a war that will be fought on the adversary's terms.

1. Nuclear Strategy

The Soviet Union and the United States have approached the threat of nuclear war in two fundamentally different ways, and an understanding of the real significance of beam weapons requires a review of both nuclear powers' strategy, from the standpoint of defense.

The West's nuclear strategy has been remarkably constant over the period of the past 25 years. In spite of the change of names and personalities, the basic assumptions and conclusions of Western nuclear strategy have not changed in broad outline.[1]

The most striking divergence between the strategic conceptions of the two sides occurs in their respective definitions of defense. Western military strategists have debated this question with great vehemence over the past 25 years with little consensus among different factions. However, in spite of the heated discussion, a policy of no defense has evolved as the operant Western military posture. In the face of high costs and difficult technological problems, the various defense options that were offered the United States during this period have all been rejected.

The resulting policy is more accurately called assured vulnerability rather than mutually assured destruction. The American policy toward ballistic missile defense has been the clearest expression of this assured vulnerability. In the late 1950s, the Nike antimissile system was dropped from serious consideration. Progress on the Safeguard missile system in the 1960s led to the signing of the ABM treaty with the Soviet Union in 1972, downgrading the research and deployment of this system to one Minuteman missile site in South Dakota; this experimental program was then abandoned in the middle 1970s. In the 1980s, Congress has twice rejected everything but small research funding for the newest generation of ballistic missile defense systems, the Low Altitude Defense System (LoADS), and its upper atmosphere relatives. The United States today does not have an active ballistic missile defense project.

U.S. Policy: Assured Vulnerability

The reasoning behind this policy of assured vulnerability is a simple and clear consequence of the fundamental assumptions of Western nuclear strategy: If the only reasonable use to which strategic nuclear weapons can be put is that of deterrence, and the alternative to deterrence is mutual destruction, then defense not only is impossible, but, in an essential way, destroys the core of the system of deterrence. That is, to the extent that one side or the other believes (incorrectly, according to Western theory) that it might survive or even be victorious in a nuclear war, then deterrence is undermined. A deterrence that rests on mutually assured destruction requires that the population and industry of each country be held hostage, each side secure in the knowledge that it retains the capacity to utterly destroy its adversary.

There is, of course, an exception to this policy, and that concerns the defense of a second-strike capability. Since, the argument goes, a second strike is the keystone of the deterrence, if the guarantee of the survivability of a second-strike capability can be strengthened by a defensive system (this question is purely one of technological and fiscal arguments), then such a defensive system might actually strengthen deterrence. This logic was used for the few years that the United States deployed an ABM system; the ABM system was to be used to protect not population centers or industrial plants, but rather Minuteman missiles. However, at the point that submarines and ballistic missile technologies outstripped ABM technology in their ability to guarantee a second strike, the ABM research was dropped for reasons of cost-effectiveness.

The development of beam weapons for strategic missile defense (as opposed to their development for tactical, battlefield application against armor, aircraft, or cruise missiles) has been affected in two distinct ways by the Western neglect of ballistic missile defense. First, and most simply, beam weapons have been tarred with the same brush as all defensive systems: They are irrelevant, if not destabilizing, to the basis of Western nuclear strategy. Thus, beam weapon development has suffered from underfunding, misunderstanding, and sabotage from the highest levels of the Department of Defense and the Pentagon. This situation reached such a pitch in the Air Force (a traditional source of opposition to new technologies that threaten to undermine the basis of current nuclear strategy) that the head of Air Force intelligence, General George Keegan, resigned in protest in spring 1979 over Air Force policies in regard to beam weapon development. He resigned after having proved to his satisfaction that the Soviet Union would be capable of deploying a beam weapon in a ballistic missile defense role by the early 1980s, and having met a complete barrier to a serious response to that fact.

Since that time, the Defense Department has continued to downplay the significance of U.S. research on beam weapons, at the same that time that it classifies Soviet progress on beam weapons. In congressional presentations year after year, the directors of the U.S. beam weapons research program testify to the following facts, which, more than anything else, demonstrate that the two superpowers are operating from widely differing conceptions of defense in nuclear strategy:

(1) The Soviet Union has a beam weapon research program that is between 3 and 5 times the size of the U.S. program.[3]

(2) The Soviet Union is proceeding too rapidly toward weapons deployment.[4]

(3) The Soviet Union will have a space-based beam weapon deployed during the middle 1980s, for use against other satellites as well as various "air and ground targets."[5]

(4) The U.S. program is not limited by technological problems, but rather by monetary constraints.[6]

(5) The U.S. program is a purely research program (as opposed to a development program) designed to answer questions about the feasibility and desirability of a beam weapon.[7]

(6) Official policy is that it would be "premature" to push the beam weapon research program toward the engineering and development questions of weapons deployment.[8]

(7) The United States does not expect to have the data necessary to determine the type or advisability of a space-based beam weapon demonstration test until the late 1980s.[9]

The Question of New Technology

Compounded with the denial of defense, this policy of assured vulnerability has had a second, much more fundamental result: a generalized suspicion of new technologies in either military or civilian application. From the first period of nuclear strategic thinking in the United States, it was recognized that the inability to fight strategic war had several profound interconnected impacts on the relation between military policy, economics, and new technology. These ideas were outlined in a series of books, the earliest and most influential of these being General Maxwell Taylor's memoirs on leaving the post of Army Chief of Staff, *The Uncertain Trumpet,*[10] and a Rand publication by a then rising young think-tanker, James R. Schlesinger, *The Political Economy of National Security*.[11]

These books made the fundamental point that science, by making strategic, global war impossible, (1) had drastically limited the sphere in which new technologies might have military usefulness, and (2) changed the formerly intimate relationship between industrial and economic strength and national security.

Taylor argued the first point in his book, pointing out that already by 1959, the United States had reached the point of diminishing returns to be had from further investment in strategic nuclear armament, since an effective deterrent had already been achieved with the existing arsenal. He maintained that a much larger portion of U.S. military effort should be directed toward preparation for "conventional" wars. Because American interests could not be actively defended by nuclear weapons, Taylor said, we must have lower intensities of military force available. The forces would be armed with the lower technology conventional weapons of the general type seen in previous wars.

Schlesinger argued the second point in his book, which has had a profound effect on the strategic thinking, especially of the Air Force, in the 20 years since it was published. He began his argument with a general statement about the modern nation and growth and industry:

> We have gone around the world spreading the "gospel of plenty" raising the level of expectations. . . . In the nature of things, these rising expectations can never be satisfied. . . . Despite the modification of the original Malthusian dogma over the years, the danger remains that excessive growth of population will wipe out the gains of economic progress. Any economic revolution will shortly be wiped out by a Malthusian counterrevolution and the illusion of growth. It is unwise to overstate the importance of economic growth per se. . . .
>
> We must in our strategic policy return to the days before the industrial revolution and prepare to fight limited wars. . . . Higher Soviet industrial development rates than attained in our production will have very little strategic significance. . . . The industrial mobilization base is only one of several gauges of power. A strategic menace may be based upon a rather modest economic structure. . . . We must build our miliary force on the exact opposite of the industrial potential notion.

In Schlesinger's strategic context, the development of qualitatively new technologies and their military applications are totally foreign elements. As a result, military expenditures are characterized by what he called "in width" as opposed to "in depth" procurements. Schlesinger accurately noted that this tendency toward emphasis on conventional war fighting capability in local situations, only weakly integrated with the civilian economy, was the characteristic feature of the Nazi military machine. He maintained that the "decoupling" between traditional measures of economic health and military power—and hence, a decoupling between rates of technological progress in either—is an essential feature of war in the nuclear age, anticipated by the Germans because of their doctrine of the blitzkrieg.

The resulting military mission defined by Schlesinger is one of "resource and population control" that is geared to defend the supply of strategic materials to the United States. This is the stated belief not only of Taylor and Schlesinger, but also of Henry Kissinger, Robert McNamara, Zbigniew Brzezinski, Alexander Haig, and many others.

The critical point to be stressed is that the present hostility in United States policy-making circles toward beam weapon development is explicable only on the assumption of limited resources, a halt to general economic progress, and the inadvisability of general technological development. Only a faction with a deep antitechnology bias would oppose the development of a beam weapon for missile defense.

Such was not always the case. Even since World War II, the United States has had military leaders who defined national security as primarily a function of domestic economic well-being, and saw the military's mission as one of "nation building," domestically and abroad. Generals

Eisenhower, MacArthur, and Bradley, and Admiral Rickover are four leading exponents of that theory, and they represent the traditional American doctrine of military thinking.

Once this school of military outlook was displaced by the "systems analysis" group around Robert McNamara, the idea of a comprehensive ballistic missile defense system was replaced with concern over basing modes of our ICBM force. Instead of pushing for the broad front of technological and scientific innovation that simultaneously revolutionizes warfare and fires economic development, the systems analysis group supports the "Rapid Deployment Force" for the protection of "strategic resources."

The Soviet View of Defense

The whole structure of Western military strategy, deployment, and order of battle proceeds from the assumption of the unwinnability and unfightability of nuclear war. The clear and painful irony is that our only nuclear-armed adversary does not share that assumption. The Soviet Union has structured its whole strategic outlook, deployment, and order of battle around the reality of world nuclear war—its fightability, winnability, and qualitative similarity to other kinds of war.[12]

It is for this reason that the Soviet thinkers have so strongly emphasized the role of defense in a nuclear war. Although many Western observers have characterized Soviet concern over defensive capabilities as paranoid or obsessive,[13] the actual structure of the Soviet defensive deployment is entirely consistent with their overall military strategy, and perfectly rational given their assumption that nuclear war is terrible but fightable. The Soviets have three distinct thrusts to their defensive policy.

The first is a large, high priority, research and development effort. In the Soviet conception, the most certain aspect of the world today is rapid progress in science and technology. While making no clear distinction between civilian and military applications of scientific work, the Soviets have devoted massive amounts of money and manpower to research projects in high-energy density physics (plasma physics, beam generation, pulsed power production, and so on), aerodynamics and astrophysical engineering, and electronics. These fields are those most central to new weapons development as well as to new industrial technologies. In most Soviet discussions, the primary importance of this scientific work applied to military ends is not the development of new weapons themselves, but, first, the prevention of a "surprise" by the West and second, the economic importance of the technologies provided by this research.

The quality of Soviet thought on the importance of scientific research is exemplified by an essay by General Major A.S. Molividov:

> There is taking place a vigorous erosion of the boundaries between theoretical and applied knowledge; the entire scientific knowledge front is being applied to the development of military affairs. Today one cannot specify with assurance a single branch of science in which the military aspect would be neutral. Every scientific field is either being utilized for the military or there exists a potential for such utilization.[14]

The resources devoted to this Soviet research effort are huge. The Department of Defense has testified every year for the past decade before Congress on the large and growing disparity between the U.S. and Soviet military R&D expenditures. The DOD now estimates that over the past decade the Soviets have made a cumulative $100 billion R&D expenditure beyond that of the United States. This massive effort was described by the DOD as follows:

> Soviet priorities, trends, and accomplishments show that there was no hollow rhetoric in the Communist Party Central Committee Resolution on December 1973, which said: "The development of Soviet science has special significance when the scientific-tech-

nological revolution has become the most important area in the competition of the two opposed world systems." The U.S.S.R. has deliberately emphasized the greatest possible rate of advance in military technological programs at the expense of improvement in the civilian standard of living.

The foremost—and unquestionably the most important—conclusion from our assessments in this area is that the Soviet Union shows every sign of continuing to concentrate a major portion of its military RDT&E on strategic weapons, both offensive and defensive. Soviet success in enhancing their strategic forces and in creating a base for further improvements is more pronounced than for any other area of military R&D specialization.[15]

That this Soviet program has been successful is dramatically indicated by President Reagan's statement at a press conference March 31, 1982, to the effect that there were areas of "Soviet superiority" in strategic weapons.

It is frequently argued today, as it has been for the past 20 years, that the Soviet Union cannot afford the diversion of the best scientific and engineering talent to military research. The consensus among Western observers in the early 1960s was that the Soviet Union would face increasing unrest domestically if it tried to expand its military budget in any significant way, especially in those high technology areas so needed by the civilian economy. This was clearly an unfounded hope 20 years ago, and is even more unfounded today. The extent of the Soviet military commitments over the past decade, in fact, has been grossly underestimated by all official Western sources. In a recently completed study of the Soviet economy, researchers at the Fusion Energy Foundation report that the Soviet military budget increased by approximately 30 percent in 1975 and again in 1978. These two increases put the current Soviet military budget at a level approximately 50 percent greater than the U.S. military budget. Although this study shows that there have been serious economic strains as a result of these two sudden jumps in military procurement, there are indications that these expenditures can be endured for a considerable time to come.

The hope that this Soviet military expenditure will be unaffordable reflects a grave misunderstanding of the potentially dramatic increases in productivity that can be induced by properly structured military research expenditures. In the same way that the NASA program in the United States paid for itself many times over through induced productivity, military research in the most advanced areas of plasma physics, space physics, and electronics can profoundly affect the civilian economy through the misnamed spinoffs. The critical point at the current juncture is that the Soviet defensive conception of R&D has focused that nation's research on precisely those areas most conducive to future economic payoff: advanced plasma technologies, beam generation and propagation, space development, and electronics. Only in the last area can the United States claim any degree of advancement over the Soviet Union. In the other areas, Soviet superiority is evident, as follows:

Plasma physics. The Soviet Union continues to have the most broadly based and innovative nuclear fusion research program in the world, in spite of severe cuts in funding for civilian applications in the past five years. The bulk of the new approaches and scientific concepts have come from the Soviet fusion research program. The United States has excelled in elaboration and engineering development of ideas like the tokamak, the tandem mirror, and so on, but the basic work on these was done in the Soviet Union. It is because of the large Soviet investment in fusion that they are today ahead of the United States in the development of the beam weapon.

Beam generation technologies. Soviet work in this area, keying off from the Soviet fusion program, promises a breakeven electron beam fusion experiment by 1985.[16]

Space research. The Soviet Union continued a large and aggressive manned space program during the 1970s when the United States did not conduct even a single manned space mission.

The Soviet Union now launches approximately twice as many satellites each year as the United States, with more than double the payload, and is conducting a series of extensive tests of antisatellite and antimissile weapons in space.[17] According to DOD testimony from 1982, the Soviets have already developed (but apparently not deployed) an antisatellite weapon in near-earth orbit and are close to having an antisatellite weapon capable of destroying satellites in the highest earth orbits. Most important, the Soviet Union plans to have a permanent manned space station orbiting the earth by 1985, which will be continuously occupied by 10 men; there is no similar U.S. program.

