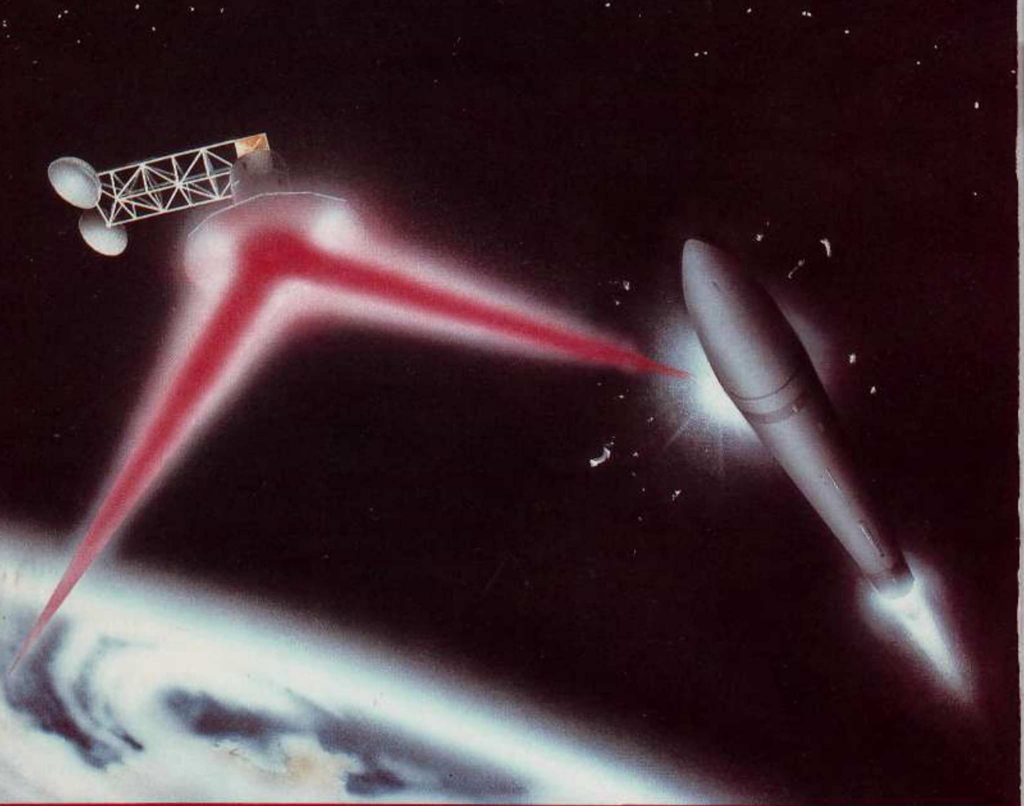
BEAM DEFENSE



An Alternative to Nuclear Destruction

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Beam Defense

An Alternative to Nuclear Destruction

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Contents

Chapter 1

President Reagan: The Age of MAD Is Over

"I call upon the scientific community, those who gave us nuclear weapons, to turn their great talents now to the cause of peace: to give us the means of rendering these nuclear weapons impotent and obsolete."

In a 30-minute address to the nation March 23, 1983, President Ronald Reagan called for an end to the specter of nuclear holocaust that has haunted the American people for 30 years.

The President declared that the military doctrine of mutually assured destruction, aptly called MAD, can be ended by a major effort of the nation's scientists. The purpose of this effort is to develop the means to protect our national territory and population from nuclear missiles. We can develop defensive technologies more precise and efficient than those missiles, defenses with greater *firepower* than the offense, and thus defend our nation and its people. If we develop these high technology defensive weapons to intercept and destroy nuclear-armed ballistic missiles in flight, the President stated, we can "provide a hope of something better. . . . Tonight we are launching an effort which holds the promise of changing the course of human history."

One major advocate of beam weapons for antimissile defense remarked the following day that President Reagan's extraordinary speech had the effect of "lifting off the manhole cover that had been sitting on people's heads for 25 years." Reagan's call for antimissile defense was kept a total surprise to all but a handful of his closest advisors until two hours before the President went on television—a sign that this was a rare Presidential "command decision" that truly launches a new strategic direction for the nation.

The President's inner circle knew that had Reagan circulated his speech in advance, half of official Washington would have been on the phone within an hour trying to stop him from giving the speech. This is how ingrained the MAD doctrine, its scenarios, and its planning and procurement habits have become throughout the U.S. government agencies, the military, and all those who seek to advise them. In fact, General Brent Scowcroft, head of the Scowcroft Commission on Strategic Forces appointed by the President, told a congressional committee in April that he considered the President's March 23 speech "unfortunate"! President Reagan was breaking out of the MAD straitjacket.

What are these revolutionary new potential weapons? Dr. Edward Teller and a few other scientists have called them "third generation nuclear weapons," with a much higher, more efficient *concentration* of energy that produces "novel effects" with relatively small total energy flux. At a background briefing before the President spoke on March 23, several of his aides identified these weapons as lasers, particle beams, microwave and plasma beams, plasma accelerators, and magnetic accelerators for projectiles.

Taken as a whole, these new weapons are known as "energy beam weapons." They may also be called "relativistic beam weapons," because they propagate beams that travel at what are called relativistic velocities—at or near the speed of light. This is part of the secret of their tremendously concentrated firepower, as will be explained. They use very large, rapid pulses of power to generate coherent and precise beams of energy and to aim and propagate these beams over distances of thousands of miles with enough power to disable a missile.

As *lasers* these beams travel at the speed of light. Their phased electromagnetic radiation can range in frequency from the below-visible infrared, through the visible light bands and the ultraviolet, all the way to extremely high frequency X-ray lasers. The higher the frequency of the laser's beam of electromagnetic radiation, the more efficient the beam in disabling the missile. Antimissile lasers must also operate at high power levels, and this is a greater scientific challenge at high frequencies. The combination of increasing radiation-wave frequency and increasing beam power gives the beam greater and greater *energy density*, or concentration of the energy to do its task.

Above the highest frequencies of electromagnetic waves, we can generate beams of even higher energy density—particle beams, made up of clouds of charged or neutral atomic or subatomic particles accelerated to relativistic velocities near the speed of light.

Other, older antimissile intercept technologies are also essential for some aspects of a complete defense of the nation and its armed forces. But it is beam weapons that alone raise the prospect of true defense—not just of missile sites, but of entire nations and their peoples.

A Good Idea

To the ordinary American, eliminating the threat of nuclear war by developing a capability to knock out hostile nuclear missiles in the first few minutes after launch sounds like a good idea. The question is, can it be done?

In terms of science and technology, the answer is yes, we can do it!

The President's science advisor, Dr. George Keyworth, told the press in a Washington briefing on the President's March 23 speech, that Reagan made his decision after an extensive review with scientific and military advisors of the recent scientific advances that make "multilayered" systems of defensive weapons realizable. In fact, the United States has a great depth of experience with energy beam technologies in its national laboratories—and so does the Soviet Union. With the invention of the laser in 1960, it was soon realized that lasers and particle beams could revolutionize all fields of industry, agriculture, technology, and science. As will be shown below, within two years after that invention, in 1962, the authoritative Soviet military textbook was discussing the use of high-power lasers for antimissile defense.

The basic field of science involved in beam weapon development is plasma physics, and thus the work done by many countries in thermonuclear fusion research has laid the basis for such an antimissile defense. In fact, by developing such a defense as rapidly as we can, we shall, in the process, take on the most difficult scientific problems of plasma physics and create breakthroughs in fusion and other plasma technologies.

Although none of the President's advisors has wanted to make a public estimate of how soon we can end MAD, this caution is not based so much on a scientific assessment but on political pressures and deference to unfortunate scientific secrecy laws. The important thing is that we know we can do it. Recent rapid progress in laboratory beam technology experiments convinces the authors of this book that effective beam weapon systems will be deployed for antimissile defense *in the 1980s*. Dr. Keyworth said in a recent *Washington Times* interview: "These programs are a lot closer than people think. All the components already exist—we simply have to assemble them."

For many readers, it should be enough to remember that since the era of Edison, many respected scientists have said that certain major technological breakthroughs could not or would not be made. It was even predicted, in 1945, that the atom bomb would never go off. Yet each of these gainsayers was made to eat his words.

The instant we make clear our unshakable national determination to end MAD, we already begin to attack its unstable balance of thermonuclear terror, even before the first beam weapon is deployed.

What Are Beam Technologies?

Laser beams, particle beams, plasma beams, and microwave beams all travel at or near the speed of light—186,000 miles per second. A chemical or gas laser defensive beam weapon system would be able to find, track, and destroy nuclear-armed intercontinental missiles, ICBMs, *preventing their explosion*. This system would offer protection against an accidental ICBM launch or against an attack by a runaway third power (not the United States or Soviet Union) possessing nuclear weapons. And it would protect our missile silos from attack.

More advanced systems based on higher frequency lasers—which may take no longer to develop—would give us protection against an all-out nuclear attack.

The tasks involved are an enormous challenge to scientists: Aiming a beam weapon at an ICBM in its boost phase, perhaps 3,500 miles away, is like hitting a piece of thread seen at 100 yards—while it is moving at 10,000 feet per second. Yet, all of the required technologies are either in use now, or have been developed in the laboratory.

- Computers exist capable of processing the millions of pieces of data in seconds to track ICBMs. These computers must be made lighter and more compact.

- Telescopes exist in the space program that can point to a region of the sky with the accuracy required by a beam weapon. Laser antimissile pointing "telescopes" must be able to track such a moving missile stably once they have "seen" it.
- The optics (mirrors) exist of the quality required to focus the beam weapon on the target. They must be made larger and more resistant to being heated by the power of the beam.
- Lasers exist that can be scaled up to the required power. They must have power pulses that can fire them more rapidly and efficiently.

The challenge now is to put all the pieces together into an operational beam weapon system.

21st Century Technologies—Today

As remarkable as it will be to have technologies that can make nuclear weapons obsolete, the development of beam technologies will have even more far-reaching consequences than removing the threat of nuclear holocaust. Beam technologies will take us into the 21st century—in the next few years.

- Beam technologies will give us an unlimited, cheap, clean energy source—fusion—whose fuel is seawater. About 80 percent of the remaining problems to be solved in the development of nuclear fusion as a commercial energy source will be solved in a successful beam weapon program.
- They will speed the perfection of the plasma torch, a high-temperature method of reducing garbage and dirt or low grade ore into its constitutent elements, thus providing us with unlimited mineral resources.
- They will make possible fusion propulsion, which will enable us to explore and colonize distant parts of the universe by vastly reducing the travel time necessary.

What the President Said

I have become more and more deeply convinced that the human spirit must be capable of rising above dealing with other nations and human beings by threatening their existence. Feeling this way, I believe we must throroughly examine every opportunity for reducing tensions and for introducing greater stability into the strategic calculus on both sides. One of the most important contributions we can make is, of course, to lower the level of all arms, and particularly nuclear arms. . . . If the Soviet Union will join with us in our effort to achieve major arms reduction we will have succeeded in stabilizing the nuclear balance. Nevertheless it will still be necessary to rely on the specter of retaliation—on mutual threat, and that is a sad commentary on the human condition.

Wouldn't it be better to save lives than to avenge them? Are we not capable of demonstrating our peaceful intentions by applying all our abilities and our ingenuity to achieving a truly lasting stability? I think we are—indeed, we must!

What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack; that we could intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies?

I know this is a formidable technical task, one that may not be accomplished before the end of this century. Yet, current technology has attained a level of sophistication where it is reasonable for us to begin this effort. . . . I call upon the scientific community in our country, those who gave us nuclear weapons to turn their great talents now to the cause of peace: to give us the means of rendering these nuclear weapons impotent and obsolete.

- They can immediately be applied to U.S. industry—laser cutting and welding, for example—to cut costs, cut materials, and produce a longer lasting product that requires less maintenance. With these new laser technologies, the engine block for a car might be made out of aluminium, with a laser heat-treated surface that provides the required strength. And with a plasma steel furnace, we could produce more steel at a fraction of present costs.

In all, the applications of beam technologies to the civilian economy will have a more revolutionary effect on our lives than the introduction of electricity did 100 years ago.

Can we do it? Can we harness the power of beam weapons to stop the threat of nuclear war *and* bring about the economic well-being that will ensure peace? As President Kennedy told the nation 20 years ago: "Our problems are man-made; therefore they can be solved by man. And man can be as big as he wants. Man's reason and spirit have often solved the seemingly unsolvable, and we believe they can do it again."