The second aspect of Soviet defense deployment is in the area of civil defense. Despite recent media reports of a Soviet peace movement that defines nuclear war as unthinkable, the Soviet Union is committed to civil defense as an essential part of nuclear war-fighting capability, with a comprehensive, expensive, and serious program for protection of urban and industrial targets. It is clearly committed to the evacuation of its urban areas in time of war, the dispersal of industry, and the sheltering and feeding of critical cadre of skilled workers, administrators, and military personnel. According to 1981 figures, the Soviet civil defense program has more than 115,000 full-time employees and approximately $2.3 billion per year in expenditures.[18] Authoritative sources estimate that with three days' warning of a nuclear attack, the Soviet civil defense preparations would result in Soviet casualities from a nuclear war not exceeding those they suffered in World War II. These losses would be extremely serious, but the Soviet Union is psychologically and militarily unawed by them. The Soviet military has proven to itself that civil defense works, and they are committed to it as an essential part of a nuclear war-fighting capability. In 1974, Soviet Colonel General A. Altunin, Chief of Civil Defense and a Deputy Minister of Defense, summarized this thinking as follows:

> Under present conditions, when there has arisen the threat of wide use of means of mass destruction, and first of all of missile-nuclear weapons against the entire territory of the country, the preparation of the country's rear for defense against means of mass destruction has become, without a doubt, one of the decisive strategic factors ensuring the ability of the state to function in wartime, and in the final analysis the attainment of victory in war.[19]

Third, the Soviet Union has consistently identified ballistic missile defense as a critical component of its overall defense posture. In marked contrast to the West, Soviet military commentators have never regarded the ICBM as an invulnerable offensive weapon, nor have they regarded the dominance of the offensive side of war today as anything but temporary. They, of course, admit the tremendous technical problems involved in ballistic missile defense, but constantly analyze the role of even the rudimentary defensive weapons that do exist against ballistic missiles. The general Soviet outlook is well summarized by Major General M. Talensky:

> Antimissile systems are purely defensive and not designed for attack. It is quite illogical to demand abstention from creating such weapons in the face of vast stockpiles of highly powerful means of attack on the other side. Only the side which intends to use its means of attack for aggressive purposes can wish to slow down the creation and improvement of antimissile defense systems. For the peace-loving states, antimissile systems are only a means of building up their security. The creation of an effective antimissile system enables the state to make its defenses dependent chiefly on its own possibilities, and not only on mutual deterrence, that is, on the good-will of the other side. And since the peace-loving states are concerned with maximum deterrence, in its full and direct sense, it would be illogical to be suspicious of such a state when it creates an antimissile

defense system on the ground that it wants to make it easier for itself to resort to aggression with impunity.

> Some say the construction of antimissile defense systems may accelerate the arms race, and that the side lagging in such systems may build up its nuclear-rocket attack weapons. That is one of the arguments against defensive systems.
>
> Such a development is not at all ruled out, in much the same way as the possibility that the nuclear-rocket race may be stepped up quantitatively and qualitatively even without any antimissile systems. In any case, there is this question: What is more preferable for security as a result of the arms race, a harmonious combination of active means of deterrence and defense systems, or the means of attack alone?
>
> Another argument is that it is not in the Soviet Union's interest to spend large sums of money and resources to build antimissile defenses for cities and economic areas because the West has adopted the "counterforce" strategy and will not use nuclear weapons against nonmilitary objectives. This argument will hardly convince anyone. History has taught the Soviet Union to depend mainly on itself in ensuring its security and that of its friends. The Soviet people will hardly believe that a potential aggressor will use humane methods of warfare, and will strike only at military objectives, etc. The experience of the last war, especially its aerial bombardments and in the particular combat use of the first atomic bombs, is all proof to the contrary. That is why the Soviet Union attaches importance to making as invulnerable as possible not only its nuclear-rocket deterrent but also its cities and vital centers, that is, creating a reliable defense system for the greatest number of people.[20]

More recently, Soviet research has concentrated on the development of beam weapons for ballistic missile defense. The exact state of progress by the Soviet researchers is not available in the open literature in either this country or the Soviet Union, but the following facts are known:

(1) The Soviet Union has developed a land-based laser capable of "blinding" U.S. surveillance satellites. Using an intense beam of visible light, the Soviet weapon can overload the sensitive cameras in the spy satellites, and, in some cases, can destroy the delicate optics. This weapon has been available for at least three years.[21]

(2) The Soviet Union has developed a land-based high-powered laser capable of destroying pilotless, subsonic aircraft. These experiments have been observed by Western reconnaissance for several years. It is not known if this is a deployable weapon or still a laboratory testbed.[22]

(3) The Soviet Union has tested a number of complex, extremely high-energy power sources ideally suited to beam weapons use. These involve both conventional explosive technologies and nuclear technologies. Advanced MHD techniques have been used to produce pulses of electrical energy of precisely the size and timing needed for directed energy beam weapons.[23]

(4) The Soviet Union has developed a high-energy microwave technology that has been used for ionospheric modification. An exotic weapon using beam technology, this microwave generator would enable the Soviet Union to "tailor" the upper atmosphere so as to block radio transmissions, destroy radar reception, and conduct electronic warfare on a global scale. The engineering state of this development is not known.[24]

(5) The Soviet Union has tested a plasma beam weapon that generates discrete plasma "bullets" capable of long-distance travel. Similar to ball lightning, these plasmoids carry large energies in an electromagnetic field-plasma complex sufficient to destroy a ballistic missile.[25]

(6) The Soviet Union has tested a high-energy iodine laser, which has successfully downed a ballistic missile. This experiment was a test of a strategic beam weapon, not intended for battlefield use as an antitank or antiaircraft weapon, but as a ballistic missile defense system.[26]

DOD spokesmen estimate that the Soviet commitment to beam weapon development has put them two to four years ahead of the United States in this program.

Perhaps the best summary of the Soviet approach to nuclear strategy is provided by the Soviet response to the Antiballistic Missile Treaty, signed in 1972. This treaty, the brainchild of Henry Kissinger, was a prototype of nuclear strategy on both sides. Kissinger, as his motives are portrayed by General Maxwell Taylor, hoped to avoid the development of a new, ABM technology. Kissinger believed that arms control could be an efficient means of technology control and saw the then Soviet impasse in ABM development at the time as an opportunity to stifle this technology, which was then considerably further developed in the West than in the Soviet Union. In effect, Kissinger negotiated the treaty to prevent the development of ABMs not in the Soviet Union, but in the United States. It was purely on the personal influence of Kissinger that the treaty was implemented.

The Soviet motivation was quite different; by signing the treaty the Soviets gained a respite from a technology race that they were losing. In consequence of the treaty, they were able to concentrate on the questions of guidance and precision for their ICBMs, and the development of multiple reentry vehicle technology. In retrospect it seems clear that they would have had great difficulty in doing both of these things and simultaneously developing an ABM system.

The treaty relieved them of that choice. As it was finally signed, it limited each side to one ABM site for experimental purposes and so restricted the missiles and launchers on this site that no general ABM deployment was possible under the treaty. Consistent with the U.S. conception of assured vulnerability, the U.S. experimental site was constructed near a Minuteman missile base in South Dakota. The so-called Safeguard ABM was begun in the early 1970s but was discontinued by the mid-1970s. As the Defense Department pointed out in justifying the demise of the program, the whole object of U.S. nuclear strategy is to preserve a second-strike capability; that is the only strategic significance of nuclear weapons. In this view we are guaranteed such a second-strike by our submarines, so why continue to spend money on a system that does not provide a second-strike as effectively as submarines?

The Soviet ABM development has continued through several generations of ABMs in the past decade, although the Soviets have not engaged in general ABM deployment. The single site allowed them under the treaty was constructed around Moscow, as part of their general nuclear defense program. As Soviet commentators have pointed out in discussing this ABM site: What would be the point of using an ABM system to protect missile silos that would be empty by the time they were attacked?

2. How a Beam Weapon Works

The Physical Problems of a Beam Weapon

The physical task of defending against nuclear armed ICBMs is formidable. Many physicists have claimed that these difficulties are so great that a beam weapon could not be deployed for ballistic missile defense before the turn of the century, and, in all likelihood, that it would be neglected then for better options.[1] The requirements that a beam weapon system must meet are, in fact, the same as those for any active defense against ballistic missiles. Note that these problems do not arise in the deployment of beam weapons for tactical or battlefield missions. Indeed, the short distances involved in antitank, antiaircraft, and anti-cruise-missile applications of beam weapons have made this development very attractive, and considerable funding is provided (approximately $850 million in fiscal year 1983) for this development.

All analysts agree that a beam weapon would be the ideal method for defense against ballistic missiles, if it could be developed. These analysts describe a beam of laser light, subatomic particles, or plasma—traveling at or near the speed of light—that can be aimed at a rapidly moving small target many hundreds or thousands of miles distant. This beam (like the death ray of science fiction fame) would be capable of storing within it sufficient energy to destroy the target. This destruction would be essentially instantaneous. Since the beam travels at the speed of light it would travel the thousands of miles to the target in the time the target moved several feet. No "leading" of the target would be necessary; the beam needs only to be aimed and then fired. The evidence of the destruction of the missile would be almost immediate as well, and no evasive action or beam avoidance by the target would be possible.

Two modes of deployment for these weapons have been considered. In the first, the simpler and nearer term mode, the beam weapon would be based on the earth, with its guidance and aiming capabilities either orbiting the earth or launched on warning of an attack. This exo-atmospheric guidance and tracking would provide identification and tracking of the target as well as the mirrors (for a laser) for directing the beam at the target. This basing mode has the great advantage that the size and weight of the beam weapon are not a consideration, and the delicate optics, power generation equipment, and large fuel supplies can be stored safely. This weapon could provide either point defense (that is, for a city, industrial complex, or military target) by destroying reentry vehicles coming into the area immediately above the target, or area defense by use of an orbiting mirror that would reflect the beam back toward the missiles in their launch phase (rather than waiting until they had dispersed their reentry vehicles).

A second deployment mode is to mount the beam weapon directly on a satellite orbiting the earth. In such a deployment, approximately 20 satellites would be required to protect the entire United States from a major nuclear attack, a mission that they would accomplish by destruction of the enemy missiles in the five minutes after their launch. These enemy missiles would be destroyed before they released their warheads by the satellites immediately above them at the time (most of the satellites would be out of range at any one time). These studies show that with a 5-megawatt chemical laser with a 4-meter diameter mirror to aim the laser beam, ballistic missiles could be destroyed at the rate of one per second by the satellite. If a realistic attack of 1,000 missiles were spread out over a period of 15 minutes, these satellites would be capable of providing a credible area defense for the United States.

The development of a beam weapon of this sort has been variously projected to be possible within the next 5 years by industry experts,[2] and within 25 years by various experts from the Department of Defense,[3] while others have concluded that beam weapons "have little or no chance of succeeding as practical, cost-effective defensive weapons."[4] These analysts do agree,

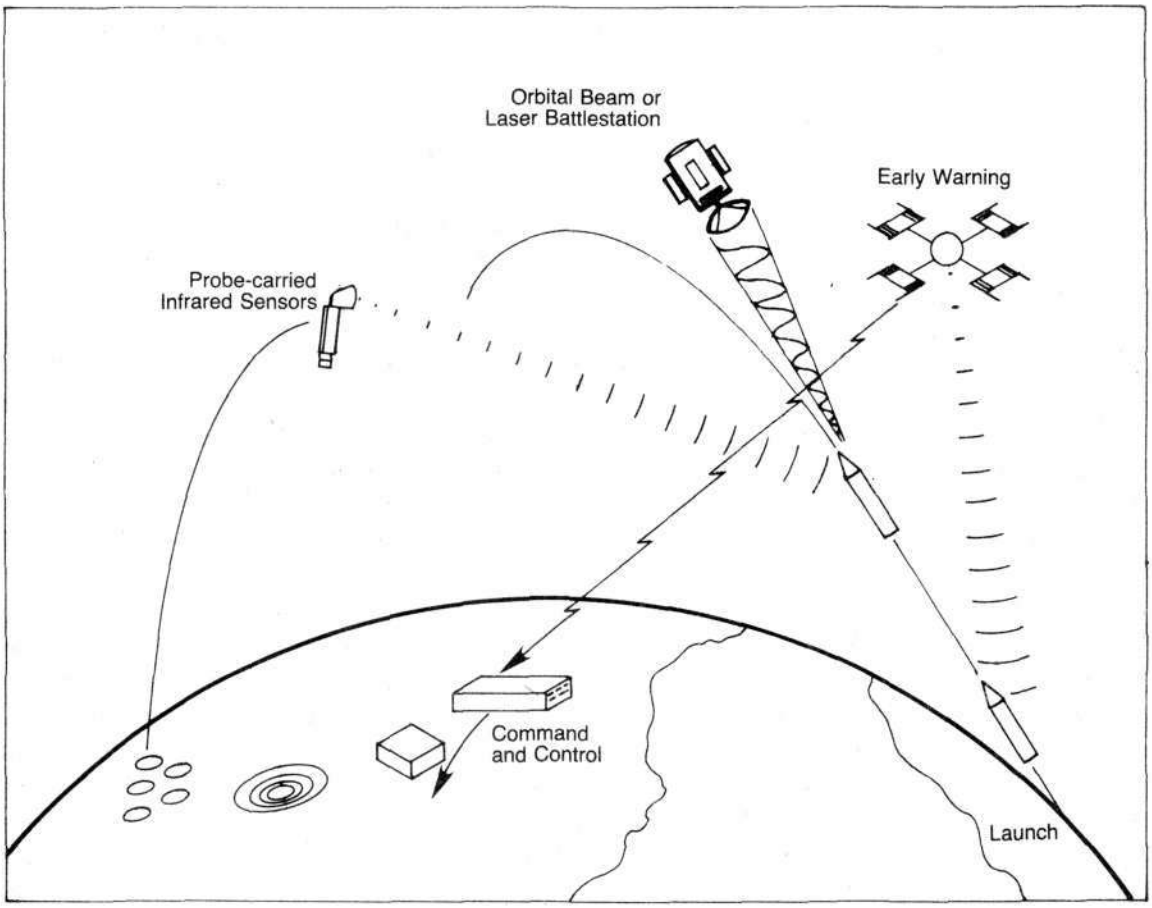

Figure 1
A SPACE-BASED BEAM WEAPON

A space-based beam weapon provides the only feasible means for area defense against nuclear-armed ballistic missiles. The deployment of approximately 50 satellites, each with a weapon capable of generating an intense beam of laser light, atomic particles, or plasma, in an orbit around the earth, would protect the entire United States from incoming ballistic missiles.

The figure shows the basic components of a space-based beam weapon system. The heart of the weapon is, of course, the beam-generating mechanism on the satellite. Either a laser, a large particle beam accelerator, or a plasma gun is mounted along with its fuel supply on a satellite in earth orbit. This satellite, its fuel supply, shielding, and tracking equipment would be continually "on patrol" around the earth. The satellite would also contain the second essential component, a set of infrared, long-wavelength telescopes and computing equipment for detection and identification of the ballistic missiles as they are launched. These telescopes are capable of identifying the missiles, determining their trajectory, and providing coordinates for the aiming of the beam weapon.

The diagram indicates a third component, the ground-based battle management and sensing equipment. This includes a main computer and communication links, as well as a rocket-borne set of sensors and telescopes, which would be launched on detection of a ballistic missile attack. These sensors would provide secondary target detection and identification, as well as guidance for auxiliary antimissile systems using conventional weapons.

Typical calculations show that an arrangement of 50 satellites in such a configuration would result in every area of the globe being continually accessible to beam weapon defense. On launch of the ballistic missiles, the beam weapon satellite would identify the launching, distinguish between actual missiles and decoys, target the missiles, and be capable of firing many pulses of energy each minute. These pulses would destroy the missiles in first phase after they were launched. There is an approximately 10-minute "window" during which the missiles are vulnerable to a space-based beam weapon, sufficient time for the thousands of missiles in a major attack to be destroyed.

however, on the details of what a beam weapon would have to accomplish to provide defense against ballistic missiles.

Ballistic missile defense, whether done by beam weapons or conventional technologies, requires a solution to the following problems:[5]

(1) early warning that hostile ICBMs have been launched

(2) detection and assessment of the threat

(3) derivation of trajectories and prediction of targets

(4) discrimination of warheads, reentry vehicles, and decoys

(5) targeting of interceptor (the beam)

(6) guidance of the beam

(7) destruction of the target.