Chapter 2

The Straitjacket of MAD

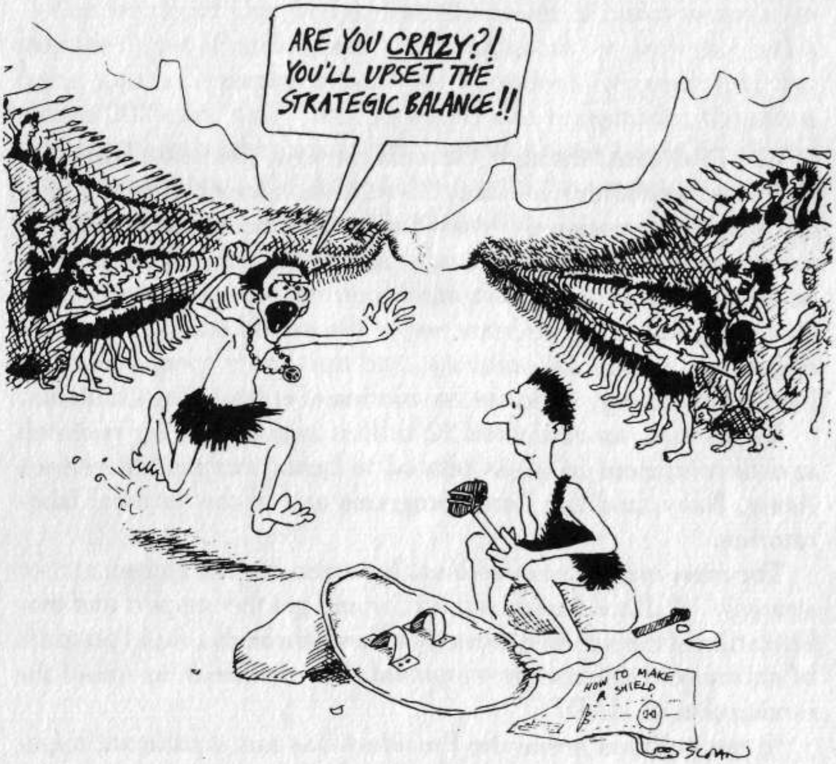
The President, through National Security Decision Directive 83 issued just after his March 23 television speech, established a special commission to review the state of beam technology research in the national laboratories and to recommend a timetable and a course of action. This commission met in Washington during summer 1983, and the branches of the armed services, various industries, private laboratories, and university specialists have been asked to work on ideas for solution of outstanding problems.

Meanwhile, an estimated $2 billion is budgeted for research and development in areas related to beam weapons in various Army, Navy, and Air Force programs and in the national laboratories.

The most important questions, however, are not technical, but strategic. Will the President ask for and get the support and mobilization of the nation necessary to force through a rapid program of antimissile defense development that can break us out of the straitjacket of MAD?

In the political arena the President has met significant opposition to his new policy. The Russians angrily and repeatedly attacked the President and his advisor Dr. Teller, and the Soviet weekly *Literaturnaya Gazeta* ran three consecutive attacks on U.S. economist and Democratic Party leader Lyndon H. LaRouche, Jr. who has campaigned internationally for a U.S. beam-weapon defense strategy. Soviet leaders—and, incredibly, the same Soviet scientists who are working on beam weapons—claimed that these systems would start a new arms race.

In fact, it is the Soviets who are ahead in this ongoing race now, but given the greater U.S. technological depth, we are likely to get there first—and to get a much greater development of our



technological capabilities all-around in the process. It is for this reason that the Soviet leadership wants the genie of beam weapons kept in the bottle.

Some Americans agreed with the Soviets, especially those U.S. policy makers who do not want to give up MAD. And the national media, in particular the liberal press, ridiculed the President's policy as "Star Wars."

Interestingly, among those who oppose the President's defensive beam weapon policy and who advocate MAD are a good many leaders of the nuclear freeze movement. They see MAD as a maintainer of "stability."

MADness

The MAD doctrine that has governed U.S. strategic policy for the past 25 years was devised in the postwar period, ironically, by the elite "peace and disarmament" grouping known as the Pugwash Conference, organized by Lord Bertrand Russell and his many collaborators. MAD overturned the traditional American military policy, exemplified by General Douglas MacArthur in the Far East during and after World War II.

From the beginning, the Pugwash Conferences had high-level support from the Soviet academies of science, and by 1961, Pugwash virtually controlled the policies of the U.S. Arms Control and Disarmament Agency, which had been created through the efforts of Pugwash scientists. The Pugwash group also wanted to keep the genie of civilian nuclear technology in the bottle, and so it constantly increased the public fear of nuclear weapons, "radioactive fallout," and so forth while promulgating the doctrine of Mutually Assured Destruction.

It will surprise most readers to know that what they think of as "Pentagonese" terms for discussion of nuclear war were all invented at the Pugwash Conferences from 1957 onwards. "Deterrence," "first strike," "second use," "counterforce," "coun-

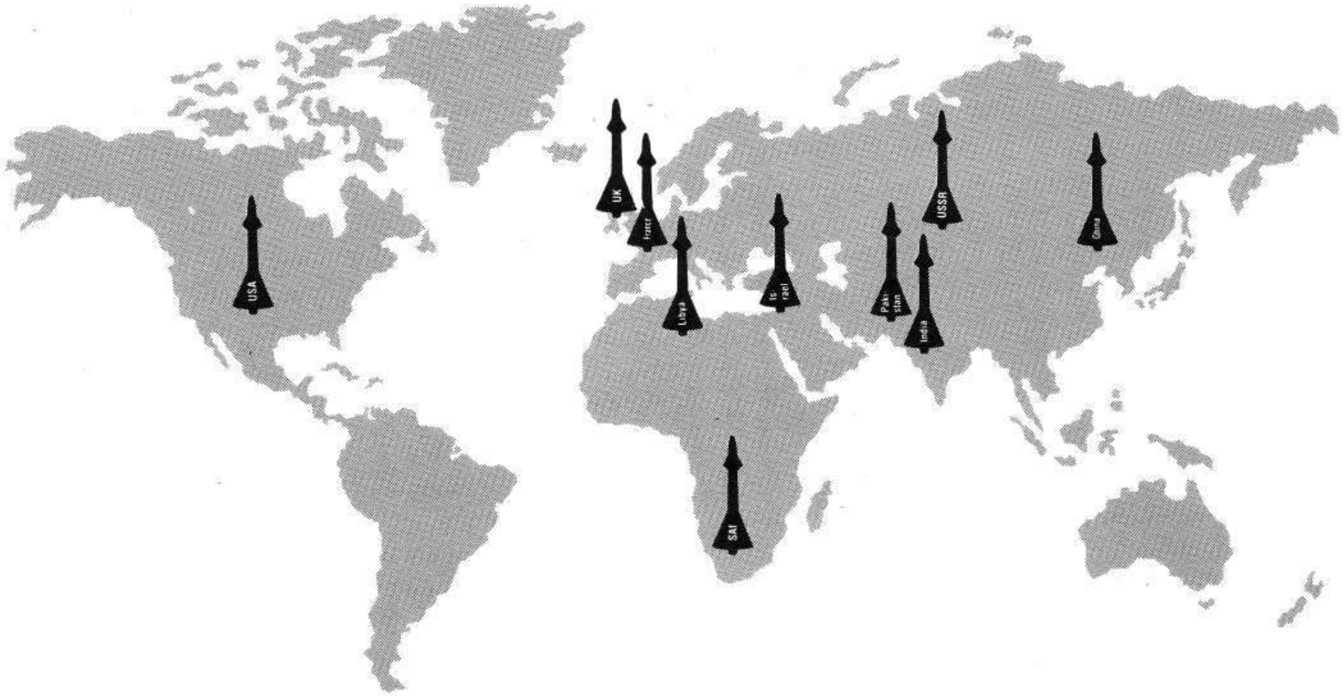


Figure 2-1
The Nuclear Powers

In the past few years, several nations in addition to the superpowers and their allies have acquired a nuclear capability and, according to reliable sources, are in the process of developing intercontinental missile delivery systems. A first generation beam weapon system based on a chemical laser could provide the United States with a means of stopping a nuclear attack by a runaway nuclear power.

tervalue," and all the other scenario-words of MAD were invented by the "Ban the Bomb" scientists at Pugwash Conferences, and then later came into use by both Soviet and U.S. officials. It was at these Pugwash Conferences that "Dr. Strangelove" was born.

One of the ways President Reagan began to "lift the manhole cover off our heads" in his March 23 speech, was to abandon this jargon and use plain English to describe the MAD concept of "deterrence." He called it the threat of revenge. The obligation of a military commander is to protect the population of his nation, not merely to avenge them after they are destroyed, the President said.

Thus President Reagan began to reestablish the fundamental American military principles abandoned under MAD: the obligation to defend one's nation, to make alliances on the basis of principle, and to defend one's nation's allies as well.

The idea of mutually assured destruction is that the national security of the United States as a superpower in the nuclear age is based solely on amassing a doomsday artillery of nuclear ICBMs, large enough or "invulnerable" enough to destroy the Soviet Union after a Soviet attack has destroyed the United States. According to the MAD doctrine, this puts too high a price on that attack, and makes all-out war "unthinkable."

Arms control treaties negotiated under this doctrine have concentrated on *banning* attempts to build antimissile defenses, in order to guarantee the vulnerability of cities and populations on both sides as "hostages" against a strike. Following the MAD doctrine, the nuclear arms race has proceeded, with a "peace" maintained by the threat of mutual annihilation.

During the Carter administration, Defense Secretary James Schlesinger escalated the MAD doctrine to a policy called Forward Nuclear Defense—the idea that the United States should have the capability to fight a "limited" nuclear war. For this purpose, the decision was made to deploy U.S. missiles and tactical nuclear weapons in Europe.

Given this threat of nuclear holocaust, it is easy to see why technological pessimism and environmentalism have spread in the train of MAD, especially as more and more hot spots develop around the world that could trigger a nuclear confrontation.

Throughout the history of playing by the rules of the so-called MAD doctrine, there has been a great impetus to irrational behavior by the nuclear powers toward the nonnuclear nations—the majority of the world. The threshold may be very high for warfighting between the nuclear powers. But just the opposite is true when it comes to wars in the developing countries. The nuclear powers have involved themselves in almost continual "surrogate warfighting" of a terrible character in the Mideast, Asia, Africa, and Latin America. It is the supposed unlikelihood of an escalation to world war that has made such local wars "tolerable."

The offensive arms race has now advanced to the point that MAD itself has become outmoded. If MAD—the idea that *offensive* nuclear weapons function as a defense—ever had a rationale, today this rationale is obsolete. With the new generations of land-based missiles being deployed, particularly the shorter-range Soviet SS-20 and U.S. Pershing 2 missiles in East and West Europe, the unstable MAD "balance" breaks down completely. These advanced weapons have such accurate guidance systems and such maneuverable reentry vehicles, that there is no longer any possible defense for missile silos under attack. The Pershing 2 or the SS-20 can strike consistently within 165 feet of its target.

This means that the assurance of "successful revenge" through a guaranteed second strike no longer exists, because there is no certainty that once one side launches an attack, the other side's ICBMs would survive the attack and be capable of launching a second strike. Today, if the Soviets were to decide that war was inevitable and launch a preemptive strike, our ICBMs would be destroyed in their silos; we could not launch a retaliatory strike of strategic consequence. Thus, as has been admitted at last on the floor of the U.S. Senate (see below), there would be no moral reason or justification for striking back on the part of the President as Commander-in-Chief. The only way to "retaliate" and to prevent the destruction of our ICBMs in their silos would be to launch our ICBMs as soon as any enemy missiles are detected—or are *thought to be* detected. The same is true for the Russians.

Such a "launch-on-warning" policy for either side creates a highly unstable situation, especially since there is so much margin of error in the detection process. This instability is exactly

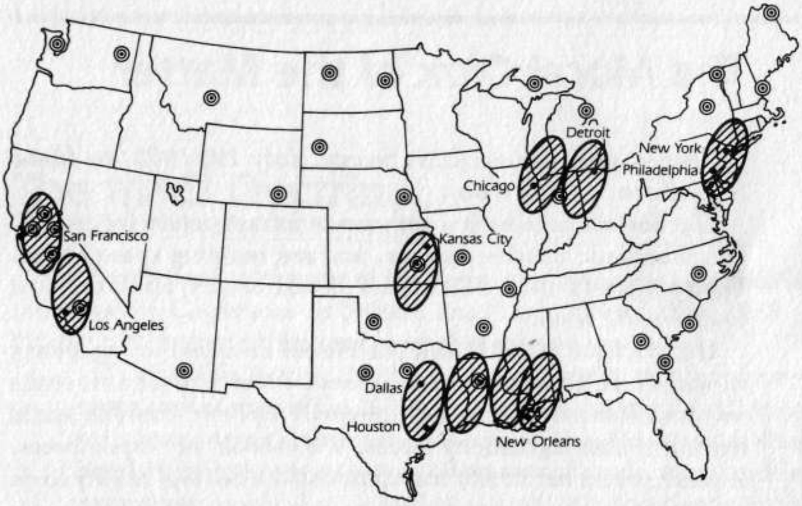


Figure 2-2
The MAD Targets: 200 Million Americans

In the mutually assured destruction scenario, a Soviet strike against U.S. military and industrial targets would kill 200 million Americans. Shown on the map (as bull's-eyes) are the potential strategic military targets—Air Force Bases—and (as shaded areas) the population centers.

Sources: Congressional Research Service; U.S. Office of Technology Assessment.

what the President wants to avoid, by developing defensive beam weapons that could prevent any hostile missile from exploding, by tracking and killing it in its boost phase (the first few minutes of its flight).

There is also the added danger today of a nuclear attack by a runaway state that has a both a nuclear and an ICBM capability (see map). This is a danger that equally concerns both superpowers. As Secretary of Defense Caspar Weinberger has said, *both sides* would benefit from a parallel development of beam weapons, whose first generation would prevent such a third party nuclear attack.

The Moral Crux of the Matter

From a speech in the U.S. Senate, July 19, 1983, by Idaho Republican Steven Symms:

The Soviets have built a nationwide infrastructure for ground-based ballistic missile defense, and are building space lasers. Their program is three to five times the size of ours, and is oriented toward early results

Our doctrine of MAD and our Forces designed to implement it, simply cannot cope with this threat. After a Soviet first strike no rational human being, certainly no President, could or would use our remaining anticity forces. Why should he? Such forces, if used, would not in any way diminish the Soviets' ability to do us further harm. If we were to use our remaining missiles, we would only make certain our own destruction. This situation is intolerable. . . . [and it] is unnecessary because it is now possible for the United States to build weapons and adopt strategies that will give the American people real hope of physical safety, and of overturning the present unfavorable strategic balance. This is what the President was talking about. The technology is available for doing this.