The first detection of an opponent's missile launching would be provided by data from satellites. These satellites, operating in both near-earth orbit and in geosynchronous orbit, have been an essential part of military capabilities for the past 15 years. The technology for the detection of an ICBM's launching has been perfected to the point that all missile launchings are routinely monitored by both the Soviet Union and the United States. However, there is a large gap between the initial detection of a missile launching and the second requirement of detection of ICBMs and the assessment of the significance of the launching. While ground-based radar plays a significant role in this assessment, several new technologies have completely changed the problem-solving for assessment, derivation of trajectories, and discrimination of warheads from decoys (problems 2 through 4 on the above list).

According to authoritative military sources, the preferred method of solving these problems depends on a launching of a missile whose only purpose is surveillance of the just-launched ICBMs:

> Early warning messages either from satellites or early-warning radars trigger the central command post to launch several rocket-borne probes from shelters in the continental United States. Each payload consists of a sensitive infrared telescope, a data-processing computer, and down-link communications equipment which together weigh several hundred pounds. Moderate-sized rockets place these probes into trajectories that keep them above the atmosphere for approximately 20 minutes, the duration of the entire engagement (subsequent engagements require new probes). The probes scan the threat corridor specified by the early warning, detecting at ranges of several thousand km the largest components from Soviet missile-payloads, i.e., fuel tanks, and shortly afterward the reentry vehicles, accompanying objects, and penetration aids. Typical threats could have approximately 5,000 reentry vehicles and upwards of 20,000 other objects in the probe's field of view.
>
> The probe tracks all these objects for three to four minutes, measuring angular information and intensities of several spectral regions of the long wavelength infrared radiation as a function of time. The on-board computer stores this information, computes approximate trajectories and launch and impact points, and based on the multispectral

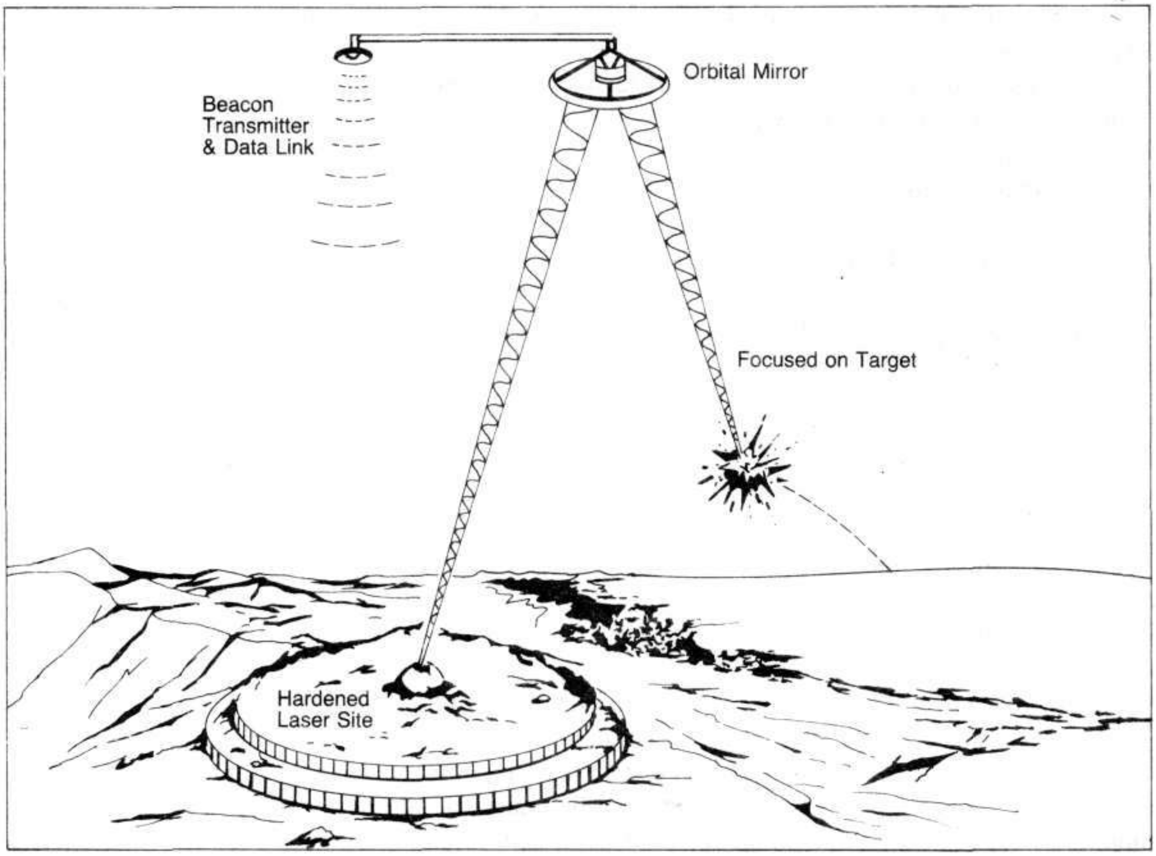

Figure 2
GROUND-BASED BEAM WEAPONS

Both area and point defense could be provided by a ground-based beam weapon system. Shown here is a conceptual design of a laser beam weapon system built on a mountaintop, which uses a relay mirror in orbit around the earth to provide aiming and tracking for the beam weapon. Using an intense beam of light, the ground-based laser generates a pulse of energy sufficient to destroy missiles as they are launched or as they reenter the atmosphere toward their target.

The critical components of this basing scheme are shown in the figure. The beam generation itself is accomplished totally on the earth, removing any problems of weight, remote maintenance, or launch capability associated with space-based weapons. By situating the weapon above the bulk of the atmosphere (the study shown here assumes a 12,000 foot mountaintop), almost perfect transmission of the laser light can be achieved by using long-wavelength chemical lasers.

Additionally, the aiming and tracking equipment is partially ground-based; the beam would be capable of being aimed at targets after their boost phase, at which point they would be entering the atmosphere above the horizon of the beam weapon. This mode of direct engagement would provide point defense of the region immediately surrounding the beam weapon.

Alternatively, the beam could be reflected off of the orbiting mirror to provide area defense against ballistic missiles. In this mode, a set of orbiting mirrors, each up to 30 feet in diameter, would be equipped with sensing and guidance capabilities. They would be required to direct the laser beam to the missile and to focus the diffuse beam that hits the mirror onto the targeted missile.

long wavelength infrared data, uses discrimination algorithms to differentiate the reentry vehicles from the other objects in the threat.

This information is relayed to the ground-based battle-management computer in real time via high-data-rate, multiple-path microwave communications links.[6]

This sensor system would not have been possible at the time that the first U.S. ballistic missile defense system was designed. The Safeguard, deployed in a minimal way in the early 1970s, relied on large perimeter acquisition radar for its early warning and characterization of incoming missiles. These large, ground-based radar were regarded by most analysts as the weakest link in the Safeguard system, being very susceptible to countermeasures. The nuclear yields from the first antimissile warheads, for example, which were themselves nuclear, would have created large regions of the atmosphere opaque to the Safeguard's radar, making detection, guidance, and battle management impossible for the entire subsequent attack. The radar itself was large, fragile, and centralized, rendering it vulnerable to attack. Four new technologies, available only since 1972, have completely changed the situation. These technologies can be combined into a solution to the problems of assessment, trajectory prediction, and discrimination:

(1) *Long wavelength infrared sensor technology*. Using a cooled infrared telescope with a half-meter aperture and an array of extremely low temperature semiconductor detectors, new sensor technology is capable of detecting fuel tanks at 5,000 km and reentry vehicles at 3,000 km, and measuring their position with sufficient accuracy (in angle and velocity) to determine the most probable trajectory of the missile. These devices have been tested for their ability to survive probable nuclear war environment (the fireball, radiation, and shock waves from a nuclear blast) and have performed considerably better than theoretical predictions had indicated.[7] This technology is considered by experts to be well within the current state of the art, a fact not denied even by the opponents of ballistic missile defense deployment.[8]

(2) *Discrimination technology*. The ability to distinguish between an actually armed reentry vehicle, accompanying objects, and decoys designed to look like reentry vehicles is essential for successful ballistic missile defense. Since it is very cheap to saturate a ballistic missile defense with cheap missile look-alikes, an effective ballistic missile defense must have a way of concentrating its information gathering and destructive capabilities on the reentry vehicles. The long wave infrared spectrum emitted by an object traveling through the atmosphere is very closely related to the mass of the object. Thus, lightweight decoys lose their heat very rapidly (and so fluctuate in temperature more quickly) than the heavier reentry vehicles. The spectrum (or signature) of a lightweight decoy is thus very different from the signature of an actual reentry vehicle. This physical fact is very advantageous for the defense, because it means that the main advantage of a decoy—the ability to launch decoys cheaply and in great numbers because they are lightweight—is nullified by a sensing method dependent on the mass of the object. Detailed simulations and experiments have been conducted on the reliability of this differentiation and on the sensitivity of the discrimination to the weight of the object. All indications are that this technology is well within our grasp. Note that these infrared sensors do not rely on detection of the rockets' hot exhausts for discrimination, but on a property inherent to the difference between a missile and decoy.

(3) *Advances in computer technology*. The on-board computer for the probe must handle the problems of trajectory determination and discrimination for as many as 20,000 targets in its infrared telescope's field of view. This involves the analysis of instantaneous information on the three spectral bands monitored by the long wave infrared sensor and a determination of position. The velocity determination is more difficult, because the probe must be able to correlate data from consecutive scans by the telescope at 10 to 20 second intervals. New computer technologies have so increased the speed and reliability of the computers required for these kinds of calculations that it is now possible to design the circuits and configuration capable of performing the approximately 40 million instructions per second required.

The primary question remaining is that of producing the required computer at a weight of only a few hundred pounds. Existing commercial computers of this speed (but much more complex than would be required for the performance of the relatively few, repetitive calculations needed in the ballistic missile defense probe) weigh approximately 10,000 pounds. Experts in the computer field are confident about their ability to use large-scale circuit integration to achieve the factor of 10 to 100 in weight reduction required.

(4) *Communications technology*. The ground-based computers (battle management computers) exist commercially today with sufficient speed and reliability to function as control points

for a ballistic missile defense system. However, new technologies have been developed that solve the problem of communication of tremendous amounts of data between the probe (or probes) and the main computer. In an undisturbed environment, data exchange at the required rates is routinely achieved in many applications. In atmosphere disrupted by nuclear explosions, communication is much more difficult. New communications techniques have been developed in the past 10 years that allow for repetitive transmission, higher data compression on given bands, and multiple path transmissions. These technologies seem today to be capable of maintaining communications in all but the most severe environments.

In spite of these technological advances, there is, of course, no beam weapon existing in the United States today. The technologies required for the deployment of such a weapon up to the point of the guiding and firing of the weapon are well within our reach, as the preceding review indicates. This fact means that ballistic missile defense using other interceptors besides beams is possible. Although I do not review the evidence here for the deployability of antimissile systems, it must be emphasized that the warning, assessment, and discrimination technologies apply equally to nonbeam ballistic missile defense systems.[9] A reliable ballistic missile defense system would have to utilize a layered conventional system—one with separate capabilities to destroy ICBMs in outer space (exoatmospheric) interception and a low altitude system (endoatmospheric interception).

Such systems have been designed and face no technological barriers. However, the designers of these systems have said:

> Laser and particle beam weapons hold the potential for an extraordinarily effective defense of all national assets against both ICBM and SLBM [submarine launched ballistic missile] attack, but are in a very early stage of development. A well-funded five- to ten-year research program will be required to establish the technology base. These systems would be triggered by the satellite detection on launch of Soviet missiles and would reach out thousand of miles with pin-point aiming and tracking to destroy Soviet missiles in powered-flight or reentry vehicles in mid-course.[10]

Having determined the position and trajectory of the hostile missile or reentry vehicle, a beam weapon defense system must now solve the problems of aiming the beam, making sure that the beam hits the missile or reentry vehicle, delivering enough energy with the beam that the target is destroyed or disabled, and finally, assessing whether another shot against that missile is necessary or whether another object should be targeted. Each of these problems is uniquely difficult with a beam weapon and presents new features not encountered with other, conventional ballistic missile defense systems.

To aim the beam weapon at a target as much as 5,000 kilometers away (about 3,500 miles) is clearly an exceedingly difficult task. At this distance, the missile presents an image about .00003 degrees wide—the same as a piece of thread at 100 meters—while it is moving at approximately 20,000 feet per second! The accuracy of a tracking and aiming mechanism is measured in two ways, the angular accuracy of a fixed position determination (which primarily affects aiming ability) and stable tracking rates (which primarily affects the ability to follow a target). Current estimates are that the required angular accuracy for pointing can be achieved with existing optical systems. Experimental cameras already exist on civilian scientific satellites that can point to a region of the sky with the accuracy (.01 microradian) required of a beam weapon.

The angular tracking rates, however, have not been achieved. Technologies exist on the drawing boards (so-called fourth generation gyroscopes combined with optics having apertures less than 1 meter) that can achieve the factor of 10 to 100 improvement required for the tracking. According to Senator Malcolm Wallop, a Wyoming Republican, Lockheed Aircraft demonstrated a laboratory aiming and tracking mechanism using these technologies that exceeded the Defense

Department's requirements for accuracy and tracking by a factor of 4, a technological accomplishment finished in less than two years of concentrated work on the problem.[11] It is unclear from the open literature whether or not this experiment also achieved the required stability.

After much ink spilled by the opponents of beam weapons in the past several years about the impossibility of aiming these devices with the required accuracy, it is generally conceded that such aiming and tracking is relatively straightforward extrapolation of presently existing technologies and presents no fundamental difficulty to the perfection of a beam weapon. The opponents of beam weapons, especially of laser beam weapons, now concentrate their objections to the difficulties of propagating the beam to the target.[12] There are a number of interconnected variables that affect the ability of a beam to deliver its energy to the targeted missile. First, the beam weapon itself must generate a beam with enough energy not only to destroy the target but also to make up for losses due to transmission and imperfect absorption on the target. Second, the beam must have high enough power (that is, energy per unit time) that the targeted missile is disabled. Finally, the energy must be absorbed by the target so that its destructive effect results in the disabling of the target.

The chief critics of beam weapons, especially of first generation laser beam weapons contend that these three challenges cannot be met. For example, one critic has written that "The power of the laser would be almost a million megawatts, which is quite unattainable." Another such critic has said: "Unless a number of fundamental impediments to the use of lasers as weapons are overcome, the objectives set forth for laser weapon development could never be achieved. Several of the difficulties arise from the physics of the propagation of a laser over long distances." Finally, these critics claim that the required energy to destroy a target could not be reliably deposited on the target.

The ultimate consideration on the physical requirements for a successful beam weapon rests on the minimum energy required to disable a missile or reentry vehicle. This energy is in actuality quite small, especially in the boost phase of an ICBM when the mechanical stresses on the missile are at their maximum. Typical calculations show that the energy of fifty .45 caliber bullets would be sufficient to disable a missile—an energy density of approximately 1,000 joules per square centimeter in several pulses of a few hundred-millionths of a second. This energy results in several distinct kinds of damage to a target:

(1) *Indirect mechanical damage*. The main effect of laser energy on a target is a result of the generation of an exceedingly hot, energetic plasma as the matter at the target-air interface is ionized. The rapid expansion of this mixture of ionized target material and air creates a shock wave whose impulse can crack or puncture the shell of a ballistic missile.

(2) *Direct thermal damage*. The direct absorption of the beam energy in the form of bulk heating is the dominant mode of energy conversion for particle beam weapons and results in the melting, vaporizing, or pyrolizing of the target.