Chapter 3

The Pros and Cons

The MAD Doctrine

Dr. Leo Szilard, a founder of the Pugwash Conference, speaking at the Pugwash Conference on Science and World Affairs, May 1958 in Quebec, on the topic "How to Live with the Bomb and Survive":

> "Let us now assume, for the sake of argument, that in the long-range rocket stage [the ICBM was then being deployed] there may occur some major disturbance affecting the Arabian Peninsula which threatens to cut off western Europe from its Mideastern oil supply. Let us further assume that America is on the verge of sending troops into Iraq and Saudi Arabia, that Turkish troops are poised to move into Syria, and that Russia is concentrating troops on her Turkish border for the purpose of restraining Turkey. Let us suppose further that at this point America may declare that she is prepared to send troops into Turkey and to use small atomic bombs against Russian troops in combat on Turkish territory and perhaps, in hot pursuit, also beyond the prewar Turkish-Russian boundary.

"Russia would then have to decide whether she wants to fight an atomic war on her southern border and take the risk that such a war might not remain limited. . . . She might proceed to name some 20 American cities and make it clear that in case of American troop landings in the Middle East she would single out one of these cities, give it four weeks warning to permit its orderly evacuation, and then demolish that city with a single long-range rocket.

"In order to make this threat believable, Russia would have to make it clear that she would tolerate—without threatening reprisals—America's demolishing cities having the same aggregate population.

"If America, being willing to lose one of her major cities, were to decide in favor of intervention, then both Russia and America would lose the same amount in 'property destroyed' and America would be free to occupy Iraq and Saudi Arabia without having to fear any further Russian reprisals.

"If Russian troops were to invade an area which is on the American list, this might show that America has underestimated Russia's willingness to pay a high price (in cities destroyed) for gaining control over certain contested areas. . . .

"Occasionally, there are hints in speeches of officials, who should know better, that there is work in progress on a defense system aimed at destroying long-range rockets in flight. Such a defense system is not in fact in sight."

Dr. Hans A. Bethe, Nobel laureate and veteran of the Manhattan Project, in the letters column of Science *magazine, Dec. 24, 1982:*

". . . If reliable defensive weapons were feasible, I would welcome this escape from the balance of terror. But I remain convinced that in the nuclear field, the offense will continue to have the advantage and can negate any defensive weapons with relatively little effort. Defensive nuclear weapons will at best remain wishful thinking."

Dr. Bethe speaking at Brookhaven National Laboratory, May 31, 1983:

> "Nuclear deterrence may be called 'MAD,' but it's the only viable concept."

Jan M. Lodal, former senior staff member and director of program analysis for the National Security Council, April 3, 1983, in the Washington Star:

> "The president obviously is sincere in his concern about the risk of nuclear war and in his desire to marshal our scientific strength to reduce or eliminate this risk. But, unfortunately, some problems simply are not susceptible to easy technological solution.
>
> "There is no way we can turn the technological clock back on the overwhelming power of nuclear weapons. Our best hope is to negotiate effective arms control agreements that contain the risk and ultimately eliminate it. As we pursue negotiations, we must maintain strong and effective military programs that will deter Soviet aggression. But it is folly to pin our hopes on the chimera of a perfect or safe defense."

Senator Gary Hart, Colorado Democrat, in a statement to the press after the President's March 23 speech:

> "If, in fact, we could build a defense system that would effectively protect our people, I would be the first to buy it. However, simply stated, President Reagan's proposal is a cruel hoax on the American people, and it is a dangerous hoax . . . a cruel hoax because technically there is no basis for believing a completely effective nuclear defense system can be built."

Robert Strange McNamara, former secretary of defense, writing in a Feb. 23, 1983, New York Times *op ed:*

> "Having spent seven years as Secretary of Defense dealing with the problems unleashed by the initial nuclear chain reaction 40 years ago, I do not believe we can avoid serious and unacceptable risk of nuclear war until we recognize, and base all our military plans, defense budgets, weapons deployments and arms negotiations on the recognition that nuclear weapons serve no

> military purpose whatsoever. They are totally useless—except only to deter one's opponent from their use."

Dr. Richard L. Garwin, IBM research fellow and long-time military advisor to the government, writing in a March 30, 1983, New York Times *op ed:*

> "Mr. Reagan's question, 'Wouldn't it be better to save lives than to avenge them?' does not go far enough. Far better than saving some unknowable number of the 150 million or more Americans who might die in a nuclear war is saving all of them by preventing that war, through 'deterrence of aggression by promise of retaliation.'. . . We should accept the reality of deterrence by threat of retaliation, make a strong effort to reduce the number of warheads from some 20,000 on each side to 1,000 each and seek a total ban on nuclear tests. We need a ban on all weapons in space and on damaging or destroying satellites."

Senator Edward Kennedy, Massachusetts Democrat, commenting March 24, 1983, on the President's speech:

> "The Democratic alternative in the House is a far more responsible answer to the real defense needs of our nation than the misleading red-scare tactics and reckless Star War schemes of the President."

The Beam Men

Dr. Edward Teller, nuclear physicist and "father" of the hydrogen bomb writing March 30, 1983, in a New York Times *op ed:*

> "Mr. Reagan explicitly stated that the answer to offensive weapons cannot remain deterrence by retaliation. . . . The conversion from mutually assured destruction to mutually assured survival is what Mr. Reagan wants to accomplish. It would benefit not only our children and those of our allies, but also children in the Soviet Union as well. If high technology can be used for

this purpose, fear will be replaced by an atmosphere in which we will no longer need worry about the consequences of sharing our technical applications with anyone in the world—in which real cooperation, the basis for peace, will become possible."

Dr. Martin Summerfield, professor emeritus of engineering at Princeton University and former chief of rocket propulsion at the Jet Propulsion Laboratory, writing in an April 8, 1983, letter to the editor in the New York Times:

"My opinion, based on more than four decades in government-sponsored research and development of rocketry and space systems and more than three decades in aerospace engineering, is that these skeptics underestimate the intellectual capacity and initiative of the American scientist-engineer. . . . There is nothing impossible in the program laid down by the President."

Columnist Meg Greenfield writing in Newsweek, *April 4, 1983:*

"It is an astonishment to me that 14 years after our own first landing on the Moon, and in an age habituated to mind-boggling scientific achievement. . . 'Buck Rogers' and 'Star Wars' should be dismissive terms of ridicule for a proposal such as Reagan's. . . . I wish the status quo nuclear gang would try to improve on Reagan's thought, not merely satirize it."

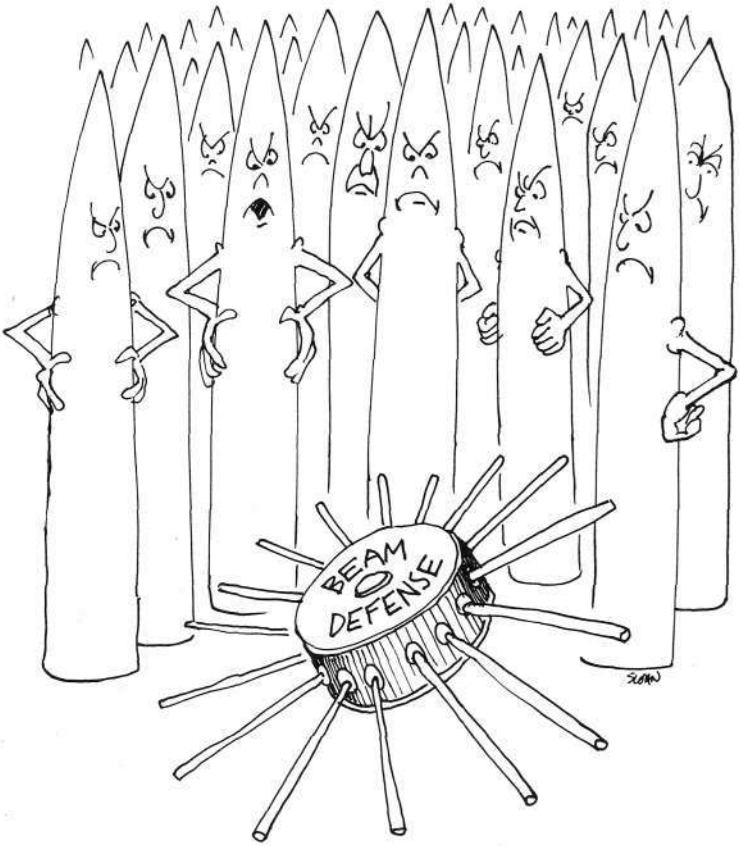
Dr. George Keyworth, presidential science advisor, in a speech to the Electronics Industries Association, April 20, 1983:

"The United States' and the world's best hope for continued peace and security lies in our ability to employ the best technology to make revolutionary changes in our defense systems. I can think of no clearer illustration of that than President Reagan's proposal last month for a radically new strategic defense. . . . I refuse to believe that we have to be resigned forever to mutual assured destruction. . . .

"We should consider how new knowledge and new technology might change the way we view these issues in the future. And we should be looking at what technologies to pursue more rigorously."

Lyndon H. LaRouche, Jr., leader of the National Democratic Policy Committee, in a March 26, 1983, statement to the press:

> "No longer must Democrats go to bed each night fearing that they must live out their lives under the threat of thermonuclear ballistic terror. The coming several years will be probably the most difficult of the entire postwar period, but, for the first time since the end of the 1962 'Cuban Missile Crisis,' there is at last hope that the thermonuclear nightmare will be ended during the remainder of this decade.
>
> "Today, I am prouder to be an American than I have been since the first manned landing on the Moon. For the first time in



Well, there goes the neighborhood

> 20 years, a President of the United States has contributed a public action of great leadership, to give a new basis for hope of humanity's future to an agonized and demoralized world. True greatness in an American President touched President Ronald Reagan last night; it is a moment of greatness never to be forgotten. . . ."

Senator William Armstrong, Colorado Republican, in remarks to the Senate, March 29, 1983:

> "The President has opened a new vista toward eliminating forever the nightmare of nuclear war that has been a plague in the world's consciousness for nearly 40 years. . . . It is not a course free of hazard, but it is the mark of a true leader to recognize that there is no such thing as a major advance without risk. Because of the President's leadership, mankind may be able once again to reach for a world governed by security, reason, and hope."

Dr. John D. G. Rather, high energy laser expert, writing in the Dec. 1982 Defense Science 2000+:

> "High energy lasers hold vital promise for replacing weapons of mass destruction with vastly more versatile and benign weapons having a highly surgical nature. While serving as major deterrents to total war, if intelligently parlayed, such lasers can also provide mankind with major nonfossil energy options, a quantum leap ahead in opening space for massive human endeavors, and enormous new defense and commercial opportunities in remote sensing, communications, photochemistry, etc."

The Soviet View: The U.S. Should Not Develop Beam Weapons

In the several statements Soviet Communist Party General Secretary Yuri Andropov made to the press commenting on President Reagan's

March 23 proposal, the message remained the same: The United States should not develop beam weapon technologies. The chief omission also remained the same; Andropov made no mention of the Soviets' extensive beam weapon development program.

Here is Andropov's argument, as he presented it in an interview to the West German news weekly Der Spiegel, *April 24, 1983:*

> "The current situation is complicated and dangerous because the arms race, which is forced upon us by the West, threatens to overtake the [arms] negotiations. In order to avoid this, and create favorable conditions for leading negotiations, it is necessary on the basis of healthy common sense, to freeze the nuclear arsenals of both sides. . . .
>
> "The facts state that the United States has entered the path of an unprecedented arms race in every field, that they are pushing international tension to the utmost limit.
>
> "Concretely, among other things, I mean the plans proclaimed by Washington to develop a broad-based, efficient, antimissile defense. The adventurism and danger of this whole plan lies in the calculation that it is possible to emerge unscathed—that a nuclear first strike can be launched on the assumption that one is safe from counterattack.

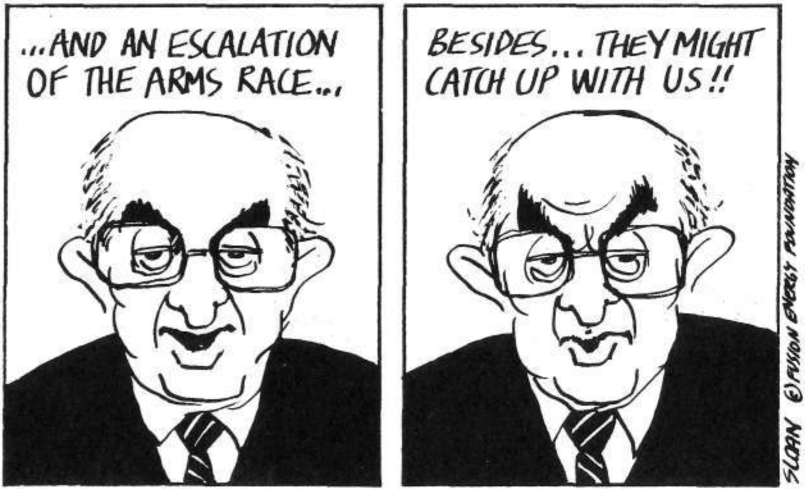
"This is not far removed from the attempt to place a finger on the launch button. That is where the danger of the new U.S. military concept lies. It can only bring the world closer to the nuclear precipice. This demonstrates that while speaking about defense, in reality a mine is put under the whole process of strategic arms limitation. . . .