(3) *Ionization damage*. Intense electromagnetic fields are the dominant effect of the absorption of a microwave or plasma beam. These fields in turn create intense beams of secondary radiation, primarily in the X-ray region of the spectrum, as well as beams of secondary high-energy particles (in the MeV range). The collapse of the magnetic structures in a plasma beam, for example, generates high-energy ion beams that very effectively focus the energy from the plasmoid in a form readily absorbed by the target. The combination of the particle energy and radiation energy is capable of destroying electronic components at large distances and causing mechanical damage at the point of impact.

(4) *Thermomechanical damage*. There is a synergistic interaction between the damage caused mechanically and that caused thermally. The effect of several short pulses of a beam will, in general, be much greater than a continuous pulse of the same total energy, because as each pulse deforms the surface of the target, the heating and percussive effects of the succeeding pulse act on an already weakened target.

The damage threshold for a ballistic missile depends on the precise mechanism of energy absorption, but the order of magnitude for the energy flux required is the above figure of 1,000 joules per square cm. It has been claimed by some analysts that it is a simple matter to increase this threshold for damage to many times this value by the use of reflective coatings, fluid protection, or even the simple expedient of rotating the target to spread out the incident energy. An assessment of currently known protective technologies sets an upper limit of this threshold for very sophisticated protection of 10,000 joules per square cm.[13] Thus, as a rule of thumb, this figure must not be ruled out in beam weapon design, even though present-day missiles (against which the first beam weapons would be deployed) would be destroyed by a small fraction of this energy.

The solution of these three problems of power, energy, and absorption by the target are highly dependent on the type of beam weapon considered and each of the four types of beam weapons solves them differently. However, all of them appear capable in principle of generating the required power and energy in a form efficiently absorbed by the missile.

Laser Beam Weapons

A laser beam, the most widely publicized of the beam weapon family, consists of a beam of very intense, single wavelength electromagnetic waves (either light or high energy X-rays). The technologies for generating laser beams of the required energies and powers have been developed in a number of configurations, differing in the form of the energy source for the laser and the mechanism for releasing and concentrating this energy.

Four major types of lasers have been considered for beam weapon applications. The oldest of these is the gas dynamic laser, which uses a gaseous storage medium in which a burning gas is suddenly decompressed. The resulting energy distribution can be stimulated to emit single frequency light at high energies. The carbon dioxide laser is the most well-known example of this type of laser. Multi-megajoule lasers of this design are used presently in the nuclear fusion research effort in the United States and Japan. They produce a long wavelength laser pulse quite efficiently, but suffer from relatively low energy density fuel.

A chemical laser is similar to a gas-dynamic laser in that it uses a gaseous medium in which a chemical reaction is induced (for example the formation of hydrogen fluoride in the HF laser); the products from this reaction can then release laser light. Chemical lasers are already operating in the U.S. beam research program with energies of 2.5 megajoules, and a similar laser was used by the Soviet Union to down a ballistic missile in tests last year.

An electron discharge laser uses the replaceable energy from an electron beam to create the energetic medium required for the laser. The discharge laser has the great advantage that the energy source for the laser is not a chemical fuel that is used up, but rather the electricity that drives the electron beam. For this reason, the long-term most attractive laser for space deployment is the electron discharge laser.

Lastly, there are two kinds of more speculative lasers, which both promise tremendous advantages of energy density and flexibility, but which have not been technologically perfected, the X-ray laser and the free-electron laser. The X-ray laser has a solid energy storage medium and is "pumped" by the reaction products from a nuclear explosive. This type of laser uses the X-radiation from a small nuclear explosive to pump some heavy metal medium, which can then release its stored energy in a very concentrated, short pulse of X-rays. Such a nuclearly pumped X-ray laser was tested in 1981 by the United States, and since then many proposals for deployment of such a weapon have been discussed.[14] The idea of using X-rays (or neutrons) from a nuclear explosion as the initial source of energy is an old one, but the practical demonstration did not appear in the open literature until last year. The X-ray laser is capable of such high powers and such efficient missile destruction (because of the high absorption efficiency of the X-rays) that in spite of its engineering difficulties, it has been widely recognized as the most promising long-range laser for ballistic missile defense. The X-ray laser, although inherently single pulse, delivers thousands of times more energy per pulse than conventional lasers.

The free-electron laser is also still in a conceptual, laboratory stage. It uses an electron beam directly as its energy-containing medium and so is free of any of the difficulties associated with the maintenance and replenishing of a gaseous medium. The interaction of the electron beam with a rippled magnetic field provides a set of energy-containing modes that can store energy and be stimulated to release laser energy. In effect, the electrons are held in different energy states by the magnetic field, instead of the nucleus of the atoms as with the gas lasers. Theoretical predictions, borne out in initial experiments, offer the hope of achieving very high efficiencies (up to 30 percent) and great flexibility in frequency tuning (a unique feature) in a laser that can be fired without a recharge of the excited medium.

Each of these lasers has distinct advantages depending on the defensive missions for which they are deployed. The chemical lasers have the great advantage that they can built today, have already been successful in proof-of-principle experiments of the destruction of ICBMs, and present no formidable unknowns. However, they suffer from two distinct disadvantages. First, because they require a continuous fuel supply (the chemicals that provide the energy that the laser concentrates), they are difficult to scale to higher energies. Thus, a chemical laser is limited by the economics of fuel transport to earth orbit for space-based lasers. Ground-based chemical lasers, of course, do not suffer from this difficulty, and the Soviet Union seems to be concentrating heavily on such ground-based chemical lasers for missile defense, antisatellite capabilities, and ionospheric modification experiments. This problem is not overwhelming, but it puts distinct limits on the extent to which a chemical technology (with its inherent limits on energy density) can be scaled up to larger and more efficient weapons. Second, all optical frequency lasers (that is, all except the X-ray laser and the free electron laser) require large, sophisticated optics for targeting. For visible light lasers, the Defense Department is planning to use a 10-meter (33-foot) diameter mirror for the targeting and focusing of the beam. This mirror not only must be perfectly ground and polished but also must be able to withstand irradiation by the laser. Such mirrors (of sizes up to 5 meters) are under construction, and new advances in mirror fabrication and analysis have occurred so rapidly in the past five years that there seems little doubt that mirrors of the required quality, thermal stability, and durability can be built.[15] United Technologies is so confident of the present mirror technologies that it has offered a fixed price bid for the construction of a 10-meter mirror.[16]

The X-ray laser avoids the necessity of both the bulky power source and large optics. By using a small nuclear charge to pump the lasing material, the X-ray laser takes advantage of energy densities millions times greater than the chemical laser, and even though it achieves efficiencies much less than .01 percent, it delivers such high power densities that each pulse is sufficient to destroy a target. There is no question of dwell times caused by low power densities. Similarly, the targeting options for the X-ray laser depend on totally nonoptical technology. Since X-rays cannot be efficiently reflected or refracted, the collimated beam of X-rays must be generated in a medium that is already aimed at the target. Tests on targeting and acquisition are currently in progress at the Nevada underground test site. Current design for X-ray laser ballistic missile systems envision a space-based satellite, containing both the X-ray laser and the long-wave infrared sensors. The power density of the nuclear charge is so great that experts estimate that enough X-ray satellites to deal with a massive missile attack could all be fit in a single Space Shuttle payload. Each "battle station" would consist of a single nuclear charge laser pump, up to 50 lasing rods (which function simultaneously as lasers and pointers), and sensing equipment. After target acquisition, the nuclear charge would be detonated, generating 50 independent pulses of X-rays; the battle station, of course, would be destroyed.[17]

All laser beam weapons must also deal with the problem of propagation of the beam to the target. This is a complex question involving the interaction of a host of physical and atomic phenomena, the optical properties of the beam, and its targeting system. In general, there is a close relation between the wavelength and power of the beam and its ability to propagate through the atmosphere—the longer the wavelength the easier it is for a beam to travel through the atmosphere. Thus, the chemical lasers are ideally suited to endoatmospheric missions, and have, indeed, been the prime contenders for ground-based systems that do not require extremely high power levels. Studies show that contrary to the very pessimistic statements by opponents of laser beam weapons about the insurmountable difficulties of propagating a laser beam through the atmosphere, a ground-based laser system could operate at long wavelengths and deliver up to 80 percent of the initial beam energy on target.[18] These studies looked at the very attractive idea of area ballistic missile defense using a chemical laser based on a mountain 3 km high, which uses an orbiting mirror for beam direction. The beam transports more than 80 percent of its energy to the mirror.[19]

The short wavelength systems, especially the X-ray laser, are almost certain to be restricted to the space-based modes. All lasers, of course, benefit from the lack of absorption, interference, turbulence, thermal distortion, and climate-dependent effects of the atmosphere, but for very short wavelengths, the high vacuum of space seems a prerequisite.

Given these considerations and the state of technological development of the optical and power systems, there is not a competent scientist who doubts that a laser weapon capable of destroying an ICBM can be built. This is not an obvious statement even though a laser has been used to destroy an ICBM in flight, for in the context of Western military strategy, the question is primarily not one of scientific possibility, but rather advisability. It is critical to understand that the most important objections to beam weapons, especially laser weapons, are political and military, not scientific.

Particle Beam Weapons

The situation with particle beam weapons is less clear-cut, since no missile has been downed by a particle beam, the guidance and targeting questions are more difficult, and the physical processes involved are less well understood. Particle beams thus introduce a new set of problems to be considered, as well as a much larger array of solutions from which to choose. The number of degrees of freedom in the deployment and development of particle beams is correspondingly larger.

As a defensive weapon, particle beams share the same basic advantages that a laser beam does; particle beams deliver energy in a highly controlled pulse traveling at near the speed of light. However, instead of consisting of a pulse of intense electromagnetic radiation, a particle beam is made up of one of three kinds of particle-carrying mass: subatomic particles, specifically electrons or protons; neutral atoms (usually hydrogen) traveling at near the speed of light; or macroscopic particles (usually magnetized) that are accelerated to speeds that, while not strictly relativistic, are many orders of magnitude faster than the motion of any other macroscopic assembly of matter ever produced.

A particle beam carries it destructive power by creating an intense shock wave in the target. Especially in the case of a macro-particle-beam weapon, the physical impact of the particle beam on the target acts like a very small, very powerful hammer. The electromagnetic and plasma effects exist, but are usually overshadowed by the simple transfer of kinetic energy that occurs when the target is slammed by a particle beam.

The acceleration mechanism for all three types of beams is conceptually similar, although the engineering implementation is vastly different: A magnetic wave is used to "push along" the particle. The magnetic wave stores energy from some electrical power source and transfers this energy to the particles. The implementation of this magnetic wave acceleration mechanism varies in form, depending on the particle being accelerated.

(1) *Electron beams.* The oldest and easiest beams to generate, electron beams are now routinely generated in the range of millions of electron volts, millions of amperes of current, and power densities inside the beam of trillions of watts per square cm.[20] This intense energy is converted to electron motion through some modern enhancements of the very old idea of electron acceleration used in any vacuum tube. However, the energy becomes concentrated in the beam because of physical mechanisms that were unexpected at the time that large-scale electron beams were proposed for various uses, particularly nuclear fusion and beam weapons.

The surprising fact, discovered by a number of scientists, is that an intense electron beam is not merely a stream of particles; rather it spontaneously generates a complex, internal structure that greatly increases the stability, propagation, and intensity of the beam.[21] Scientists have found that the electron beams of the order required for a beam weapon actually increase their own intensity by forming into a tightly bundled sheaf of separate beams. These beams propagate together in a "protective shell" of their own magnetic fields, which keep the vortex structure tied together (like a barber pole), and which concentrate each individual beam. These structured beams can then carry higher currents and more energy longer distances at greater power levels. It is important to note that the beam is in effect magnetically shielded by its own magnetic fields. An electron beam is not actually a beam of individual electrons but rather a complex structure of electrons and magnetic field.

(2) *Proton beams.* Proton beams have been a subject of intense research, especially in the Soviet Union, for the past 30 years. These require an electron beam as a "seed" and then are accelerated in their own right. Several new technologies for proton acceleration have been discovered in the past 10 years. The one that has attracted the most interest is a type of collective acceleration that uses an electromagnetic interaction to accelerate the protons to the same velocity as the electron beam seed. Since the protons weigh almost 2,000 times as much as the electrons, having the same velocity means that they have 2,000 times greater energy. This remarkable property of the protons to acquire energy from a magnetic field, so as to "keep up" with the electrons as they propagate down an accelerator chamber, results in proton beams of very high quality (uniformity of energy, energy density, and so on) that form to large extent "on their own." The main lines of research being pursued in the United States take advantage of one form or another of this collective acceleration technique; however, power densities are considerably lower than the more mature technologies of the relativistic electron beams.

(3) *Neutral particles.* Many of the problems of charged particle beams arise because of the electrical and magnetic forces that exist in the high particle densities of the beams. Electrostatic repulsion of the charges in the beam, deflection in the atmosphere, electric forces between the particles and the background atmosphere, and the like, all degrade the efficiency and controllability of the beam. While a number of exciting new technologies are coming into existence to deal with these problems, [22] a natural solution is to use neutral particles. The idea has been realized in several forms, the most promising and well-funded being a neutral beam of hydrogen atoms. It is not possible today to accelerate directly neutral atoms, so the atoms are first ionized and then electrically or collectively accelerated. These accelerated particles are then passed through a dilute background gas and neutralized. This technology arose first (like most technologies relevant to beam weapons) as part of the fusion research program, where high density neutral beams are used as auxiliary heating for magnetic fusion devices. The neutral beam for beam weapons poses several additional problems that are now being researched: achieving higher energies, collimating and controlling the beam for long propagation paths, and siting in earth orbit. By spring 1983, U.S. researchers will have produced a beam of protons at an energy of 2.5 MeV (at this energy, protons are moving at 99 percent of the speed of light) as the first step in the large-scale testing of particle beam weapons in the United States.

(4) *Macroscopic particles.* In a series of provocative papers, several physicists have proposed that the same basic "magnetic wave" acceleration technique be applied on a macroscopic

scale for the acceleration of "bullets." The idea of a rail gun—a magnetic track much like a linear induction motor—as a macroparticle accelerator has been studied for applications as diverse as space propulsion, magnetically levitated trains, inertial confinement fusion research, and weapons. These devices use a magnetic field to push particles (or trains, and so on) down a track, much the same way that the exhaust gases from a conventional shell push a bullet down the barrel of a rifle. Replacing the exhaust gases is a magnetic field capable of generating much higher pressures and consequently much higher velocities. These rail guns can be built with efficiencies of conversion from magnetic to kinetic energy of nearly 90 percent and with terminal velocities of many times the speed of sound (up to 50 km per second).[23]

According to U.S. weapons researchers, the Soviet Union has a massive program devoted to the application of these technologies to the development not only of antiaircraft and perhaps antiballistic missile systems, but also also antiarmor weapons, antiship weapons, and even handheld antipersonnel weapons. There is no known armor that could withstand even a small projectile moving at these velocities, because the percussive force of a particle at that velocity depends on totally different mechanisms from those that pertain at normal subsonic or supersonic velocities. As a weapon for ballistic missile defense, macroscopic particles present some unique difficulties (time of flight is no longer neglible, and control and targeting are more difficult, for example) but they offer unparalleled power densities because of the large mass of the particle. The same consideration that makes the proton or neutral beam preferable to an electron beam—that the particles are heavier and easier to control (compare a shot gun and rifle)—makes a macroparticle beam very attractive.

The kill mechanism of a particle beam is directly related to the mass of the particle in the beam. Light particles, like electrons, affect the target in a way that resembles a laser (which has zero mass "particles"). Electromagnetic and plasma effects combine to cause the mechanical destruction of the target. For heavier particle beams—and more specifically, for macroparticle beams—the destruction of the target is a mechanical effect. The beam deposits its energy on the surface as a series of shock waves. Macroparticles enhance this effect greatly by providing new, highly energetic mass to the system. Like a shaped charge, this mass can provide a second plasma jet that penetrates the heaviest surfaces in a most destructive way. Remembering that an ICBM and a reentry vehicle are both delicate pieces of machinery, the sort of massive destructive capability of a heavy particle weapon is very effective even in the most demanding encounters.