"It becomes more and more obvious that the U.S.A. will include the development of space weapons in their military preparations. They want to threaten humanity with these weapons from space. This must not be permitted. Space must remain peaceful.

"We have proposed an international treaty against stationing weapons of any kind in space. . . ."

On April 9, 1983, a statement signed by 244 Soviet scientists against President Reagan's March 23 call for the development of defensive beam weapons said:

"Proceeding from the understanding of the basic nature of nuclear weapons, we declare in all responsibility that there is no effective defensive means in nuclear war and their creation is not practicably possible."



Chapter 4

Firepower: Beams Have It!

When a beam weapon hits and destroys a nuclear missile, it is using a higher, more precise concentration of firepower than *any* previous weapon. That is the secret of its success.

Throughout history, the advantage in warfare has always been on the side that could achieve the greatest concentration of firepower at the right place and time. At the battle of Crecy in 1346, for example, the powerful and rapid-firing English longbow won out over the crossbow. After routing the crossbowmen in the front ranks, the longbowmen made mincemeat of wave after wave of heavily armored French knights on horseback. Though outnumbered more than three to one, the English lost only 100 men of all ranks, while the French lost 10,000!

With the introduction of gunpowder and steady improvements in the design and engineering of guns, the bow and arrow disappeared. As a technology it had reached its limits, and by 1590, the bow and arrow was thrust aside and replaced with a *higher technology*—gunpowder—capable of greater concentration of firepower without loss of mobility. What made it a higher technology? It employed a *more efficient physical principle:* chemical combustion.

Improvements in firepower and mobility continued to provide the military advantage. At the beginning of the 19th century, Napoleon beat the best armies in Europe. This was not because of improvements in cannon design, but because French scientists developed a method of cheaply producing large numbers of mobile cannon.

In World War II, Germany and Japan were defeated as the industrial might of the United States was mobilized to give the Allied forces an overwhelming advantage in quality and quantity of weapons. One major flank in the defeat of Germany was the intense concentration of aerial bombardment—firepower—on Germany's energy production and its transportation lines to the front.

In the 30 years since World War II, strategic warfighting has relied upon an entirely new, higher technology—a more efficient physical principle—the thermonuclear explosion or H-bomb. In comparison to the H-bomb's firepower, the concentrated aerial bombing of World War II has more in common with the crudest blunderbuss of Christopher Columbus's time—with which it shares the principle of chemical combustion.

Until recently, there has been no sure way to stop the guided missiles that deliver the lethal H-bombs, although various anti-missile missile systems were proposed and tested by the United States in the 1960s. For the first time in history, there has been a weapon—the nuclear-armed intercontinental ballistic missile or ICBM—for which there is no defense.

Nevertheless, a guided missile carrying its nuclear warhead is still only a highly destructive and precision-guided form of old-fashioned artillery, relying on chemical combustion for its mobility. The one way to defend against such guided missiles would be to destroy them using a higher technology. Directed energy beams—laser or particle or microwave beams—are just such a technology. These intense, highly focused beams project large energies at the speed of light to find and kill an ICBM. While the missile may reach a speed of a few thousand miles per hour in its boost phase, a laser beam travels at 186,000 miles *per second*—the speed of light. *That's about 300,000 times faster!*

A Ground-Based Beam Defense System We Could Have in Five Years

Scientists in the national laboratories estimate that ground-based laser stations built on mountaintops, with space-based mirrors to focus the beam on the target, could be in place in five years, ready to defend against accidental ICBM launches or launches by runaway third parties (but not against an all-out nuclear attack). All the technologies for this system now exist or have been tested in the laboratory; it is simply an engineering job to put them together in an operational defensive weapon system.

As shown in Figure 4-1, the beam is generated by a large chemical laser on a mountaintop, which eliminates problems of remote maintenance and refueling, or of launching the heavy laser into orbit. By placing them on mountaintops of at least 12,000 feet altitude, the problem of propagating the beam through the atmosphere is diminished; only 20 percent or less of the beam's energy is lost in passing through the atmosphere.

By using large mirrors in space like the one shown, the ground-based laser could provide protection for our missile silos, or cities, or other areas to ensure that an accidental launch was stopped. The mirrors orbit the Earth and are spaced closely enough so that before one mirror goes out of range of the laser, another has already come over the horizon. The mirror gathers the laser beam sent from the ground and focuses it on the targeted missile.

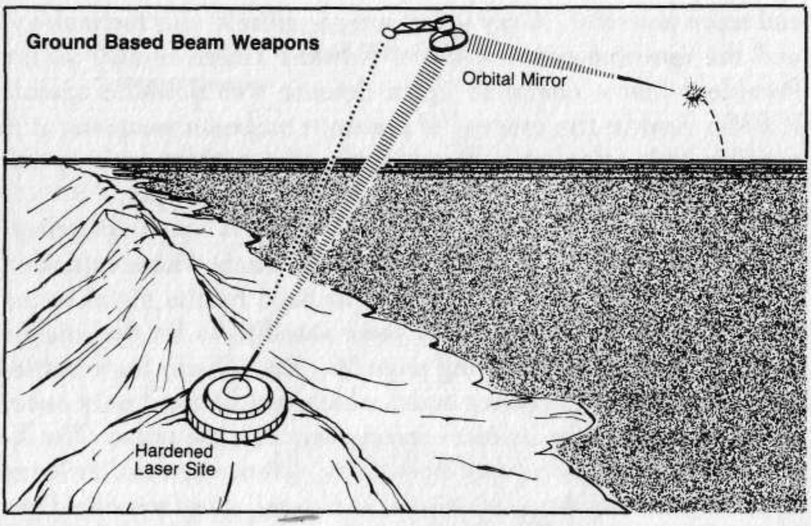


Figure 4-1
Ground-Based Beam Weapon System

Within five years, the United States could develop a beam weapon system of the sort shown here. This design is a ground-based laser-beam weapon system built on a 12,000-foot mountaintop. A relay mirror in orbit around the Earth provides aiming and tracking. 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 beam generation is accomplished totally on 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, almost perfect transmission of the laser light can be achieved with long wavelength chemical lasers.

A Space-Based Beam Defense

A more advanced "layer" of our beam weapon defense system would be based on the X-ray laser. This type of laser has wavelengths that are shorter and of higher frequency than the chemical laser of the first-generation system, and it is thus much brighter and more powerful. X-ray lasers are an entirely new technology, and the one that convinced Dr. Edward Teller as well as the President that a complete beam defense was possible against ICBMs. And in the process of research on beam weapons, it is possible that scientists will come up with another, entirely different laser or particle beam technology to do the job.

Unlike chemical lasers, the X-ray laser is small, compact, and lightweight; its fuel is a small nuclear bomb, whose explosion produces the X-rays that are then focused by the metal lasing rods sticking out of the X-ray laser satellite to hit the missile target. (See Plate 1 following page 56.) Each X-ray laser battle-station has 30 to 50 lasing rods, which can be fired only once. The X-ray laser hits its mark in one very intense pulse. The X-ray pulse is so intense, that no passive defense against an X-ray laser is possible; in other words, the missile surface could not be modified to prevent the laser from destroying the missile.

It would take about 50 laser battle stations in space to provide complete protection against an all-out nuclear attack on the United States or its allies. Such X-ray laser stations could remain in orbit at all times, or could "pop up," be sent into orbit upon alert. This "pop-up" system is the one preferred by some scientists, like Teller.

As shown in Figure 4-2, no mirror is necessary. The X-ray laser battle stations would each have a set of infrared telescopes and computing equipment for detection of missiles and decoys as they are launched. The telescope and computer combination can follow the ICBM missiles' precise locations and calculate their trajectories.

On the ground is the battle command and control center that includes a main computer and communication links. A separate rocket-borne probe of sensors and telescopes is launched on detection of a missile attack and as guidance for auxiliary anti-missile systems. Early warning of missile launchings is achieved by satellites already in orbit today.

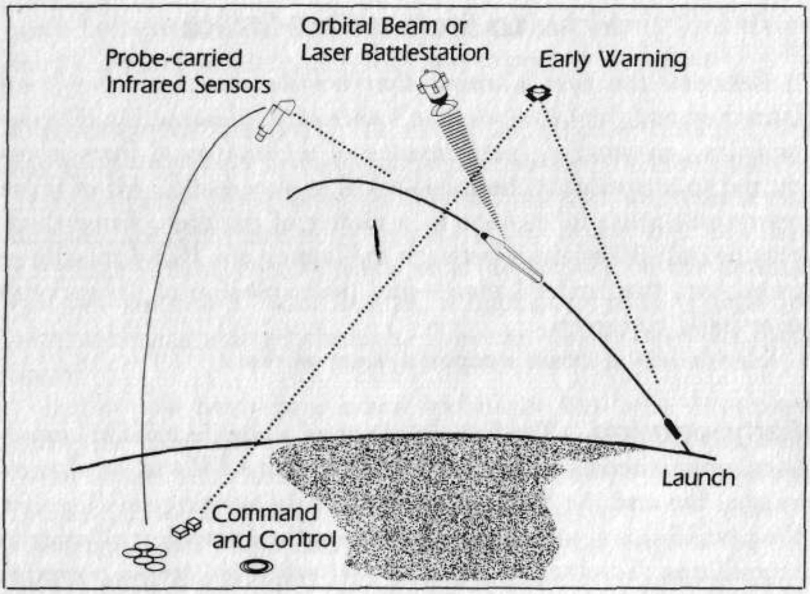


Figure 4-2
Space-Based Beam Weapon System

Shown here are the basic components of a space-based beam weapon system, which provides area defense against nuclear missiles. The deployment of approximately 50 satellites, each with a weapon capable of generating an intense beam of laser light, would protect the entire United States from incoming ballistic missiles. The satellites could be stationed in orbit or "popped-up" upon alert. The satellite would also contain 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 ground-based battle management center 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 ballistic missile attack. These sensors would provide secondary target detection and identification, as well as guidance for auxiliary antimissile systems using conventional weapons.

How to Stop a First Strike

Between the first warning that hostile missiles have been launched and the beam weapon's successful destruction of those missiles, an amazing performance of technological feats is required to ensure that the missile kill is successful. All of these operations must take place in a matter of minutes, since there may be only 30 minutes between the launch of a ICBM missile—from, say, the Soviet Union—and the explosion of its warhead over its U.S. target.

Here's how a beam weapon system works:

Early warning. The first detection of a hostile missile launch is accomplished by satellites. This part of an ABM system already exists. We and the Soviets have had early warning satellites for the past 15 years, and both countries routinely monitor all missile launchings. Telescopes on some spy satellites are so powerful that they can make out the headline on a newspaper being read by a man standing in Moscow's Red Square! Our satellites know within seconds when any missile is launched in the Soviet Union.

Early warning signals tell the U.S. central command post—buried more than half a mile beneath Cheyenne Mountain, Colorado—to launch several rocket-borne probes from their shelters in the United States. Each probe consists of an infrared (heat sensitive) telescope, a computer, and communications equipment for reporting to Earth. The probes orient toward the threat corridor reported by the early warning satellite, and from distances up to a few thousand miles, the computer calculates the trajectories of the missiles and detects the decoys.

Calculating the trajectories. The probe sensors immediately track the missiles, reporting to the computers where they are and what curve or trajectory each is making. This allows the computers to calculate in fractions of seconds where the missiles were launched (that tells you who launched them), and where they will land (what targets they are expected to destroy).

Detection of decoys. To make the defense difficult, the aggressor can send up several decoys for every armed missile. The decoys are cheap because they are much lighter than armed missiles and therefore need only a fraction of the fuel. But they are made to look exactly alike from the outside. If the defense can be "saturated" with decoys, a high proportion of missiles with warheads will get through. How can the defense tell them apart?

In the past two years, a new technique has been developed using the long wavelength infrared telescope to tell the light decoys apart from the heavy nuclear-armed ICBMs. As they climb into space, the light decoys cool much more quickly; the infrared telescope "sees" heat and changes in heat, and reports this information to the computer. A single telescope can follow many missiles at one time, reporting the behavior of each.

Aiming. To track and hit an ICBM, "pointing" or aiming of the beam weapon must be accomplished that is beyond the imagination of the most expert sharpshooter. To hit a target hundreds or thousands of miles away, the beam weapon must be aimed with an accuracy of .1 microradian—that is just about *6 millionths of 1 degree*. This is like taking aim in New York to hit a dime held aloft in Washington, D.C.! Yet civilian satellites already in operation have *more* than this degree of accuracy. NASA's Space Telescope, built by Lockheed and scheduled to go into orbit in 1986, will have greater than this high degree of accuracy to hold its fix on distant stars while photographing them.