Microwave and Plasma Beam Weapons

Until two years ago, directed energy beam weapons were exhausted by a discussion of laser and particle beams, at least in the West. However, the Soviet Union was pursuing aggressive research in at least two other types of beam weapons. The first of these uses high intensity beams of microwaves as the means of destroying a target. Such beams, if they could be directed and focused, would very efficiently destroy delicate electronic equipment, and, depending on the energy levels achieved, ignite chemical explosives (in the trigger of the nuclear weapon, for example), or even cause mechanical failure.

The technology for generating extremely high intensity microwaves was developed only in the past decade when it was discovered that relativistic electron beams propagating though a plasma can generate intense, directional microwaves. These microwave sources provide intensities many orders of magnitude greater than those associated with radar, the traditional military application of microwaves. This technology is being studied in a number of U.S. laboratories, and it is known that the Soviet Union has a much larger research program in microwave beams. Most researchers estimate that the Soviet Union is two to three years ahead of the United States, not only in the production and propagation of microwaves but also in the understanding of the interaction of intense microwaves with matter.[24]

Plasma beam weapons portend an even more profound reorientation in our understanding of the potential of beam weapons. A plasma beam consists of the highest energy density form of matter, a gas so hot that the electrons and nuclei have been separated and the "gas" is made up of electrically charged particles and the electric and magnetic fields they generate. This so-called fourth state of matter quite naturally forms into complex structures of particles and magnetic fields, which are spontaneously created and quite stable. One of these, shaped like a donut, is called a *plasmoid* and is the most frequent form of spontaneous plasma-field structure. It occurs naturally in the form of ball lightning and has been reproduced many times on a small scale in the laboratory.[25] Plasmoids are contained by a toroidal magnetic field that spirals around the donut and reconnects with itself. This magnetic field simultaneously confines and insulates the plasmoid. Contrary to other beam weapons, for which the atmosphere is a hindrance to the guidance and propagation of the beam, the plasma beam could not exist without it; it requires something to "push against" to hold in the plasma. These plasma blobs are exceedingly stable given their energy density, with lifetimes measured in seconds. The exact physical mechanism involved in this family of closed field structures is the subject of heated debate within the Western scientific community with most Western scientists expressing profound skepticism concerning the significance or even existence of the phenomena.

The Soviet Union, on the other hand, has had a major research program in plasmoids since the middle 1950s when the first plasmoids were produced at Lawrence Livermore Laboratory in California.[26] A review of Soviet research on ball lightning lists literally hundreds of experimental projects devoted to the subject.[27] The Soviet research in this area has been well funded and has attracted the highest levels of Soviet scientific interest, including P. Kapitsa, the Soviet Nobel laureate. Recent intelligence reports indicate that the Soviet Union is now conducting large-scale propagation experiments involving the generation of high energy plasma beams. The appearance at regular intervals of a high frequency radio signature typical of plasmoid experiments has been interpreted by European intelligence agencies as striking confirmation of the practical application of the long-term Soviet interest in plasma beams.

The first public indication of serious interest in such a device in the U.S. military literature appeared in a very interesting article by two scientists from Lawrence Livermore National Laboratory in the April 5, 1982 issue of *Physical Review Letters*.[28] The article discusses possible applications of a "collective accelerator based on magnetically confined plasma rings." These rings are the plasmoids seen by many researchers using different kinds of plasma guns, and they have been theoretically shown to be a very low free energy state (and hence stable state) of high internal energy. The rings spontaneously generate a large, force-free magnetic field (so-called because it confines the particles without leaving a residual unbalanced pressure in the plasma), which simultaneously confines the plasma and stores up to 10 kilojoules of magnetic energy.

These rings can then be accelerated, by methods similar to the magnetic wave method used for other accelerators, to energies of up to 10 megajoules in lengths as short as 100 meters. That is, the hypothetical accelerator described in the article would be capable of generating a very high energy plasmoid moving at approximately 1,000 kilometers per second. The question of the propagation of such a plasmoid through the atmosphere over militarily significant distances is not addressed in the article, but it is not ruled out a priori. These rings would constitute an almost ideal plasma weapon. They carry high energies, are stable, and can be accelerated to very high velocities. It is not known if this is the same configuration used by the Soviet Union in its experiments, but the interest on the part of the Soviet scientific establishment in smaller scale applications of the ideas is well known.

Speculation on the guidance and targeting of such a beam is difficult. That such structures can propagate long distances through the atmosphere is known from observations of ball lightning, but the physical principles governing ball lightning have not been unraveled. Thus, the parameters for technological manipulation of the properties of a plasma beam weapon are difficult to estimate.

3. The Science of the Beam Weapon

An engineering analysis shows that beam weapons for ballistic missile defense can be built. The problems of detection, discrimination, target acquisition, beam generation, and target destruction are all within our scientific and technolgical capabilities. Even for a chemical laser beam weapon, which is not "off-the-shelf" technology, there is no question that such a weapon could be built in the next five years with technologies available today.

Despite this engineering certainty, the beam weapon confronts us with a host of fundamental scientific questions as soon as we demand a detailed understanding of the scientific basis of beam generation and propagation. It is certainly a historically commonplace occurrence for man to perfect a technology whose scientific basis remains obscure for many generations after the technology is in practical use. The steam engine preceded the discovery of thermodynamics by at least 150 years; the use of X-rays preceded their theoretical description by several decades; and animal breeding was used long before genetics was understood in even the most rudimentary way. The practical problem whose solution demands a new technology may have a greater long-term impact because it raises a challenge to accepted scientific dogma. This was certainly the case with discovery of X-rays; by forcing the paradoxical phenomena of radiation before the eyes of a scientific community steeped in the complacency of Maxwell's etheric theory, the technology of Roentgen's X-ray tubes was a major aspect of the revolution that led to quantum mechanics and relativity theory.

Beam weapons pose a similar challenge to present-day physics. Contrary to accepted opinion, a host of fundamental scientific problems is raised by physical phenomena occurring in the energy-dense regimes necessary for beam weapons. For more than 100 years, science has been working from the ideas of the German classical school of mathematical physics—Leibniz, Gauss, Weber, Riemann, and their successors. The major discoveries of the past period all derive from the results and method of these scientists, but this method has been attacked with increasing success over this period by the British or Newtonian school, with the result that the most essential tools of continuum mechanics and Riemannian global geometry are used in the West in the only the most rudimentary way.

The Newtonian Vs. the Riemannian Method

The divergences between these two approaches are central to the question of the science of the beam weapon:

(1) *The question of energy*. Conventional Newtonian or Maxwellian physics defines energy as an internally measurable, conserved, scalar quantity. The role of energy in the evolutionary properties of various beam weapons systems makes this assumption of scalar energy measure untenable. Newton's original opponent on the question of the nature of energy, Gottfried Leibniz, defines a dynamic, directed concept of energy much more adequate to deal with the nature of energy than the Newtonian atomic one, but the mainstream of Western science has rejected the Leibnizian formulation. The experimental evidence already gathered from high energy plasma physics poses a fundamental challenge to this Newtonian idea.

(2) *The direction of evolution in physical systems*. The most fundamental assumptions of the modern physics insist that changes with time in a physical system are the result of the summation of microscopic dynamics; particle-by-particle interactions "add up" to the global behavior of a physical system. As a consequence, the quality of this global evolution is statistical and random

in a systematic way. Even the most avant-garde of the proponents of a so-called nonreductionist formulation of physics, like Ilya Prigogine, begin with this Newtonian fact. The behavior of high energy plasmas (like those in a beam weapon) overthrows this premise in a rigorous way. Beam weapon experiments present striking evidence of an inherently global kind of causality that directs the microscopic evolution of a physical system but is not reducible to microscopic interactions. This invariant quality is a negentropic, developmental direction to physical evolution that appears in a dramatic form in high energy beam weapons.

On the one hand, failure to recognize the fundamental scientific challenge posed by the new physical phenomena characteristic of beam weapons leads supporters of beam weapon development to underestimate the long-term economic and technological impact of beam weapon development. They fail to see the qualitative changes implied by the perfection of a technology based on a physical theory as different from conventional physics as the quantum mechanical revolution (and its technological descendants like lasers and transistors) was from the Maxwellian physics before it (with its technologies of electric motors, resistance lighting, and so on).

On the other hand, failure to recognize this fundamental challenge by opponents of beam weapons leads them to try to assess the scientific and technological feasibility of beam weapons on the basis of totally inadequate physical considerations. The attempt by a physicist who does not understand the implications of these new experimental results in plasma physics, to project the behavior of a beam weapon is ludicrous—and disproved as imperiously by the existence of these new phenomena as were the theories of the impossibility of ballistic missiles 30 years ago.[1]

The debate implicit in an examination of the scientific basis adequate to describe beam weapons has been at the center of an intellectual and policy fight up through and immediately following World War I. This debate pitted the followers of the Newtonian atomistic tradition against the followers of the Leibnizian hydrodynamics school. The final round of that fight in the West was concluded when Bertrand Russell conducted a successful attack on the two most important modern representatives of the Leibnizian school, Georg Cantor and Bernhard Riemann.[2] Russell identified the central nature of the Leibnizian school as its commitment to the "Platonic" idea of nested manifolds connected by a negentropic invariant, and against this he defended the radical Newtonian idea later formulated in his *Principia Mathematica* that all phenomena are reducible to fixed, atomistic (and logical) structure.

This debate, now largely unknown among Western physicists, is not an academic question. On the one side, the information most subject to immediate classification are those results of Riemannian physics that threaten the intellectual hegemony of the Newtonian idea. In case after case, the methodological and mathematical tools of the Riemannian school have been kept hidden by the supporters of the Newtonian school (we review the most egregious case below). On the other side, the Soviet Union has based large parts of its physical research on beam weapons on an at least implicit understanding of the hydrodynamic method. The education given Soviet physicists, the design of experiments, and the originality of Soviet theoretical work in continuum mechanics all are evidence of a generally recognized methodological divergence between Western and Soviet science. What is not generally understood is that this methodological difference derives from the fact that the mainstream of Soviet science is in the Riemann-Leibniz tradition, while the mainstream of Western science is in the Newtonian one.

The defense of the Newtonian position in this fight reached absurd proportions in 1976, when British military intelligence classified the experimental work of a Soviet physicist! Leonid Rudakov, the director of the Soviet electron beam fusion research program (and a leading contributor to the Soviet military beam weapon program and inventor of several critical technologies in electron beam production), visited several U.S. weapons laboratories in summer 1976. His lectures at Los Alamos National Laboratory and Lawrence Livermore National Laboratory created great interest among American scientists, because he addressed one of the several central problems in the interaction of high energy beams with matter—the production of soft X-rays. This topic, although at a lower level of elaboration, was studied in the United States and the results were classified. Rudakov presented new results, not previously known to the American researchers. At the instigation of the British military intelligence, Rudakov's lectures were classified here by the U.S. Department of Energy, and they and remain classified today.[3]

The non-Newtonian phenomena characteristic of all phases of beam weapon research are typfied by two general classes of physical effects. These effects occur over and over again in different manifestations in the production and propagation of beams. Ordinary common sense, and its formalization in theoretical physics, expects that highly energetic systems will not differ in any essential way from lower energy systems. Thus, the most basic property of normal, inert matter—that it decays or loses order over time—should be characteristic as well of highly energetic states. This concept is the content of the Second Law of Thermodynamics; a complex system, left to itself, will "run down."

However, energy dense systems, with or without energy flowing into them, frequently behave in a directly opposite manner. They will increase their structure; they will become more differentiated rather than more homogeneous; they will concentrate energy on their own. The tendency of high-energy density systems to form large-scale structure spontaneously is a well-documented and highly controversial aspect of continuum systems. The formation of complex vortex structures, solitons (discrete concentrations of energy or particles out of originally almost uniform distributions), and almost singular electric or magnetic field structures, are all evidence of behavior for which the Second Law of Thermodynamics is either irrelevant or incorrect.[4] The spontaneous formation of large-scale structure, in fact, is the dominant feature of evolution in high energy density systems.

One class of these large-scale structures is especially important in determining the quality of evolution that a system with high energy density will undergo. Shock waves, first discovered by Bernhard Riemann,[5] are conventionally studied as merely another form energy propagation in a continuum medium, the nonlinear form of a normal wave. The actual significance of shock waves, which Riemann implicitly recognized in his paper, is that they are a means by which a system changes state. That is, the imposition of energy on a system will generate large-scale structure, as noted above. This self-organization of the system results in dramatic concentrations of energy and, among other things, shock waves. These shock waves, in turn, can transform the medium, inducing qualitative and singular change in the laws governing that medium.[6] The property of shock waves as means for achieving a change in the equation of state is the key to understanding their physical significance. They are the singular phenomena that change the Riemannian manifold.

A shock wave, over and over again, appears as the causal physical phenomenon in high energy beam experiments. In the generation of pulsed power for a beam, in the creation of the beam, in the propagation of the beam, and in the destruction of a target by a beam, shock waves not only carry the energy of the interaction, but do so in a form that results in a change in the qualitative properties of the system. A shock wave is the quintessence of energy as a nonscalar quantity, as a director of evolution.

Scientific Problems of Beam Weapons

The scientific challenges posed by beam weapon development occur in four areas of beam research: pulsed power production, beam generation, beam propagation, and target destruction. In each of these fields, the frontiers of physics are being pushed by the results from the development of beam weapons.

One of the persistent problems in the scaling of beam weapons to higher and higher energies is that of generation of a sufficiently large pulse of electricity to fire the beam. In the case of some lasers, particle beams, and plasma beams, electrical energy in a discontinuous form is needed. Present-day high power lasers, for example, concentrate more energy into a pulse for a billionth of a second pulse than the rest of the world uses during that billionth of a second! The technology for electrical power production has traditionally been concerned with producing steady, low power currents, and the inherently more difficult problem of pulsed power has been intensively studied only in the past two decades.

The most natural approach to the problem of pulsed power production, and that most intensively pursued in the United States, is to develop technologies for the concentration of energy and to derive the energy itself from the conventional low power electricity sources. Fly wheels (in several different forms), inductive generators, and capacitor banks have all been perfected as means of storing energy from the commercial power grid by slow accumulation, and then suddenly switching this energy in a sharp pulse. The technologies are not pulsed power producers, but rather energy storage or concentration mechanisms. They suffer from several insurmountable problems in their application to beam weapons: Commercial power sources will not be reliable during wartime, so that the existence of line voltage used to charge the capacitor banks, or the line currents used to spin up inductive storage systems, cannot be counted on. Second, the time between pulses can be very long, depending on the available power and capacity of the machinery. In every case, the recharge time between pulses is measured in minutes; this means that the beam could not be fired any more rapidly than the pulses could be generated. In an actual ballistic missile defense situation, this delay would be intolerable.

In addition, each of these technologies is inherently low power per unit mass. That is, fly wheels, inductive generators, and capacitors all require large masses of material to store energy so that the final energy per unit mass is quite small. Thus, for the space-based systems, mobile units, and ship-based units, some other technology must be found. This last feature of conventional pulsed power systems is not a problem, of course, for large, ground-based ballistic missile defense systems. These problems have led some analysts to conclude that beam weapons are unrealistic because they could never be fired.