In the case of mirrors for beam weapons, we will require mirrors with a diameter somewhere between 5 and 10 meters (between 200 and 400 inches). The famous 200-inch telescope on Mount Palomar in California was built almost 50 years ago. A revolution

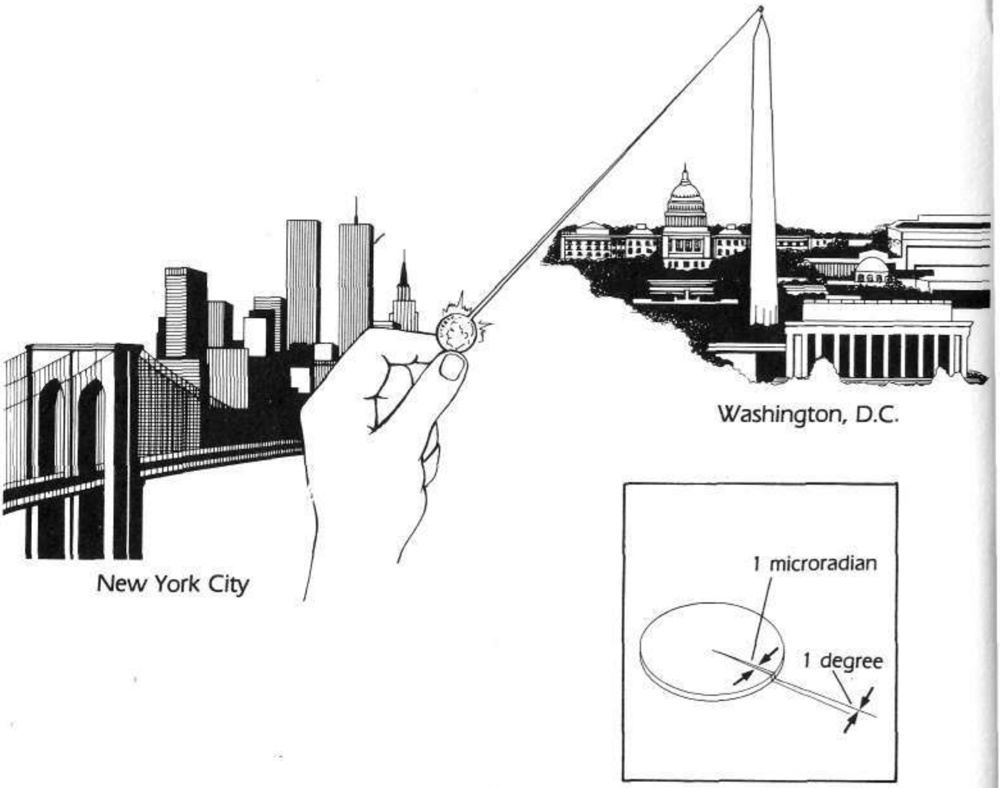


Figure 4-3
Pinpoint Accuracy at 3,500 Miles

The amazing precision necessary for aiming a beam weapon at a target as much as 3,500 miles away is already here! The thin sliver of pie above is one degree, or 1/360th of a full circle. To hit a target 3,500 miles away, the beam weapon must be aimed with an accuracy of about 6 millionths *of that 1 degree, one tenth of a microradian. This is like taking aim in Washington D.C. to hit a dime in New York. Yet civilian scientific satellites already in operation have more than this degree of accuracy.*

in telescope mirror construction to solve the problems of very large mirrors is under way at this very moment. Astronomers at McDonald Observatory, University of Texas, have a 300-inch mirror under consideration, and work being done by Roger Angel at the University of Arizona is contributing to the project. Recently, United Technologies offered to build a 400-inch mirror on a fixed-price contract.

Tracking. Since it takes time for conventional laser beams to burn the target missile sufficiently, the beam must be kept moving along with the missile. The required accuracy of tracking is expressed as .1 microradian per radian per second. A radian is a very small measure of angular movement of the beam pointer as it follows the target. A microradian is one millionth of a radian. So this requirement means that if the beam is sweeping out an angle of one radian per second as it follows the missile, the beam cannot "wander" by more than 1 ten-millionth of a radian off its course. This is the incredible accuracy with which the pointing and tracking devices must guide the beam.

Such accuracy *has been demonstrated* on the latest generation of gyroscopes in laboratory tests. Now we need the engineering to attach such a gyroscopes to a telescope for use in a laser system. It should be noted that the X-ray laser is so bright, that no tracking system is needed!

Firing. All it takes to disable a missile is the energy of about ten .45 caliber bullets if this total energy is delivered in several smaller pulses! A chemical laser can do that. The X-ray laser, however, can give only one pulse because it is triggered by a small nuclear explosion. This harmless nuclear explosion in space sends X-rays down the metal rods, each aimed at a missile. But the X-ray laser station is destroyed in that one pulse, to be replaced if necessary by a rocket carrying new ones. Of course, the X-ray laser more than makes up for its inability to send several pulses by its tremendous brightness.

Chapter 5

How a Beam Weapon Works

A blast from a beam weapon has less energy than 10 bullets from a high-powered rifle; yet it is capable of destroying a ballistic missile many thousands of miles distant in a tiny fraction of a second. This combination of small energy, very high power, extreme accuracy, and large range is what makes a beam weapon so ideal. If the target can be seen, it can be hit with a surgical application of energy whose total amount is small, but whose power is so large that the target is destroyed. It is the difference between being hit by a thousand snowballs over 20 winters or by a bullet just once.

Every kind of beam weapon is able to generate these intense blasts of energy with exceedingly high accuracy. Beam weapons, whether of optical lasers, X-ray lasers, elementary particles, macroparticles, microwaves, or plasmas, all work because of this combination of intense energy and accuracy. However, each of these systems works in a totally different way.

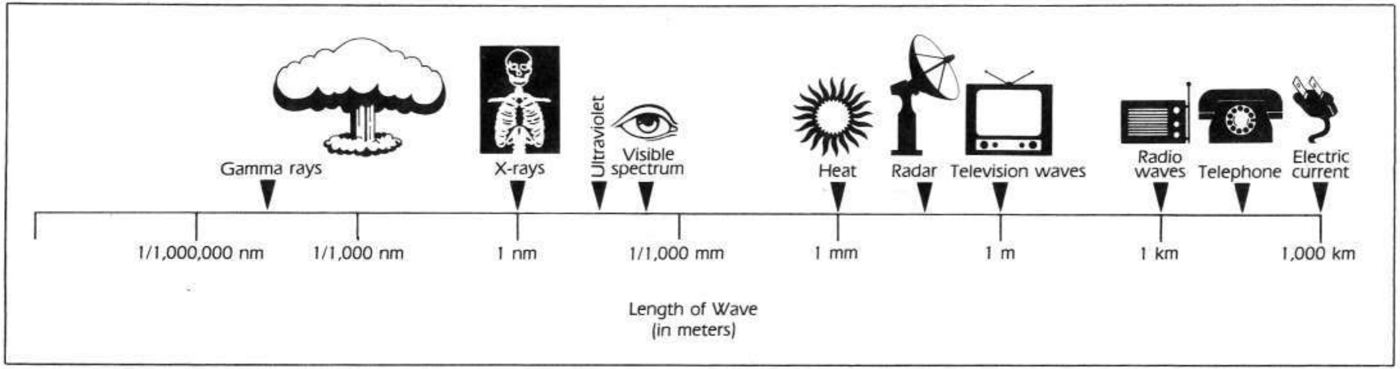


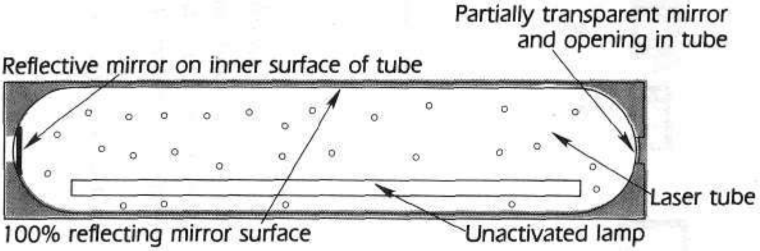
Figure 5-1
The Electromagnetic Spectrum

The electromagnetic spectrum can be divided into characteristic ranges based on the wavelength of the radiation, which determines the energy of the radiation. At the shortest wavelengths, high energy X-rays (gamma rays) exist. As the wavelength increases, X-rays of medical interest, ultraviolet radiation, and visible light appear. At slightly longer wavelengths, infrared radiation (radiant heat) and microwaves are the form of electromagnetic radiation. At the longest wavelengths, radio waves and electrical oscillations carry electromagnetic energy.

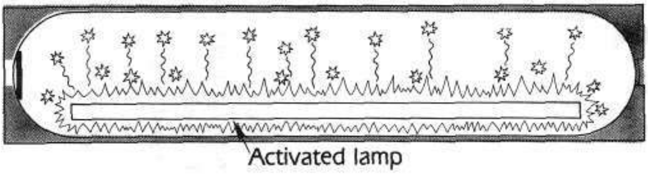
The frequency of the wavelength decreases in proportion to the length of the wave. Thus the shortest wavelengths are those of the highest frequency.

Figure 5-2

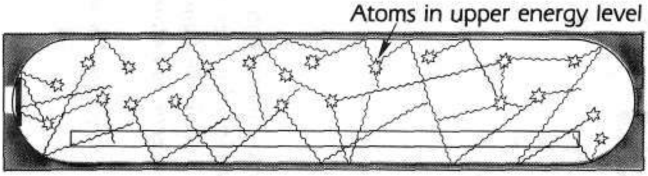
How a Laser Works



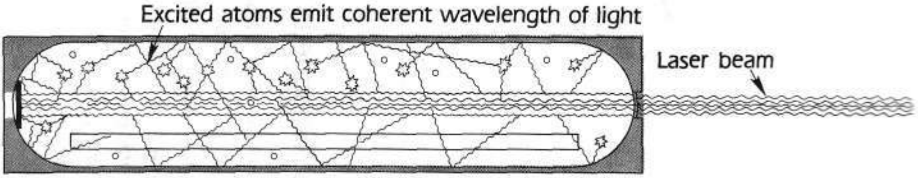
a *Laser tube with atoms of a gas at their normal energy level.*



b *The atoms are excited to higher energy levels by absorbing their characteristic wavelength from white light.*



c *As the atoms "de-excite," they emit their characteristic wavelength, and that wavelength only. This can occur either spontaneously or by encountering the emission of another atom. The reflective inner walls of the laser tube reflect these light waves back into the tube and toward other atoms, causing them to emit light also.*



d *Some of the light waves are allowed to leave the tube, in this case through a semitransparent portion of the mirror and an opening in the tube wall. These waves emerge as a coherent beam of light, a laser beam. The beam is aligned as a result of reflections back and forth between the reflecting mirror at the left and the semitransparent mirror on the right.*

Optical Laser Beam Weapons

In an optical laser beam weapon, an intense beam of highly organized "light"—electromagnetic energy—carries energy from the weapon to the target. This beam is propagating in the *infrared* part of the electromagnetic spectrum (see Figure 5-1) and would be more accurately called a beam of heat, or a heat ray. This heat ray, when it hits the outside of a ballistic missile, literally burns through the skin of the missile, melting the outside and weakening the structural parts of the missile. In addition, the heat may cause the missile's fuel tanks to rupture and the missile to explode. In either case, the missile—already a fragile machine exposed to tremendous mechanical stresses during its boost phase—is physically disabled by the beam energy, and the missile falls back to Earth.

To generate the heat ray, an infrared laser is required that can convert chemical, nuclear, or electrical energy into highly organized electromagnetic radiation. A chemical laser uses volatile—easily excited—gases (such as hydrogen, deuterium, or fluorine) to generate infrared light. A gas dynamic laser uses a carbon dioxide gas excited by an electron beam to create the light. Many variations of such devices exist. The highest energy single-beam laser in the world is a chemical infrared laser—the 2.2-megawatt Sealite chemical laser developed by the U.S. Navy for beam weapon research.

Optical lasers operate in a three-step process to produce their light (Figure 5-2). First, energy from a chemical reaction, electricity, or other light energy (from "flash lamps") is used to prepare the lasing medium. The medium absorbs the energy and enters into an unstable energy state. In this energy state, the second step is the introduction into the medium of a "seed-crystal" (called a laser oscillator), which condenses the energy in the system into a single frequency of light energy. The energized medium releases all its energy at the same frequency as soon as it receives the signal from the laser oscillator. The net result is that a large amount of disordered energy has been converted (with some loss of total energy) into a smaller, but very intense, amount of highly ordered energy. This ordered energy is then further ordered and focused in the third step, the use of a set of mirrors to force all the light energy into a form in which it is traveling in exactly the same direction and with all the waves in step or in phase.

The resulting light beam is very highly focused, easy to control, and capable of carrying millions of times as much energy as a conventional light beam. This laser beam can be used for jobs as delicate and precise as eye surgery, or for the massive jobs of welding steel, cutting rock, or destroying ballistic missiles.

X-ray Laser Beam Weapons

An X-ray laser beam weapon uses an intense beam of highly organized X-rays to carry energy from the weapon to the target. This beam of light is in the X-ray part of the electromagnetic spectrum, with a wavelength of only .04 micron. When it hits the outside of a ballistic missile, the X-ray beam destroys the missile by the shock wave it creates; the effect is much like hitting the missile with a sledge hammer. The shock wave heats the outside of the missile and weakens its structural parts. The missile is either crushed, ruptured, or broken into pieces, and it falls back to Earth.