To solve this complex of problems, two technologies for the production of pulsed power have been devised. These technologies, all the specialties of Soviet laboratories and originally designed by Soviet scientists, allow for the creation of energy in a concentrated form to begin with, and thus inherently overcome the problems of low power density concentrators.

Pulsed MHD Generators

In 1962, at the First International Conference on Magnetohydrodynamics, held in England, two prominent Soviet scientists announced that their country had embarked on a program to develop a revolutionary new technology for electricity generation. They outlined a four-phase effort, which they predicted would yield a commercial technology by the early 1980s. This new technology, called magnetohydrodynamics, or MHD, has since been aggressively pursued by the Soviets—in both military and civilian spheres. Today the Soviet Union operates an experimental 25-megawatt electrical power plant using MHD in Moscow (it supplies enough power to run the Moscow subway system) burning natural gas, and they have a pulsed MHD generator for beam weapons testing using small nuclear explosives as the power source.

MHD is an ideal representative of plasma technologies, the new frontier of industrial, power, and military technologies opened up by beam weapon development. All matter above 5,000 degrees leaves the normal, non-electrically-charged gaseous state, and becomes a plasma, a "gas" made up of electrically charged components of the original gas. In one sense, the plasma is a "gas" of electrons and nuclei; however, there is almost no similarity between a plasma and a normal gas, because the electrical and magnetic forces generated by the charged particles in the plasma change the properties of the plasma in a qualtiative way. Even the low temperature plasmas of everyday life (like flames, neon signs, and the like) are extraordinary states of matter.

The new potentialities of the plasma state are the result of the ability of the electrical and magnetic fields generated by the plasma itself to contain energy. A normal gas can store energy only in the form of heat (a random motion of the gas particles) and sound (organized motion of the gas particles). These are the only two "modes" in which a gas can receive or give energy. However, a plasma has literally thousands of modes of energy containment. In the simplest, the particles exchange energy of motion with an electric field; in more complicated ones, organized motion of the particles interacts with changes in the electrical and magnetic fields.

The results of this incredible richness of energy behavior is that a plasma cannot really be studied as a collection of particles and fields; rather, it behaves as a new entity that in some essential way is more complex than any collection of simpler pieces. MHD takes advantage of these properties to create an electrical generator with no moving mechanical parts that is capable of efficiencies more than twice those achievable by conventional technologies, and able to convert heat directly into electricity. The critical idea of an MHD generator is the simple fact that electricity is moving electrical charge; so is a plasma. MHD uses the internal properties of the plasma to organize that charge in motion to generate electricity.

When a plasma moves through an external magnetic field, the plasma will generate a uniform electric field perpendicular to the magnetic field. This unique plasma phenomena in effect is turning the motion of the plasma into a steady electric field. If this electric field is connected to a load (like an electrical power grid), electrical energy is taken from the plasma with a high degree of efficiency (of up to 60 percent of the plasma's heat energy can be extracted as electricity). This remarkable property is the result of the unique, self-structuring behavior of a plasma. The same effect (called the "Hall Effect") is responsible for a number of other remarkable features of a plasma, including the fundamental physical basis for the plasma beam weapon discussed above.

A reactor using these principles is now generating on a significant scale in the Soviet Union. Called the U-25, this device creates a plasma by burning natural gas, passes this plasma through a very intense magnetic field, and extracts electrical energy. The United States is no longer pursuing research in this area, after budget cuts in 1980, 1981, and 1982 reduced the federally sponsored MHD research to zero.

The Soviet Union successfully accomplished the first three phases of their 1962 program, and expects to have a large (1,000-megawatt) MHD plant in the next several years.

It should be clear that the five-year lead that Soviet Union has in the technological development of MHD would have also been put to military use. A very revealing paper on precisely this topic appeared in the April 1974 issue of the Soviet Journal *Atomnaya Energiya*, titled "MHD Conversion of Energy from Pulsed Thermonuclear Reactors," written by one of the most famous of Soviet plasma physicists, E. P. Velikhov.[7] In this paper, Velikhov and his coworkers outline the several options for the use of MHD to convert the tremendous energy of a small nuclear bomb to electricity. Their most advanced design, which Velikhov called an "inductive MHD reactor," involves the extraction of 15 billion watts (15,000 megawatts) from a huge, steel, dumbell-shaped chamber that encloses the nuclear explosives. This radical suggestion was ignored in the United States until late in 1977, when General George Keegan, then head of Air Force Intelligence, announced that satellite photographs showed that the Soviet Union was constructing a large pair of steel chambers, deeply buried in a rock cavity. The fabrication of these 70-foot diameter spheres with 13-foot thick walls was a monumental feat itself, beyond the capability of American technology then or now.

These suggestive data were made even more serious by the announcement the next year by the Swedish radiation monitoring service of a series of radioactive releases from the area of the same Soviet military testing ground at which the chambers had been fabricated. These radioactive releases contained isotopes of molybdenum, which had never been seen before in the debris from a nuclear explosion. However, just such isotopes would be expected from an advanced MHD experiment of the type outlined by Velikhov. According to authoritative sources, these releases have continued sporadically for the past three years.

There is only one plausible use for such huge quantities of energy in a pulsed form—the generation of beam weapons. The controlled extraction of pulsed electric power from a nuclear explosive is an almost ideal energy source for plasma and particle beam weapons in which large, repetitive bursts of electricity are required. It is ironic that the original impetus for the Soviet MHD program came from their intense interest in the development of nuclear fusion, the plasma technology for energy production by fusion of hydrogen. This advanced form of nuclear energy is a natural candidate as a heat source for an MHD generator, since the exhaust products of the fusion reactors are a very high temperature plasma that must be cooled first if conventional electrical generation technologies are used. The uncontrolled form of nuclear fusion, the hydrogen bomb, was proposed by Velikhov as the first form of fusion energy for MHD! Only by pursuing the frontiers of physics in fusion research was the idea for pulsed power production for beam weapons solved; in turn, the military solution will open up roads to the civilian power production that would never have been tried otherwise.

There is little question that advanced MHD figures largely in the Soviet beam weapon program. The United States does not conduct MHD research on a governmental level, although there are several private companies with innovative but small MHD research programs. One significant report of U.S. pulsed MHD power research was made public in 1981, describing the use of conventional explosives to generate hundreds of megawatts of electrical energy using a pulsed MHD generator. The scientific challenge of the plasma physics of pulsed power production by MHD was summarized by the chief scientist of the project, who said: "The pulsed plasma MHD generator operates in a realm of plasma physics that is not well understood, and early experimental results were a factor of 10 off the expected results. [But] at present, there is no competitive approach to generating gigawatts of power in something you can hold in your hand."[8]

Flux Compression (Liner) Generators

The Soviets have pioneered work in a second technology of pulsed power production that they believe to be a competitor to pulsed MHD, a technology called magneto-accumulative generation. The Soviets have constructed a second beam weapon laboratory to study this technology, at a test site near Kazakhstan in the southern Soviet Union.[9] Satellite photographs show that approximately two years after the initiation of the pulsed MHD experiments at the Semipalatinsk test site, construction began on a completely different design of pulsed power generator. Detailed satellite photographs revealed a beam generator of some sort (opinions are divided between a large chemical laser and electron beam) powered by a complex switched set of 12 explosively driven electrical generators. The construction, begun in November 1979, was essentially completed a year later.

The 12 explosive generators most probably use a technolgy intensively studied in the Soviet Union for many years in connection with their nuclear fusion research program—imploding liners. The basic physical principle involved in these devices is the unique properties of a highly magnetized plasma that make it resemble a highly elastic fluid. Because the plasma generates its own magnetic field, a magnetic field trapped in the plasma cannot disappear; it is imbedded in the plasma. If the plasma is compressed, the magnetic field will also be compressed. The plasma here demonstrates in a dramatic way its bizarre physical properties; no matter how much the plasma is compressed, it is constrained by its internal geometry to retain the same amount of magnetic energy. A physical compression of the plasma results in a compression of the electromagnetic energy of the magnetic field.

The idea of the liner experiments uses this physical fact to achieve "flux compression," the intensification of a magnetic field and its energy density by means of physical compression of the plasma that has trapped the magnetic field. The most efficient technique for this, developed by the Soviet Union and applied to the generators seen at Kazakhstan, is to propel a small amount of magnetized plasma into a metal cylinder called a liner. This metal cylinder is then compressed using conventional explosives, a plasma compression technique, or pistons. As the liner crushes the enclosed plasma, the magnetic field in the plasma is also compressed, generating tremendous electromagnetic fields. At the conclusion of the compression, the whole assembly explodes in a tremendous pulse of electromagnetic energy.

This idea, first proposed as a means of achieving the high temperatures and densities required to ignite a nuclear fusion reaction, meets one major stumbling block: What is to be done to prevent the plasma from squirting out the ends of the cylinder when the liner is compressed? The Soviet solution to this problem is to use a naturally structured plasma (which contains itself) for the initial plasma to be injected into the liner. Plasma rings—like smoke rings but with internal, twisted magnetic fields that hold the ring together—are just such structured plasma entities. Plasmoids of this class (similar to the ones used in plasma beam weapons) all consist of a toroidal combination of magnetic and electric fields, as well as a toroidal current flowing through the ring. This arrangement of parallel currents and fields has been known for many years to represent a very stable state of a plasma,[10] but its truly remarkable properties have only recently begun to be appreciated in the West:

(1) *It occurs naturally in almost all plasmas with magnetic fields.* This plasma vortex ring, in a certain sense, is the most natural mode for the plasma to contain magnetic energy, and the plasma spontaneously seeks to achieve the plasma vortex configuration if the boundary conditions (the external walls of the experimental chamber, the type of plasma generator, or the relation between initial current and fields) allow it. There is very good evidence that any magnetized plasma, left to itself long enough, will "settle down" into this plasma vortex. Such plasma vortices (or their cylindrical relatives) have been seen in astrophysical plasmas, the ionospheric plasma, laser created plasmas, low density laboratory plasmas, and explosively created plasmas.[11]

(2) *The resulting plasma structure is stable in large measure because it is force-free.* This means that the plasma currents do not require energy to flow against the magnetic field (as is the case in every other configuration of currents and fields). The plasma is able on its own to find this "frictionless" state and can, once this state is achieved, maintain the structure for orders of magnitude longer than conventional plasma configurations.

(3) *Conventional calculations of plasma behavior had predicted that such a plasma state would either be very rare or unstable.* The ability of a plasma to achieve a highly ordered state spontaneously has caught the mainstream of physicists off-guard. The dominant intuition about physical evolution in physics (as well as everyday life) is that inanimate objects (like plasmas) tend to become more disordered if left to themselves, and will quite rapidly decay as their entropy increases. The behavior of a plasma as it progresses to this plasma vortex state is totally contrary to that intuition and continues to surprise plasma physicists.[12] Soviet scientists, on the other hand, have been using this insight for many years, and it has figured significantly in their research on beam as well as on astrophysics, fusion research, and ionospheric studies.

Here is a striking example of the interaction between theoretical physics and the frontiers of weapons development. The mainstream of opinion in Western circles has been admirably stated by the group of analysts at the Massachusetts Institute of Technology, C. Tsipis, et al., who continue to claim that the problem of power production for a particle beam cannot be solved. However, they are basing their judgment on the presumptions of conventional Western plasma physics, which has traditionally ignored the self-organizing properties of plasmas. Hence, they, along with their colleagues in the Department of Energy and the mainline of the national laboratories, have ignored research in plasma liners and flux compression for the obvious reason that no plasma they knew of could be contained in a compressed liner. They rejected the idea because they were using the wrong scientific method, one based on the assumptions of particulate matter and the Second Law of Thermodynamics (the Newtonian-Maxwellian assumptions). These assumptions are dramatically wrong; when applied to a plasma, they result in the wrong predictions. The Leibnizian continuum approach (to which the Soviet scientists are much closer) is absolutely required not so much to explain the results of the plasmoid formation, but more to conceive of its possibility in the first place.

What has been the reaction of the responsible officials in the United States to revelations about Soviet work in liners? On the one hand, there has been a smug dismissal of the importance or reality of the Soviet research. When informed about the discovery of the Kazakhstan test center, one intelligence official was quoted in the press as saying: "Just when we thought we had put the hoax of Starwars-type weapons to rest, up pops evidence of the construction of charged-particle test bed in Kazakhstan." He was seconded by a staff memeber of the House Select Committee on Intelligence: "The general reaction here is purely negative, based on the fact that these allegations have cropped up so many times before. But . . . one of these days there may be something there and we will ignore it."

The Department of Energy took stronger action: In the same year that the Soviets began construction of this device, the Soviet Union made an official proposal for collaboration on construction of a liner experiment for fusion development, a field in which the Soviets were then (and are now) at least five years ahead of the United States. The responsible DOE officials then classified all U.S. work on the subject, and turned down the Soviet proposal saying that such research was classified in the United States.[13]

Advanced Laser Physics

The frontiers of physics touched by the problems of pulsed power generation are surprisingly similar to those met with in the production of the beam itself. In the case of advanced lasers, particle beams, and plasma beams, the same kind of self-organizing, energy-densifying behavior dominates the plasma and, in fact, is the marginal dynamical effect that makes the beam weapon possible. Without an appreciation of at least the fact that new scientific principles must be dealt with in beam weapon physics, real progress is ultimately impossible.

The production of energy in advanced laser systems involves a new set of physical phenomena differing in several important ways from those required for the production of conventional (optical) laser energy:

(1) The production of X-rays or gamma rays requires the use of nuclear transitions, rather than electronic or molecular transitions used in optical lasers. That is, conventional laser techniques use the relatively low energy modes of electrons in a gas. Thus, distortions of electron clouds in a carbon dioxide gas molecule are the energy modes used in a carbon dioxide laser. However, in the X-ray or even higher energy gamma ray laser, a new, much higher energy set of energy modes must be used.

(2) In the realm of nonequilibrium energy exchange of all lasers, a rule of thumb is that the stability of the modes used for the laser radiation varies inversely with the energy. Thus, the high energy modes required for an X-ray laser are very unstable and short-lived. This vastly complicates the process of pumping these modes.

If these two problems can be overcome, then the production of an X-ray laser would proceed in much the same way that a conventional laser does: An external source of energy (the "pump") supplies energy to a normally unexcited mode of the lasing medium. In the case of the carbon dioxide laser, for example, it is a molecular-electron distortion that is pumped. The pump energy is absorbed by this mode, and is temporarily suspended in a higher energy state. Then, the excited medium will spontaneously give up this energy at almost the same instant, as each molecule, stimulated by the emission of radiation from a nearby molecule, releases its energy in response to the stimulating radiation. The result is the almost instantaneous release of electromagnetic energy.

According to reports on the U.S. X-ray laser, the device tested consists of a set of rods, made of a high atomic number element, arranged around a small (less than 1 kiloton yield) nuclear device.[14] This device pumped the rods with the X-rays released by the nuclear explosion, and, the rods lased (that is, had nuclear modes stimulated by the X-rays from the bomb) and released a mono-energetic beam of X-rays in a sharp burst. The efficiency of the device was estimated to be less than .001 percent, but given the huge energies in the explosive pumping the laser, approximately 500 kilojoules (several ounces of dynamite) of X-ray energy was released.

This is a remarkable achievement, but scientific analysis of the publicly available information on the X-ray laser has pointed the direction to a number of other facets of the problem. First, the very low efficiency is probably due to the fact that the X-rays from the bomb explosion were used for the pumping. A much better choice would be the neutrons released by the bomb. A nuclear bomb releases tremendous quantities of energy, some in the form of radiation (X-rays carrying most of the radiative energy), a blast wave (kinetic energy of debris, the atmosphere, and so on) and subatomic particles, especially neutrons. The exact division of energy among these three depends on the design of the nuclear device (the famous neutron bomb has the bulk of its energy released in the form of neutrons rather than X-rays, for example). X-rays, as a pumping mechanism, are inherently limited by their very short range in matter, which means that they can excite only the surface layers of the lasing medium. Neutrons overcome this problem, since they can penetrate deeply into matter, but are efficiently absorbed by the proper combination of elements. Second, the pumping efficiency of all radiative transitions is poor since the X-rays (like all electromagnetic pumps) are absorbed by many other modes than the one to be excited. Neutrons overcome this problem by exciting only nuclear modes.

Friedwardt Winterberg has shown that a suitable profile of heavy metallic materials could solve the problem of absorption and pumping by neutrons and allow the generation of an intense pulse of X-rays, a device that would be optimally pumped by a neutron bomb. To achieve this result, however, requires the solution to the problem of the extremely short lifetimes of the nuclear modes involved.[15] Winterberg's solution is quite extraordinary:

> One principal problem, resulting from the shortness of the X-ray laser transition, is that the pumping can in any case be done only by a traveling wave excitation along the rod with the excitation wave moving with the velocity of light. This problem is solved with the concept of a neutron induced bleach-out wave. This can be done by poisoning the laser rod with a neutron absorber the concentration of which changes along the rod. Then, if the rod is exposed to the intense neutron flux of an exploding neutron bomb, a nuclear excitation wave will propagate along the rod as the neutron absorbing reactions transmute into nonabsorbing nuclei. It turns out that by a certain exponential concentration profile one can thereby generate an excitation wave propagating along the rod with the velocity of light, as is required for an X-ray laser.

Winterberg has extended this idea to the generation of even higher energy beams, giving a gamma ray laser. Gamma rays can be generated in the laboratory today through the single decay of naturally excited nuclei, in a process called the Mossbauer effect. Winterberg proposes replacing the crystal lattice required for the Mossbauer generation of gamma rays with an intense magnetic field that would function like the crystal in tying the individual nuclei to the whole lasing medium. That is, Winterberg would use the intensely magnetized plasma as the geometric constraint on the individual nuclei required to make them into a nuclear crystal. This "crystal" would then act as a single source of gamma rays. Winterberg projects that such a device would be capable of 1 percent conversion efficiencies, meaning that if a large thermonuclear device were used to pump such a medium (with a yield of, say 10 megatons), then the resulting laser beam would have an energy of 100 kilotons, 100 million times greater than the energy in the X-ray pulse from the current X-ray laser. As he says, "A laser of such an energy output could be obviously used as an ABM defense weapon."

Collective Accelerators

The various short wavelength lasers discussed above share the property of not only concentrating energy in space (that is, producing an intense beam of energy) but also in time; they take the energy released by a nuclear blast that occurs over milliseconds and compress it into a pulse of radiation lasting billionths of seconds. This temporal compression not only is a feature of these advanced lasers, but occurs over and over in plasma phenomena. As matter progresses through a series of increasing ordered and spatially concentrated states, the characteristic time scale also decreases, so that changes occur more and more rapidly. There is, as Plato was the first to point out in a systematic way, a close connection between the rate at which physical evolution occurs and the energy available for that transformation. It is not, he showed, a question of speeding up a fixed set of changes, but rather of energy creating the potential for changes that were not possible with less energy. In these physical systems, energy acts as the "material" reflection of time rates of change. This conclusion, which seems inescapable from a broad consideration of plasma phenomena, has been systematically denied by the mainstream of physics research in the West. In fact, the proposals made by Winterberg to test the ideas he outlined above in the realm of peaceful use of fusion energy have been classified![16]

The same phenomena are shown on time scales billions of times longer and at particle densities millions of times lower in the problem of particle and plasma beam acceleration. Although interesting scientific questions are posed by the acceleration of simple electron and ion beams,[17] all the features reappear in the case of the plasma beam. The real promise of the beam weapon does not come from technologies, such as already proven electron and ion beams, but rather from the indications that perfecting these technologies will open up new horizons for elaboration and exploration. An adequate military research and development policy must always look for the technologies that are *not* off the shelf, but are technologies that pose the fundamental kind of questions whose solutions are guaranteed to answer problems not even posed before. Plasma beams are such a technology.

A plasma beam, as noted above, is not really a beam but rather a means of transporting discrete balls or rings of plasma. Much like a Roman candle, a plasma beam weapon would shoot blobs of plasma at a rapid rate, each one carrying the explosive force of several pounds of dynamite and traveling at more than 500 miles per second. The plasma rings projected for such a weapon are similar to those used in the flux compression experiments for pulsed power generation, except that here the stability and energy concentration properties of the rings are used in a completely different context. The ring is initially blown out of a plasma gun, in a reaction very similar to that which produces a smoke ring in a neutral gas. The plasma blob is expelled from a plasma source (called a gun or coaxial accelerator); and as it leaves the mouth of the gun, the magnetic fields of the gun electrodes are wrapped up around the ring, as if the ring were blown through a spider web. These trapped magnetic fields provide the internal stability and energy-containing modes for the ring structure.

The magnetic fields in the ring solve the two essential problems of an effective beam weapon. First, they provide spatial and temporal stability to the ring. Because the magnetic field has, in effect, nowhere else to go, it is confined to the plasma and pulls the plasma in. This internally generated compression is balanced by the plasma pressure, and the whole structure is stable with lifetimes many orders of magnitude larger than classical calculations would predict. Second, and more important for the destruction of ballistic missiles, the magnetic field is a very efficient energy storage mechanism. The magnetic field of these rings concentrates energy by virtue of the fact that the magnetic energy density increases as the inverse fourth power of the radius of the ring. This means that if the ring is compressed by a factor of 2, the energy density of the ring has increased by a factor of 16. Accelerated to the velocity required by the energy density, a plasma ring 0.1 inch in radius would carry the energy of 5 pounds of dynamite (10 megajoules).

The ability of a plasmoid to compress energy on this scale is a result of the inherent tendency of a plasma to form self-organizing, energy-dense structures. Once formed, these structures proceed to further increase their energy density and speed evolution. The initial plasma blob, formed on a time scale of millionths of seconds, in turn concentrates its final energy on a target in a thousand-fold smaller time. The form of this energy is, in its own right, a remarkable and little understood phenomenon. When these plasmoids disintegrate, as they would on hitting a ballistic missile or other conducting target, they do not transfer their energy in a disorganized way in an explosion. Rather, the tightly twisted magnetic field breaks and begins to unravel. The magnetic field configuration then breaks down in a very rapid conflagration in which oppositely directed magnetic field lines seek each other out and "cancel out" their opposing fields. This process, called magnetic field line reconnection, is one of the most efficient mechanisms for transferring magnetic energy to energy of motion of particles. The resulting reconnected field line acts like a slingshot and selectively accelerates the heavy particles (ions) in the plasma to relativistic speeds. Beams of ions of energies of 100 MeV have been observed as these magnetic field lines reconnect.

These particle beams are highly directional and focus their energy in a very small area. The result is a plasma jet—a pencil of extremely hot, high energy matter moving at hypersonic speeds. The magnetic slingshot that accelerates this jet uses a sequence of geometrically focused shock waves to initiate and direct the jet (a phenomenon seen in astrophysical as well as in laboratory plasmas, called the Petschek mechanism). This plasma jet in may ways is similar to the plasma jet that is achieved in shaped charges. The liner of the shaped charge is replaced in the plasmoid by the magnetic field lines, and the burst of debris by the beam of accelerated particles. The destructive force of a plasmoid would make it an essentially perfect antitank or antiship weapon; no known armor could even approach the ability to withstand the energy of one of these plasmoids.

The Physics of Beam Propagation

The extraordinary phenomena observed at laboratories all over the world in beam plasma experiments cannot be denied by the critics of the beam weapon. These critics have, however, directed a large part of their comments to the question of beam propagation. The repeated challenge by the critics has been: How do you propagate a laser or charged particle beam thousands of miles to its target without the slightest deviation? The atmosphere, clouds, the earth's magnetic field, or debris from a nuclear explosion will distort the beam so severely that it will never reach its target.[18]

These criticisms are as ill informed as the beliefs of the same critics concerning the difficulties of pulsed power generation. They have ignored the most important physics and technologies of beam propagation to arrive at a false conclusion concerning the problem of propagation. The objections that they have raised are based on a clinical example of Newtonian thinking, in a situation in which the Newtonian method cannot even replicate experimental results, let alone provide the basis for discovery of new potentials for beam weapon development.

These critics have identified separate problems faced by lasers and by charged particle beams. In the case of laser beams propagating through the atmosphere, clouds, dust, moisture, and other plasmas (such as those left by a nuclear explosion) will diffuse the beam. They argue that the resulting reduction in energy density of the beam will render it unable to destroy its target. The refutation of these arguments is straightforward; in every case these are real problems, but not of the magnitude that would make a laser incapable of ballistic missile defense. Calculations of the worst case, a land-based laser using an orbiting mirror for aiming, show that approximately 80 percent of the laser light would reach the target; only 20 percent would be lost to the normal atmospheric effects noted by the critics of the beam weapon. The effects of a nuclear bomb blast on the propagation of the laser beam are more difficult to calculate. However, these effects are relatively shortlived and do not affect use of a laser weapon at altitudes below those at which a ''smoke screen'' explosion would be set off. By the maintenance of multiple mirrors and lasers, redundant communications links, and satellite hardening, the effects of such an explosion would be minimized.

The objections from the critics in the case of the charged particle beam are more significant. Even in outer space, the magnetic fields of the earth would exert a considerable effect on the charged particle beam, diverting it even in the best case, they argue, by as much as 10 percent, resulting in a miss by 300 miles in a 3,000 mile trip.

The physical arguments for this prediction are based on the most straightforward application of Newtonian physical thinking. Single charged particles experience a perpendicular force when they move through a magnetic field. This effect, when applied to a plasma beam, would seem to predict that the beam would be bent by this force when it passed through the magnetic field of the earth.

This would, of course, be correct if the beam were actually a collection of particles moving through an externally determined magnetic field. In fact, this effect would limit beam generation in a fundamental way even before the beam began to propagate, since the same calculation shows that there is a strict upper limit to the density of the charged particle beam resulting from the self-diverting fields that the beam generates itself. This limit, called the Alfven limit, was thought for a long time to put an upper bound on the possible strength of a beam. However, the experimental fact is that beams routinely exceed this limit, and beams of many hundreds of times the Alfven limit have been produced.

How does the beam overcome this magnetic deflection? On one level, the effect can be described (but not really explained) by a much more careful and subtle analysis of the actual forces on the particles in the beam. It is possible to construct a beam-current configuration that defeats the Alfven limit by rearranging the currents and magnetic fields in a complex helical arrangement, with current flowing out of the beam in the center, a return current flowing along the outside of the beam, and the connecting currents spiraling between the two. The resulting barber pole turned inside out is a force-free structure. How could a Newtonian assemblage of particles and fields construct such a configuration? It is not describable by means of conventional particle-based plasma physics.

However, Newton aside, a plasma performs this construction, and it does it spontaneously. The basic point of physical science raised by this empirical fact is that a plasma is not in any real sense made up of charged particles and fields. To define a plasma in this way is much like saying a human being can be understood by studying the result of combining billions of single cells and the fluids around them. Or to claim that a poem is nothing more than the collection of letters in all the words that make up the poem. Rigorously, the problem a Newtonian faces when confronting these phenomena is that the causality for the macroscopic behavior is not contained at the microscopic parts of the system. The microscopic entities exist, but they are not primary; they are determined by the same global causality that shapes the general evolution of the system.

The role that spontaneously created structure plays in beam propagation was first systematically noted by the Soviet plasma physicist V. N. Tsytovich, who, in a 1975 review article, astounded the plasma physics community by drawing together the manifold experimental results that showed how a beam would never propagate as a simple stream of particles, but, depending on the experimental configuration, would form tiny filaments, twisted vortex structures, intensely charged "pancakes," or localized electric field structures.[19] Tsytovich pointed out at that time that a new kind of physics was going to be required to systematically explain the tendency of plasma beams to create these highly structured forms during their propagation; conventional plasma physics applied to high energy beams was simply irrelevant if not false.

The result of these structures on beam propagation is dramatic. If the considerations raised by beam weapon critics were applied to the beams of particles produced by the sun (solar flares), they would prove that these beams could not propagate out of the solar corona; yet, as we know, they actually reach out hundreds of millions of miles into the solar system. The stabilizing force on the beams is the result of a singular structure formed by the beams.[20] The beam interacts with the background plasma forming high intensity electric field concentrations, which, in effect, shepherd the beam along, allowing it to propagate. Similar effects occur in high density laboratory plasmas, ionospheric plasmas, and in laser-created plasmas. In each case, classical calculations predict no beam propagation—but the plasma stabilizes the beam spontaneously.

Even more extraordinary is the fact that a properly structured beam can actually draw energy from the background plasma. In this case, the plasma not only stabilizes itself, but it uses its own structure to organize energy from the surrounding chaotic plasma, amplifying its own energy by a factor of as much as 1 million. In a series of experiments conducted by scientists from Stanford University, for example, a small radio signal was injected into the ionosphere at the South Pole.[21] This signal propagated throughout the ionosphere along a magnetic field line from the earth's internal magnetic field, and reentered the atmosphere near the North Pole. As it passed through the ionosphere, the radio wave created an electron beam that was self-amplifying. By the time the electron beam reentered the atmosphere, it contained more than 1 million times the energy of the original radio wave. This electron beam, by introducing order into the disordered background plasma of the ionosphere, organized (or "slaved") the random energy of the ionospheric plasma. It is much like a supersaturated solution or the supercooled vapor; the introduction of a "nucleation site" or an ordering singularity will precipitate huge quantities of energy out of the seemingly chaotic background.

All of these considerations when applied to high energy density plasmas discredit the basic assumptions of Newtonian or Maxwellian physics. But perhaps the most ironic of these non-Newtonian effects concerns the propagation of plasma beams. These plasmoids are the most perfect of the structured plasmas, and so display the most intense form of ordered behavior. However, the question of guidance and aiming of such a plasma blob over long distances has not been researched, at least not in the open Western literature. The only basis for consideration of this question available is the evidence from the natural equivalent of a plasma beam weapon, ball lightning. Ball lightning, a still poorly understood phenomenon, seems to be made up plasmoids generated by some atmospheric process. The most persistent feature of ball lightning, however, is that it is highly attracted to metallic objects. Reports of ball lightning following along a metal fence, hitting metal structures like lighting rods, power lines, and so on, are recurring features of ball lightning observations.

This behavior of a plasmoid would be most useful in the realm of ballistic missile defense. The plasma beam would have only to be shot in the direction of the incoming missiles; it would then use its own "conductor seeking" guidance system to find a metallic object. The most sophisticated "stealth" or radar confusing design would be totally helpless against such a weapon!

The Physics of Target Destruction

The most profound challenge to contemporary physics comes not from the problems of pulsed power, beam generation, or beam propagation, but from the problem of target destruction. The huge energy densities created by any of the beam weapons are the entry points into a new kind of physical interaction; and an understanding of the means by which that energy is deposited, absorbed, and transformed requires new physical concepts.

As outlined above in the case of the plasma beam, the deposition of energy by the beam creates a shock wave in the target. A shock wave is inherently a non-Newtonian phenomenon, first discovered by Bernhard Riemann in 1859. Riemann's discovery of shock waves was a polemical focus for the debate between the two schools for many decades and continues today to be the most hotly contested area for the Newtonian suppression of scientific research through classification.