To generate an X-ray beam powerful enough for weapons applications, a nuclear-pumped laser is required. (There are, however, laser-pumped X-ray lasers for nonmilitary applications in biology, chemistry, and other sciences.) A nuclear-pumped laser uses a nuclear explosive that is small by bomb standards—on the order of 1 to 10 kilotons of high explosives—to excite a solid-state lasing medium, most likely a heavy metal like zinc. The

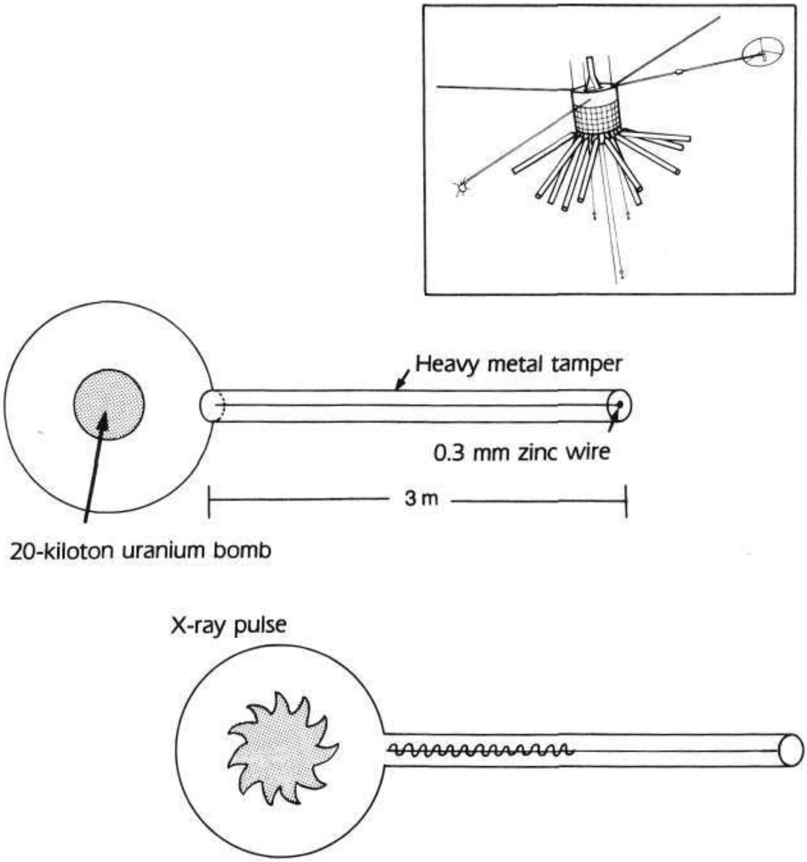


Figure 5-3
X-ray Laser Configuration

This conventional design for an X-ray laser uses an exploding atomic bomb to generate a broad spectrum of high energy X-rays. Exploded in a spherical cavity, the bomb irradiates the ends of the lasing rods surrounding the cavity. When the X-rays from the bomb ionize the solid-state lasing medium, they produce a pulse of collimated, monochromatic X-rays that travels down the rod. Inset in an artist's depiction of an X-ray laser system based on a 1981 Soviet description of tests of X-ray lasers by the Lawrence Livermore National Laboratory in 1980. Other X-ray laser configurations appear in Figure 8-1 and Plate 19, following page 56.

excited zinc then produces a pulse of high-energy X-rays. (One proposed X-ray laser design is shown in Figure 5-3.)

An X-ray laser uses only a two-step process, and the resulting beam is more difficult to control. This is a result of the fact that no mirrors exist today that are capable of reflecting X-rays more than once. However, this is a great advantage for the job of destroying ballistic missiles. Many scientists believe that in the future, it may be possible to construct an X-ray laser using a different scientific principle from the nuclear-pumped X-ray laser. This X-ray laser would use another, infrared laser as a "flash lamp" to excite the medium. The resulting X-ray beam would have much lower energy than the nuclear-pumped beam, and could be used for very detailed microscopic studies. Preliminary research on these lasers indicates that they would be able to "see" individual molecules in a living cell. Such a laser would be the greatest development in medical science since that of the electron microscope.

Elementary Particle Beam Weapons

Particle beams as defensive weapons, while posing more difficult scientific challenges than high-power lasers, share the same basic advantages of "firepower" over existing weapons technologies, and then some. They can deliver a much greater shock to a missile, because they have greater mass than waves of light, and because they have special electromagnetic properties. When we develop these advanced forms of beam weapons, we will attain a much greater degree of freedom and flexibility in their deployment. They will be the ideal beam weapons for "terminal defense"—defending a targeted area or military point against separated nuclear warheads that have "leaked" through long-range defense. These warheads are much harder, more maneuverable, and faster moving than missiles in their earlier stages of boost-off and flight.

Particle beams, like lasers, deliver energy in a controlled pulse traveling at up to 99 percent of the speed of light. But the energy is carried in three kinds of mass—subatomic particles (electrons or protons); neutral atoms (usually hydrogen atoms); or even larger particles like "bullets." The physical impact is like the shock delivered by a lightning bolt or a powerful hammer. Other kinds of shock effects, like those of electromagnetic radiation, play a "backup" role to the mechanical shock of the blow of the particle beam. The missile is shattered under the combined impact of the mechanical shock, the electrical energy, and the heat energy. Many scientists also believe that the pulse of electrical energy will destroy the electronics of the missile guidance system, even if the missile is not directly disabled by the bolt.

All particle beams are generated, or accelerated, by the same basic method. A strong, moving magnetic field—a magnetic wave—is used to drive the particles to high speed. Most interesting is what happens once the acceleration to relativistic velocity has been achieved.

An accelerated, high-energy electron beam behaves according to laws unexpected when the techniques of acceleration were developed. The beam acts *as a beam,* not as a stream of single particles. It generates a complex internal structure, a tightly bundled sheaf of separate electron beams wound around each other like stripes on a barber pole. The beams are bound in by the magnetic fields they generate around themselves. This protective magnetic shell concentrates each individual beam, and enables the overall beam to propagate in a stable manner over a long distance, with a high current of electrons and a high power level.

To accelerate high intensity beams of electrons an electrical accelerator is required. These new accelerators, like the Advanced Test Accelerator under construction at Lawrence Livermore Laboratory, use very high electric and magnetic fields to produce high-energy electron beams.

Proton beams, a specialty of Soviet beam weapon research, require an accelerated electron beam as a "seed," and are then accelerated in their own right. Electromagnetic interaction between the protons and the electron beam drives them to the same velocity as the electrons, and the proton beams form to a large extent on their own. An electron beam is shot into a plasma. Because of the energy-focusing characteristics of a plasma, this electron beam pushes the protons or positive ions in the plasma along *at the same velocity* as the electrons. But, because positive ions are at least 2,000 times heavier than electrons, if they travel at the same velocity as the the electrons, they have an energy level 2,000 times as high as the input electron beam.

This is a striking example of the use of the extraordinary internal characteristics of a high-energy plasma as a medium for the amplification of a directed energy beam that is propagating through it. Other such examples will be described below; in fact, even laser beams, although they may or may not use a plasma as a medium, depend on the same principle. The initial input "shock" of energy into the medium causes an internal transformation of the medium that enables it to greatly amplify the power of the incoming energy.

Thus, the so-called plasma collective accelerator can be used to amplify the energy of an input *electron beam* and generate a very high energy *proton* or *ion beam*.

High energy proton beams can also be generated by a variation of an electron accelerator. Such devices exist in laboratories around the world, the largest being the Particle Beam Fusion Accelerator at Sandia National Laboratory in New Mexico. This device generates 30 beams of high energy protons.

Neutral particle beams also use accelerated beams of charged ions as a "seed," since magnetic fields cannot accelerate neutral particles like hydrogen atoms. So the atoms are first ionized into a plasma of separate positive and negative ions, and these are accelerated together as electron and proton beams. When these beams pass through a thin gas, they are "neutralized" by picking up and carrying along particles of opposite charge. But they retain their very high velocity, now as a beam of neutral particles. This technology first arose in the fusion program, where such beams are used to heat up magnetic fusion gases.

Finally, the magnetic wave can be used to accelerate large particles like "bullets" along a track, called a "rail gun," in exactly the same way the newest high-speed magnetically levitated trains are driven along a railroad track. For anything from trains to antimissile macroparticles, a moving magnetic field can accelerate to much higher speeds than the heat energy from any engine. And the efficiency of transfer of the magnetic energy to energy of motion can be as high as 90 percent.

According to U.S. experts, the Soviet Union has a large program to develop macroparticle acceleration for antiaircraft, antimissile, antiship, and antiarmor weapons. There is no known armor that could withstand even a small projectile moving at these velocities (up to 30 miles per second) if it can be aimed and controlled.

Microwave and Plasma Beam Weapons

More advanced concepts for beam weapons envision the use of intense beams of microwaves (a form of electromagnetic radiation like radar) or beams of plasma (similar to electric arcs) to carry energy. These devices are much less perfected than their laser or particle beam competitors.

Microwave beams are generated by very intense electron beams in a magnetic field. These beams will produce microwaves many times more intense than the most powerful radar systems. Plasma beams are produced from devices called plasma guns, which puff out high energy "smoke rings" of plasma. Both of these devices exist today in small laboratory experiments, but they may, in the future, become the ideal third generation beam weapon because of their high efficiency.

Microwave generators produce a beam that travels well through the atmosphere, is very effective in destroying electronics on missiles, and does not require extensive pointing or tracking equipment. Plasma beams offer the potential of a whole new order of beam phenomena, which points toward self-guiding systems. (See Chapter 16.)

The Future of Beam Weapons

Beam weapons, unlike conventional weapons, have an almost unlimited possibility for improvement. As the wavelength of the radiation in laser beam weapons becomes shorter—that is, as the *frequency* of the electromagnetic radiation increases—the energy and power of the beam increase. At a higher frequency, the beam delivers *more* energy *faster* and in a more concentrated form, to the surface of the target it hits. This is the reason for the tremendous superiority of the X-ray laser over optical lasers; very short wavelength, high frequency X-ray radiation destroys the target more quickly and more effectively, by shock waves rather than heat. And, as the wavelength is shortened even farther in future technologies, a gamma ray laser may be made that will be as great an improvement over the X-ray laser as the X-ray laser was over optical lasers.

Similarly, particle beam weapons can be extended almost indefinitely by using heavier particles. As the mass of the particle increases, the same effect is achieved as in the case of electromagnetic radiation: the target is destroyed by stronger and stronger *shock waves*. As effective as an electron beam weapon will be, a "heavy" electron beam will be even more so. Such a beam will be made of particles called *muons*, which are identical to electrons except that they are about 400 times heavier.

Just as beam weapons will revolutionize warfare in the nuclear age, giving nations the means to protect themselves against nuclear bombardment, so beam *technologies* will transform all human work. In man's hands, directed energy beams of coherent

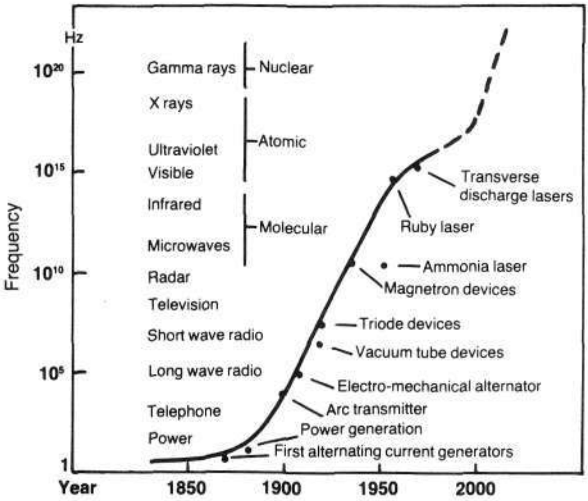


Figure 5-4

Chronology of Development of Sources of Coherent Electromagnetic Radiation

The points on the graph show the date of the first development of devices for generating coherent radiation in the range described in the list to the left of the graph line. The vertical axis shows the frequency in hertz. The development of infrared, visible light, and ultraviolet lasers increased the range of available frequencies of coherent radiation exponentially, a trend that will be continued with the development of X-ray and gamma-ray lasers.

Adapted from Baldwin, et al., *Review of Modern Physics*, Oct. 1981.

radiation—light, ultraviolet rays, X-rays, gamma rays, and particle beams—will unleash a profound, long-lasting revolution in the power of human labor and human scientific investigation. This is a revolution that has been overdue since the invention of radar during World War II and the invention of lasers 15 years later.

As Figure 5-4 shows, human civilization has, in a literal sense, been "climbing up the electromagnetic spectrum" since the discovery of the first means of controlling heat and using it for machines. The higher the frequency of radiation attained, the greater the power of the individual human being to transform and transmute matter. Yet, we have still mastered only a small part of the spectrum, as one can see. The beam weapon revolution, required for the urgent need of ending assured destruction by nuclear weapons, will open up the entire electromagnetic spectrum for our use by the next century.

Chapter 6

Why High Frequency Lasers Are More Effective Against Missiles

In June 1983, researchers at Los Alamos National Laboratory in New Mexico scored a major achievement in the development of efficient, short wavelength lasers for both thermonuclear fusion ignition and beam weapons. For the first time, they successfully "fired" a laser with a medium of krypton fluoride (KrF) gas, a maximum single-beam power of 20,000 joules (20,000 watts per second of delivered energy), and a laser light wavelength of only .25 micron.

Like all lasers, this high-power KrF laser generates a beam of light all at one frequency, or wavelength. But the KrF's characteristic wavelength is five to ten times shorter than that of the high-power chemical lasers under development since the 1970s for combination with orbiting mirrors to disable missiles at long range. In other words, the KrF's light wave frequency is five to ten times higher. This means that it has an order of magnitude greater efficiency in concentrating and focusing the delivery of its energy on impact with a target. Much more of the energy is "coupled" with the target, in a faster, shorter pulse of power.

The KrF also promises a good efficiency—4 to 7 percent—in conversion of its input electrical energy into the laser beam itself. It can be fired repeatedly in a short time, and it can be scaled up cost-effectively to large size.

These attributes make the new KrF laser unique among potential antimissile lasers.

A leading beam weapon proponent, Lyndon H. LaRouche, Jr., explained why such short wavelength lasers are most effective in a Washington, D.C. meeting two months before the Los Alamos announcement.

> If we concentrate even a fairly small quantity of wattage on a sufficiently small area, the concentration of energy can be made sufficient to "boil," so to speak, any material. This much seems to be explainable in terms of the widely accepted theory of heat; the second principle cannot be so explained. . . . Lasers have a property which is sometimes called "self-focusing." This is described more accurately by reporting that each range of the upper electromagnetic spectrum (that is, ranges of shorter wavelength) has very distinct qualities of harmonic resonance. In one range, this focuses the energy on the molecular scale, and in higher ranges, on the subnuclear scale. To cause a laser to work as desired, one must tune the laser to monochromatic frequencies such that very little of the laser's beam is absorbed by the medium through which it is transmitted, and the beam is tuned at the same time to the part of the spectrum of matter of the target selected. . . .
>
> The principles governing the way in which a coherent, directed beam does work on its target are, most immediately, the principles defined by Bernhard Riemann's 1859 paper, "On the Propagation of Plane Air Waves of Finite Magnitude," the principles of propa-

> gation of shock waves. In the process leading to the production of the shock wave, the upper part of the wave overtakes the midpoint of the wave, creating a steep front, which is the shock wave. The greater the ratio of the height of the wave to the length of the wave, the greater the tendency to produce shock. Obviously, the shorter the wavelength, the more work we get out of the beam we use, which is why the upper ranges of the electromagnetic spectrum are so attractive for us.

Shorter wavelength (higher frequency) laser light is qualitatively superior in "coupling" its light energy onto either a fusion fuel target or a military target. In crude terms, the percentage of the incident light energy that gets converted into a shock wave propagating through the target is greater. Less of the energy is used merely to heat the target. So the disabling (if the target is a missile) occurs by a fast punch, rather than a slower burn.

The Limits of Mirrors

For directly related reasons, the high-power KrF laser will be ideal for use in combination with large refocusing mirrors in orbit. An antimissile laser on earth (on a mountaintop or other high altitude site) propagates a beam that diverges slightly as it passes through the atmosphere. To minimize its loss of energy to the atmosphere the beam frequency must be tuned. But we also want to use a large mirror in orbit above the atmosphere to refocus the beam and direct it to the target over the horizon.

Short wavelength, high frequency lasers are highly desirable—but above a certain limit the frequency is too high to be refocused by any mirror material. When radiation gets into this high ultraviolet or X-ray range, all mirrors become transparent. This limit is at about .1 micron wavelength. Thus the X-ray laser, at a wavelength of only .04 micron, will use no mirror, nor need any. Although the X-ray laser will be superefficient in terms of target kill, it cannot propagate through the atmosphere at all, and must be fired from space.

The KrF type of laser will be a crucial complement to X-ray lasers in overall defense systems. At about .25 micron, this laser is near the very shortest wavelengths of laser light that can still be reflected and refocused by a mirror. By comparison, the large chemical lasers that are under development for antimissile systems generate laser wavelengths from 2.7 microns, down to about 1.0 micron.

Comparing the use of these high-power lasers with refocusing mirrors, the size of the mirror required to "catch" and reflect the beam decreases rapidly as the wavelength of the light gets shorter. While a 2.5 micron laser beam may require a mirror 10 meters (33 feet) in diameter, for example, a krypton fluoride laser with a .25 micron wavelength will need a mirror only 1 meter in diameter.

Since the refocusing mirrors must be incredibly smooth and evenly curved and must be put into orbit in space, this difference is extremely important in building a laser antimissile system.

Multiplying the Power

The krypton fluoride laser as a beam weapon (see Figure 6-1) will have other interesting characteristics. These foreshadow the new regimes of generation of power and work from energy technologies that will be discovered in the process of developing beam defense systems against ICBM attack.

The KrF laser is driven by a power source that is an electron beam. To convert the electron beam energy efficiently into laser energy, the resulting laser pulse must be only hundreds of billionths of a second long. This may seem minute enough, but for effective military applications or effective laser fusion use, the pulse must be compressed into an even shorter time—5 billionths of a second. This can be done using optical techniques, as follows:

Hundreds of mirrors break the initial 20,000-joule laser pulse into a number of smaller pulses, and then "stack" the pulses in a kind of waiting line that makes them into a single, repeated-pulse beam. In addition, the same system of "stacking mirrors" (the *accumulator* in the figure), which handles one 20-kilojoule beam, can take up to 30 other 20-kilojoule input beams from 30

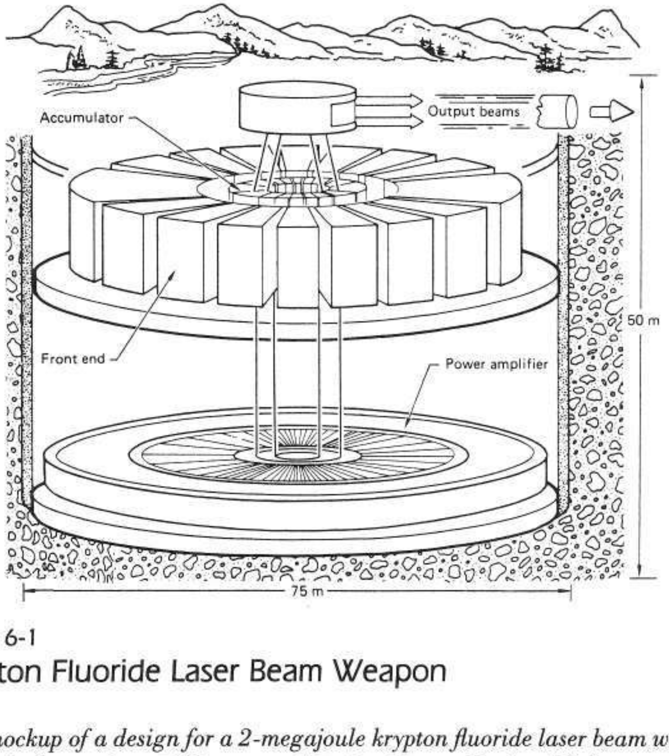


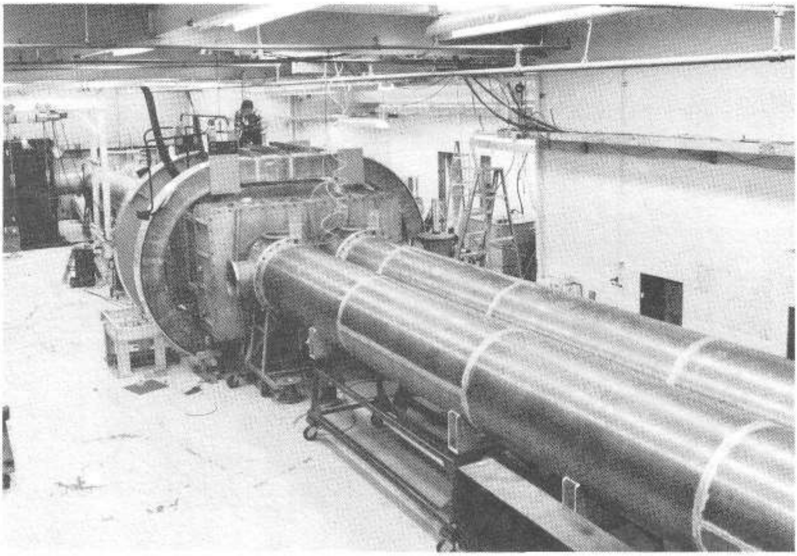
Figure 6-1
Krypton Fluoride Laser Beam Weapon

This mockup of a design for a 2-megajoule krypton fluoride laser beam weapon system is from a June 1981 report of the Los Alamos National Laboratory. The system would be buried in the ground and would have a pop-up turret for shooting the beam.

different KrF modules, break up all of these beams into supershort pulses, and "stack" all of these pulses together.

Finally, the pulsed beam is emitted and passed through still another thin gas medium, which interacts with the laser light to improve its optical quality and focus for long-distance, stable transmission through the atmosphere.

Such a large laser station will be used on the ground, as shown in the figure, and will operate both directly against incoming warheads, and in combination with orbiting mirrors for aiming the laser beam at missiles in any stage of their trajectory. Some mirrors could be kept "on station" in space all the time—but



The krypton fluoride gas laser at Los Alamos National Laboratory. In the foreground is a long section of pipe through which electrons pass. The electrons energize containers of krypton-fluoride gas located between the two large magnets that are used to generate the magnetic fields that confine the flow of electrons.

Fred Rick/Los Alamos National Laboratory most would be placed aboard backup rockets and launched only if needed.

After the KrF laser is brought on line, a second generation system can be developed by combining it with a free electron laser, which could increase the overall efficiency of the laser system by more than 25 percent. (See Chapter 12.)

Illustrations following page 56

Plate 1. *X-ray laser beam weapon satellite deployed into orbit by the Space Shuttle.*

Plate 2. *Artist's conception of the destruction of a tactical missile at the White Sands, N.M. laser weapons test range by the 2.2-megawatt deuterium-fluoride Mid-infrared Chemical Laser. The device was built by the U.S. Navy and TRW, Inc. in the Navy's Sealite program for the development of lasers for aircraft carrier defense.*

Plate 3. *Laser beam weapon hitting a missile in its boost phase. In this hybrid system, the laser is based on a mountaintop with a mirror in space.*

Plate 4. *Artist's drawing of the U.S. Air Force Airborne Laser Laboratory, showing location of laser and instrumentation in the aircraft. The lab is a modified Boeing NKC 135 cargo aircraft equipped with a 400-kilowatt, 10.6 micron carbon dioxide laser.*

Plate 5. *Mobile Test Unit, a 100-kilowatt chemical laser mounted on a U.S. Marine Corps LVTP-7 tracked vehicle. In 1976, a high energy electric laser of low power mounted on the MTU destroyed aircraft at the Redstone Arsenal in Alabama. Inset is a U.S. Army laser system developed by Hughes Aircraft Co. This system, integrated into a tank or aircraft, projects laser light onto a target so that a tactical missile equipped with a sensor for the laser light reflected by the target homes in on the target after firing.*

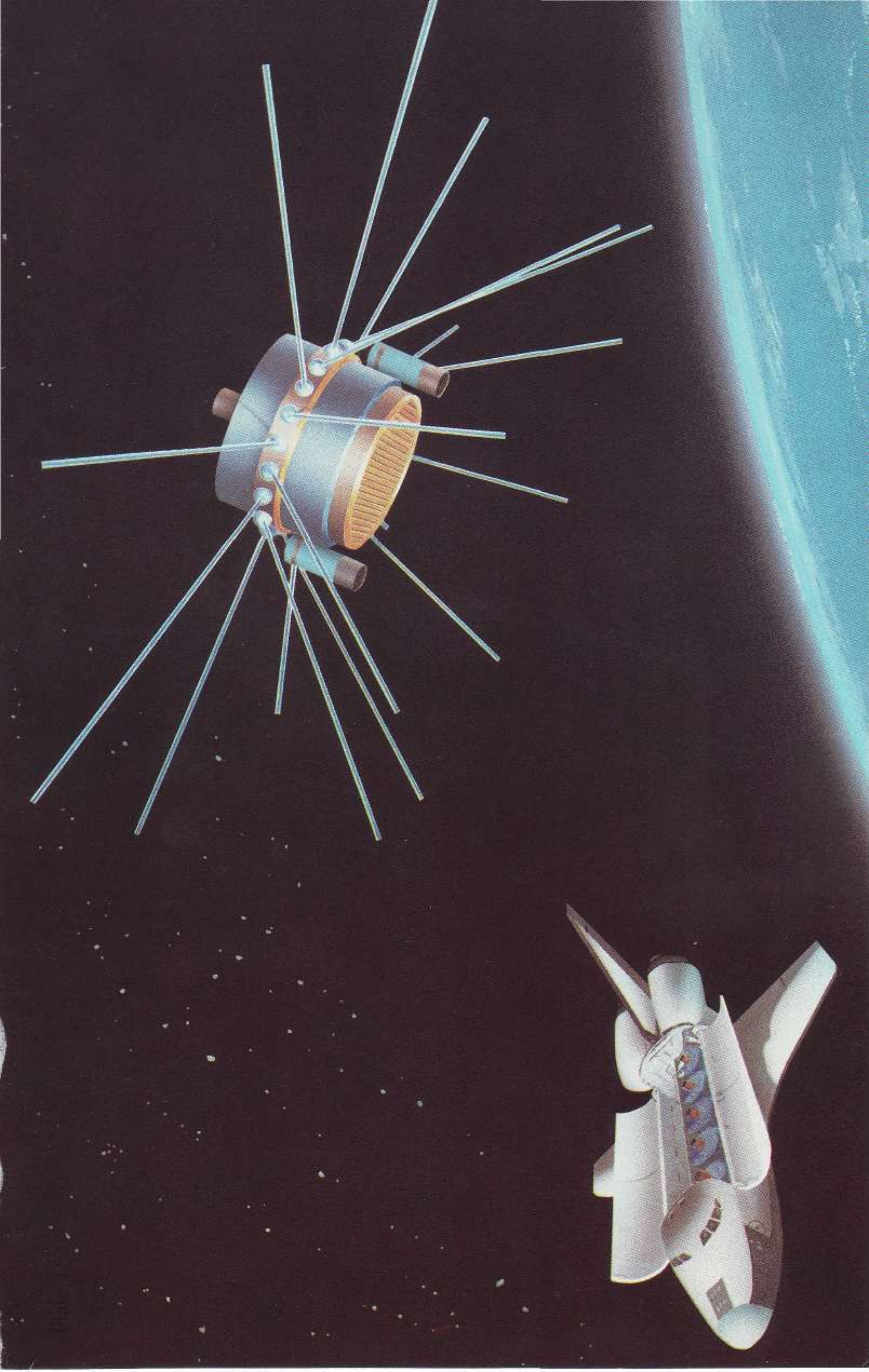
Plate 6. *Eight-foot primary mirror of the Space Telescope being fabricated by Perkin-Elmer. Inset is an artist's depiction of the Space Telescope, which will achieve the pointing accuracy required for a beam weapon.*