Riemann, in his 1859 paper, pointed out the following facts about the propagation of strong energy disturbances through a continuum medium:

(1) Many media have the property that the disturbance (be it a sound wave, as in his original paper, or some other) will travel faster in the regions in which it is the strongest. That is, a sound wave (a compression wave) travels faster in denser media, so that the peaks of the compression wave (where the gas will be slightly denser because of the compression by the sound waves) will travel faster than the troughs of the wave.

(2) If certain simple criteria are satisfied, the peak of the wave will catch up with the front edge of the disturbance, and an increasingly sharp pressure change will develop at the front edge. At a certain specifiable point, the disturbance will in fact become singular—a finite change in the pressure will occur in an infinitesimal region of space.

(3) This phenomenon had been derived from the equations of gas dynamics by physicists before Riemann, but they had dismissed it as a mathematical fiction. Riemann, on the contrary, said that this singularity was a real physical effect, and that it would continue to exist as an entity in the gas with new laws governing its behavior.[22]

(4) The critical point in Riemann's paper—a point that is often brushed over—is that the shock wave is not merely a singular, very concentrated form of energy transmission, but more fundamentally, it is a means of changing the qualitative properties of the medium. In technical terms, the shock wave is most in evidence because it causes a change in the equation of the state of the medium through which it propagates.[23] That is, a shock wave transforms the laws that govern a physical system.

This point has been contested by the Newtonian-Maxwellian school for more than a century. They contend that a shock wave, like everything else, is merely the collective expression of the motions of innumerable particles. In their analysis, a shock wave is not fundamentally different from any other energy mode of a gas; it differs in its quantitative aspects (higher densities and so on), but it is still the result of atomic or plasma motions.

The inability of the Newtonian method to deal with shock waves stems from its denial of the fact and necessity of qualitative change in the physical system induced by the singularity of the shock wave. In a real sense, the shock wave is the natural state of a gas, and, as Riemann showed, all energy in a gas or plasma will tend to accumulate as shock waves as long as the few conditions he noted are met. For this reason, the field of shock wave physics has been relatively neglected in the West. All the world's leading experts on shock wave physics are in the Soviet Union; even the standard English language textbook on shock wave physics was written by Soviet physicists.[24]

The American approach to the study of shock waves has been to use large computer models of gases and plasmas to simulate the properties of shock waves. This endeavor systematically excludes the possibility of exploring those properties of high-energy density matter that do not follow as extrapolated from Newton-Maxwell physics, since the computer model must assume that the relevant equations are already known. Indeed, it is typical in laboratories to find that experimental results that are not consistent with the computer simulation are redone! The experiment is a success if it can replicate the predictions of the computer models—not the other way around, as one might expect. Thus, only discoveries of the known are possible, since any other phenomena are excluded in principle. Shock wave phenomena have shown, over and over again, that this method is a dead end.[25] American science must generate new concepts, new techniques, and new experiments if phenomena like shock waves are to be understood.

Conclusion

4. "The Most Revolutionary Weapon Since the Hydrogen Bomb"

The stark dilemma of the past 20 years is cleanly and irrevocably swept away by the existence of an antiballistic missile beam weapon. Humanity is no longer held hostage to the insanity of having no defense against nuclear holocaust. That single technological achievement changes the whole complexion of the coming decades.

The military impact of a beam weapon has been stated eloquently by many of its proponents. Senator Harrison Schmitt, the former astronaut, said in 1981:

> This new strategic policy option [of beam weapons] will in the not-too-distant future make weapons of mass destruction obsolete, to provide a strategic policy option based on the principle of protection of human beings rather than their mass destruction. . . . If we can protect against ballistic missile launches by using space [for basing beam weapons], all those innocents held hostage for years will not be sacrificed on the altar of human competition.[1]

His colleague in the Senate, Malcolm Wallop, said:

> We are at a cross-roads in this country. We have spent money, dollar after dollar and billions and billions, for weapons whose only consequence is to kill people. Now we have within our capability the possiblity of developing weapons whose only real role in the world is to kill the things that kill people.[2]

Major General George Keegan sounded the alarm in 1979 that the Soviet Union was on the verge of developing such a weapon:

> I don't know of a more alarming development in modern history. This is even more significant than the development of the atom bomb, or certainly as significant. I find it wholly as awesome as any challenge that modern civilization has had. We discovered positive evidence that this [beam weapon] technology experimentally had been tested on at least eight major occasions [by the Soviet Union]. . . . It indicated to me the Soviets were in fact twenty years ahead of the United States, and had good reason to believe that within the decade they would probably have found an operational solution to the American missile nuclear retaliatory deterrent.[3]

Some Western military analysts concurred with Keegan. Air Vice-Marshal Stewart Menaul of the British Foreign Affairs Research Institute said:

> The revolution in strategic defense is taking place now and represents a potential greater than the discovery of nuclear weapons. In time, the new weapons will provide strategic policy options that will relegate weapons of mass destruction to the dustbin of history. The whole concept of strategic defense is based on the principle of defending and

protecting human beings and property rather than continually providing for their mass destruction. With high priority and sufficient funding such strategic defensive weapons could begin to become operational toward the end of this decade, increasing in effectiveness in the 1990s to the point where all ground-based and submarine-launched ballistic missiles would become highly vulnerable in the boost phase of their trajectories.[4]

The Economic Impact of Beam Weapon Development

The military impact of the development of the beam weapon is, in turn, overshadowed by the economic and civilian impact. The beam weapon requires that we solve central problems now facing the United States, problems that define the real threat to our national security. Political economist Lyndon LaRouche, writing in a white paper on defense policy centered on the question of the development of the beam weapon, stressed this connection:

> The first line of development of in-depth defense potential of the United States is directing of hundreds of billions of dollars of low-cost medium- to long-term credit for rapid technological progress of U.S. agriculture and other goods-producing and transportation industry, in an increasingly energy-intensive and capital-intensive mode.
>
> This must define a shift in the composition of the employment of the nation's labor force, toward a goal of 50 percent of the labor force employed in a high-technology goods producing and transportation for agriculture and industry. . . .
>
> The matriculation of qualified scientists and engineers must reach ratios per member of the total labor force comparable to those of the Soviet Union today. Federal funding of research and development in areas relevant to hard and biological technology must not only be restored but greatly expanded over recent levels, combined with generous tax-incentives for private research and development in such categories.[5]

Such a set of policies provides the only credible or realistic context for the development of the beam weapon. The beam weapon, precisely because it represents the development of qualitatively new scientific and technological capabilities, can arise only in an economy capable of receiving those changes.

And because of that capability to absorb these new technologies, the development of the beam weapon will pay for itself many times over. The impact of the development of the beam weapon will, in this respect, resemble the impact of the NASA Apollo program during the period from 1965 through 1975. The economic results of that development program are often summarized by pointing out that there are two kinds of direct results from the introduction of a qualitatively new economic capability: first, the direct application of the capability to the economy, and second, the products produced for that capability that have applications elsewhere. Many studies have been done of the impact of the space program on the economy in terms of the direct use of space, in the following areas:

(1) *Weather information.* Hundreds of millions of dollars per year are saved in storm damage, and $50 million per year are saved in agricultural planning and water planning, all made possible by a single snow cover inventory. Much else less quantifiable is also gained.

(2) *Resource development.* There are large savings in exploration costs, generating many millions of dollars per year in otherwise inaccessible resources.

(3) *Communications.* More than $300 million in communications costs are saved, plus an immeasurable amount of savings because of communications that would have been impossible without the use of space.

These three rather pedestrian examples alone cover the "cost" of the space program, and they describe only the most superficial direct uses of space.[6]

Similarly, the second conventionally measured impact of a new technology comes in the uses of new devices and technologies originally derived from the unique challenge of space, but applicable in other areas. These so-called spinoffs from space exploration include new materials (teflon, refractory ceramics, new alloys), electronic technologies (all miniaturization, sophisticated automation techniques), medical technologies (heart monitors, telemetry devices, new plastics), and many others.[7] Conservative estimates are that these spinoffs resulted in a return of $14 for every dollar spent on the space program.

However, studies done by Chase Econometrics and confirmed by independent studies using the Fusion Energy Foundation's econometric model show that there is a much greater impact that the development of a qualitatively new technology has on an economy. This impact is, strictly speaking, not measurable by adding up all the new products and new techniques that a new technology introduces; it is the *increase in productivity* throughout the economy as the result of the combination of higher manpower skill levels and new scientific knowledge entering industrial production.[8] One study of this induced productivity effect estimated that U.S. productivity increased 0.1 percent for every billion dollars spent on the space program. This change in productivity alone represented an additional $3 billion to the GNP every year it was present. An interesting comparison is possible between the expenditure of a $1 billion aliquot of the federal budget on a high-technology R&D oriented program (like the Apollo program or the development of a beam weapon) and its expenditure on transfer payments, bureaucratic services, or the like. The Chase Econometrics study showed that the expenditure of this money on high-technology R&D actually *lowered* inflation, while the other expenditure had the opposite effect, raising inflation by 0.2 percent.

These beneficial effects are the result of three interconnected properties of the development of advanced technologies:

(1) *The increase in the skill levels of the manpower required for (and generated by) the development and use of new technologies.* New technologies have the unique property of training the better educated, more skilled work force required for their implementation. Thus, the space program trained tens of thousands of engineers who would not have been otherwise trained; employed many thousands of skilled machinists and their apprentices; and created new jobs like computer analysts skilled in image enhancement, automation, and remote sensing. Perhaps even more profoundly, it provided inspiration for a generation of students to demand the most of themselves so that they could be part of the excitement of the space program.

(2) *The development of new technologies in local industries.* The spread of better ways of doing things has a large, short-term impact on the economy, as measured in the studies mentioned above. New products, new techniques, and new materials all are major results of a qualitatively new technology.

(3) *The creation of new industries.* The most important effect of the development a qualitatively new technology is that it revolutionizes all aspects of consumption and production. We are now seeing only the beginning of the space-related revolution, which itself has been slowed by the lack of investment in the current economic depression. The space industries of communication, industrial processing in a zero-gravity environment, remote sensing, and the Space Shuttle, however, are aspects of the impact of the space program that transcend the spinoffs in any one area. It is this total change inherent in a qualitatively new technology that is the real secret of the economic impact of a new technology.

The same qualitative impact magnified many times will result from the development of the beam weapon. The perfection of a beam weapon for ballistic missile defense would usher in the "plasma age." The first decades of this century were shaped by the introduction of electricity and the revolution in living standards, industrial production, and materials that it brought. The decades after that saw the beginning of the atomic age and, most recently, the beginning of the space age. The next great step that man will take will be toward the mastery of technologies using the highest energy form of matter known today—a plasma.

Mastery of a plasma would put at our command the following:

(1) An energy source—nuclear fusion—that has an unlimited fuel supply taken from seawater and is cheap, clean, and inherently safe.

(2) Access to a supply of raw materials that would be virtually inexhaustible through the technology of a fusion torch, which is capable of refining the lowest grade ores economically.

(3) New materials processing technologies that allow the creation of nuclear-tailored materials (isotope separation on a large scale), the degradation of radioactive wastes, and the ultimate recycling of wastes (using the plasma torch).

The almost science-fiction aspects of these technologies come from the same source as their military application in the beam weapon. Plasma technologies use energy densities millions of times greater than the energy densities now industrially available. Instead of a working fluid at 500 degrees, as present in today's energy sources, fusion works at a temperature of 100 million degrees. Instead of applying .01 electron volts per atom in material processing, the plasma torch applies 10 or 100 electron volts per atom.

This dramatic increase in energy density is the source of the qualitative changes that plasma technologies bring with them. The Apollo program is a useful paradigm for assessing the impact of these plasma technologies. In educational terms, a study done by the Fusion Energy Foundation estimated that an additional 20,000 engineers would have to be trained annually in this decade to begin to develop the beam weapon and its related plasma technologies; and this force of engineers (about twice the number of American engineers that are now graduated) would have to be supplemented by a quadrupling of the number of nuclear, plasma, and high-temperature physicists graduating over the next decade. A major upgrading of science education at all levels would be a prerequisite for the sustained training of this level of scientific manpower.

The spinoffs in product terms are easier to quantify:

(1) *Laser technologies.* Already high-power lasers are used in medicine, metal working, textile, construction, and communication industries. The ability to reliably and compactly produce high power, high quality laser energy would vastly speed up this development. The beam weapon program addresses this question immediately. There is an especially close and interactive relation between the beam weapon program and the technique for inducing nuclear fusion using lasers. Both require the mastery of high-energy, short-pulse lasers. The solution of the problem in one area would immediately push the other.

(2) *Particle beam technologies.* Particle beams have also found important medical uses and applications to energy production. The solution of the difficult technological problems involved in the production and control of high energy particle beams would immediately solve the similar problem in particle-beam-induced nuclear fusion, in the use of particle beams for microwave production, and in similar areas.

(3) *Magnet technology.* Plasmas can be controlled only through the use of a force-field like a magnetic field. Because the high temperature plasma would destroy any solid matter it touched (or be cooled off by the solid matter), plasma technologies use magnetic fields as confinement and insulation devices. The mastery of the problem of stable confinement of plasmas for nuclear fusion is intimately related to the problem of controlling particle beams and plasma

beams through the use of magnetic fields. The major research on particle and plasma beams has come out of the fusion program, and the pursuit of these technologies for application to a particle beam would have far-reaching impact on the fusion program.

(4) *Pulsed power production.* The production of high intensity electric pulses is required in the fusion program at every stage. This technology has been brought to its present state of development almost entirely as a result of the fusion program.

(5) *Nuclear materials.* The control of a beam weapon requires the use of materials able to withstand very large, sudden pulses of energy. The perfection of materials such as this can be expected to have at least as great an impact as did the development of exotic materials in the space program.

(6) *Advanced automation techniques.* The tracking and control technologies required for the successful operation of a beam weapon will have wide application in industry for optical tracking of production processes, infrared monitoring of energy use, control of fast processes, and automated control. The automation impact of the space program is now being seen in Japan with the widespread introduction of robots; a similar result will come from the perfection of automation and control technologies in beam weapon development.

While all these specific results can be expected from beam weapon development as the pathway to the "plasma age," the much more profound result will come from the introduction of the whole family of plasma technologies into industry. The availability of a high-intensity, low-cost, unlimited energy source in nuclear fusion will have untold impact. Technologies that exist today but cannot be used for lack of energy will be unleashed: Widespread desalination of seawater, hydrogen production, and synthetic fuel from coal are the three most important of these. Without the cheap energy of fusion, these technologies are almost inconceivable in economic terms. The introduction of high-temperature plasma processing for steel will revolutionize the metal working industry; plasma processing on a small scale is now used in East Germany to produce very high quality tool steel because of the unrivaled control over impurities that the plasma technique provides. Similar processes will be possible in the chemical industry, the nonferrous metals industry, and the petrochemical industry.

The fusion torch will provide the capability to focus huge amounts of controlled energy on the problem of materials extraction and refining. This technology uses the high temperature exhaust of the fusion reaction to break down any material to its constituent atoms and separate the resulting plasma.[9] This technology will revolutionize mining and refining more than the introduction of electricity.

Real National Security

At first sight it seems ironic that the solution to man's material problems might come out of a military development. To produce enough food, water, and shelter has never been possible; but with the energy and energy-density of plasma technologies, for the first time in man's history, this is a realistic goal.

This is the irony of national security: Real national security rests on economic growth, technological development, and human advancement that simultaneously provide a strong military and the objective self-interest that make war unlikely, if not unnecessary. A country producing new resources (rather than fighting for old ones), educating and training its population (rather than being plagued by unemployment or apparent overpopulation), and providing a hopeful future for its people, is a country with real national security. These are also the prerequisites for a military establishment committed to national development, technological innovation, and peace winning.

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