Plate 7. *Beam-amplifying system of the Shiva laser fusion experiment at Lawrence Livermore National Laboratory.*

Plate 8. *Shiva target chamber. Inset is a view of the inside of the target chamber with the beams centered on a tiny pellet of fusion fuel.*

Plate 10. *Design for a lithium-waterfall laser fusion reactor. The reactor is at the center of the building at right, while the laser system is in a separate building on the left. The laser beams are conducted through underground concrete tubes to the final focusing mirrors that look into the reactor chamber. In this closed fusion system, the neutron and X-ray energy from the implosion of the fuel pellet is absorbed in the liquid metal lithium that forms a thick wall around the center of the reactor. The lithium, circulated through a series of heat exchangers, is also the heat-transfer fluid.*

Continued on page 57



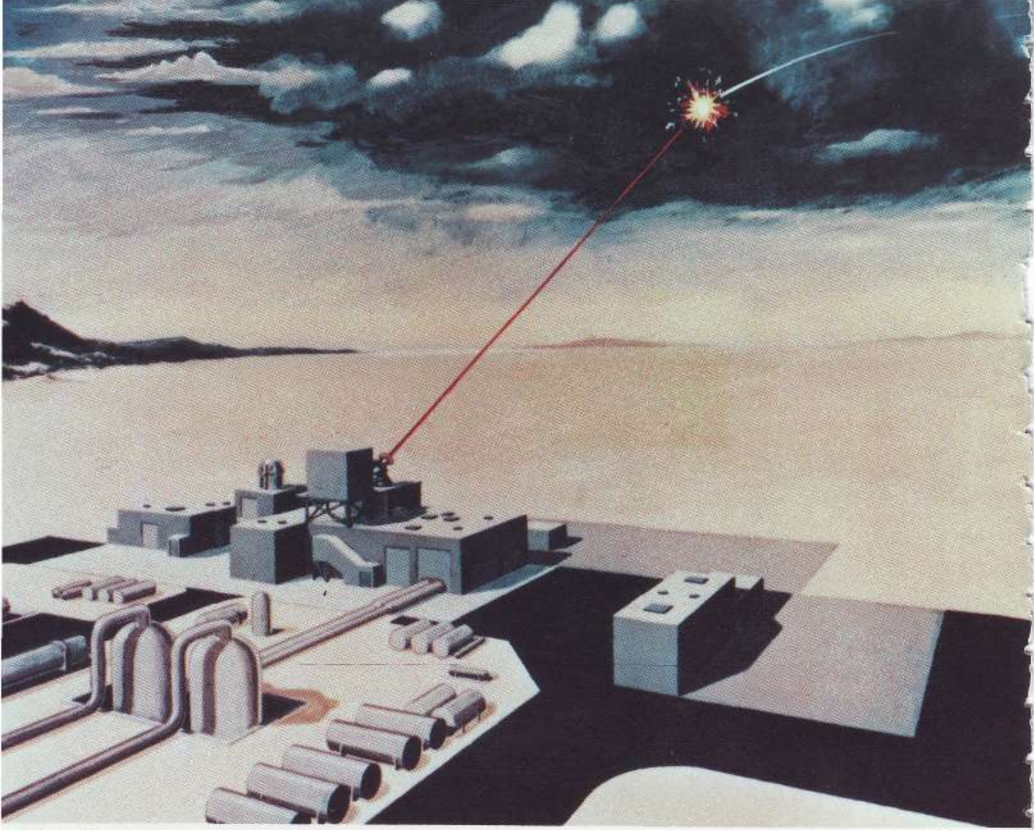
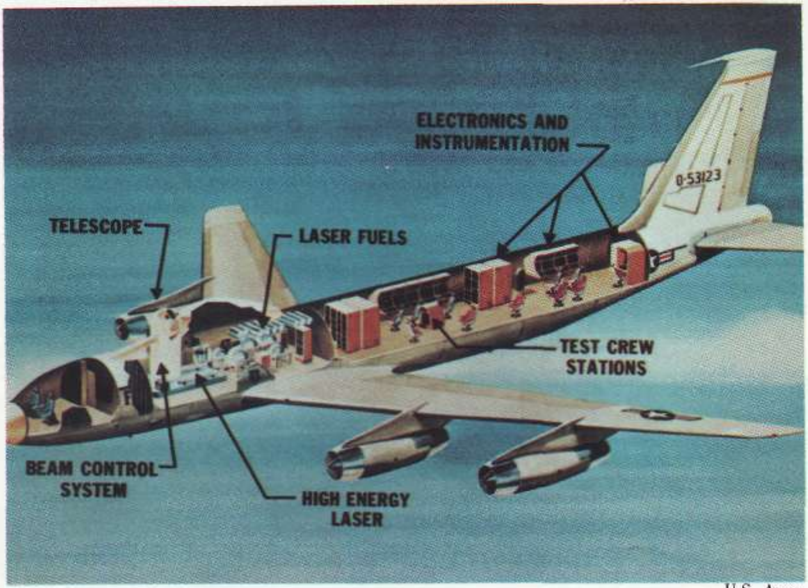


Plate 2.

U.S. Navy

Plate 3.

Plate 4.



U.S. Army

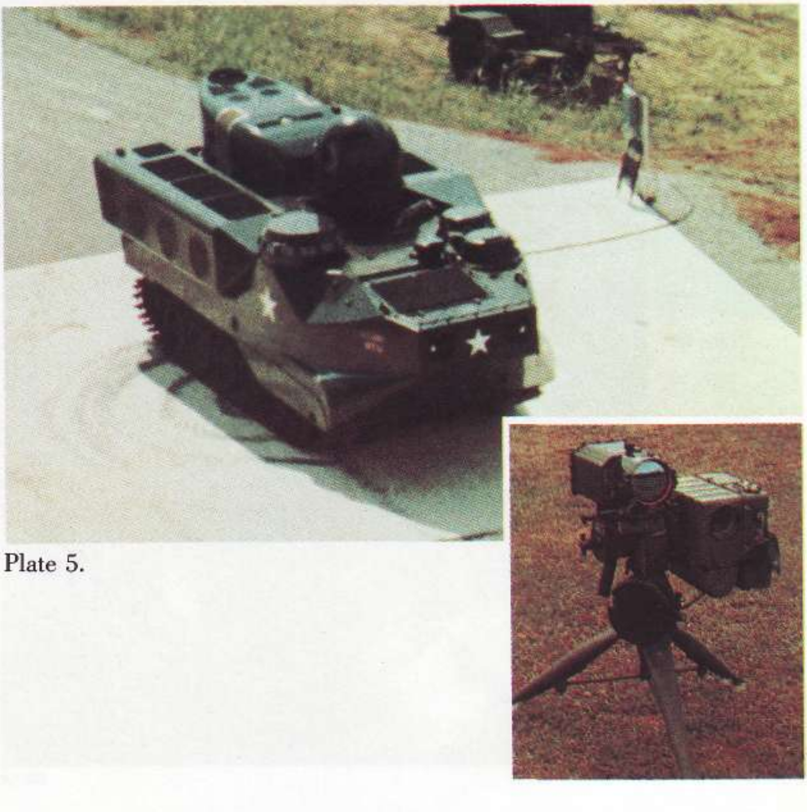


Plate 5.

U.S. Army

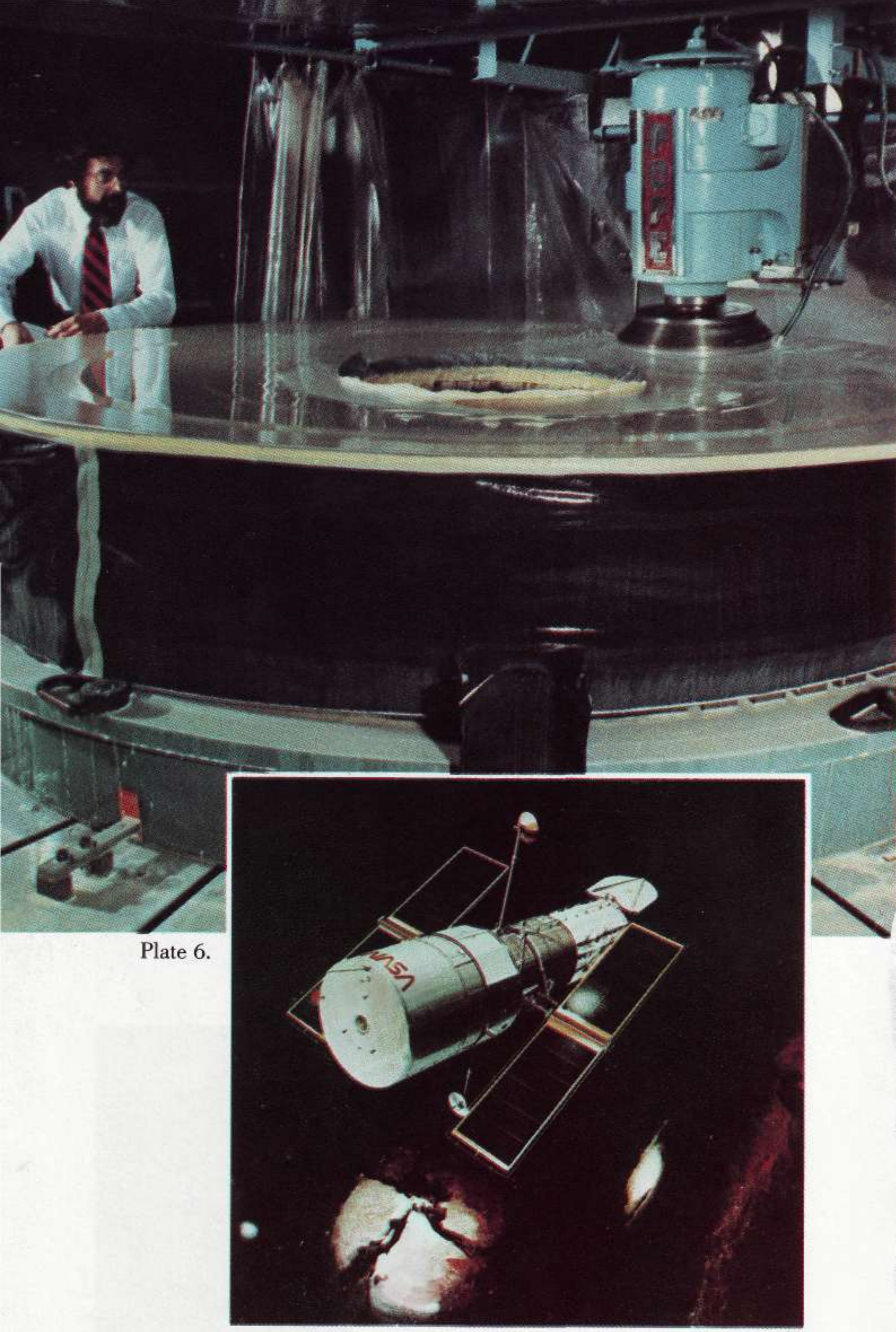
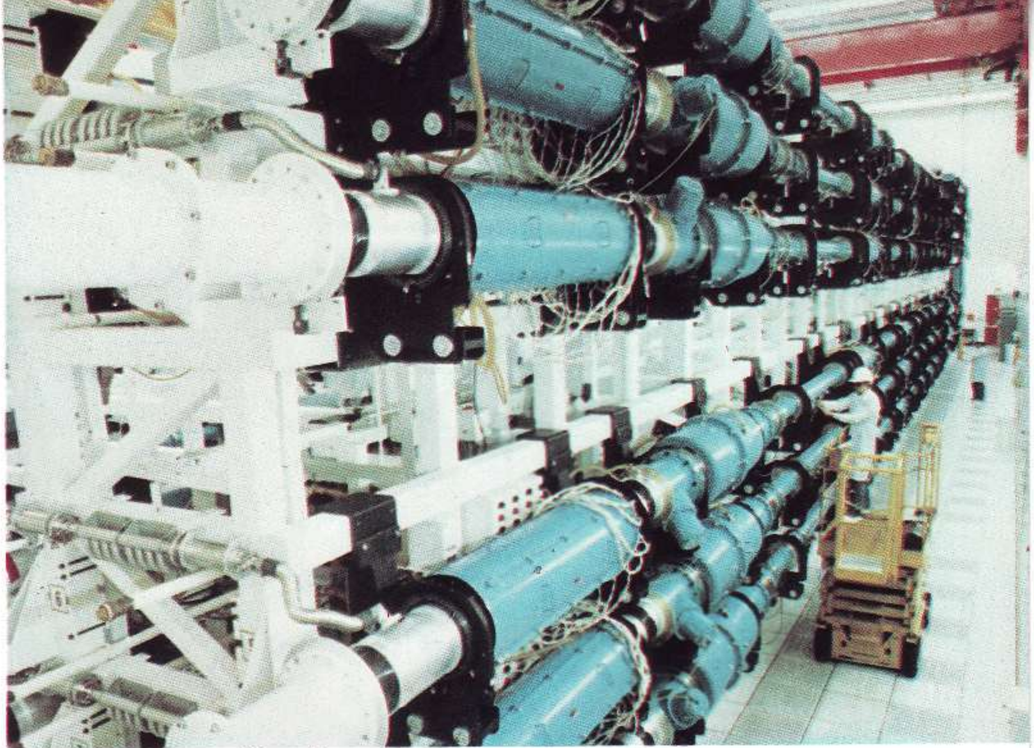


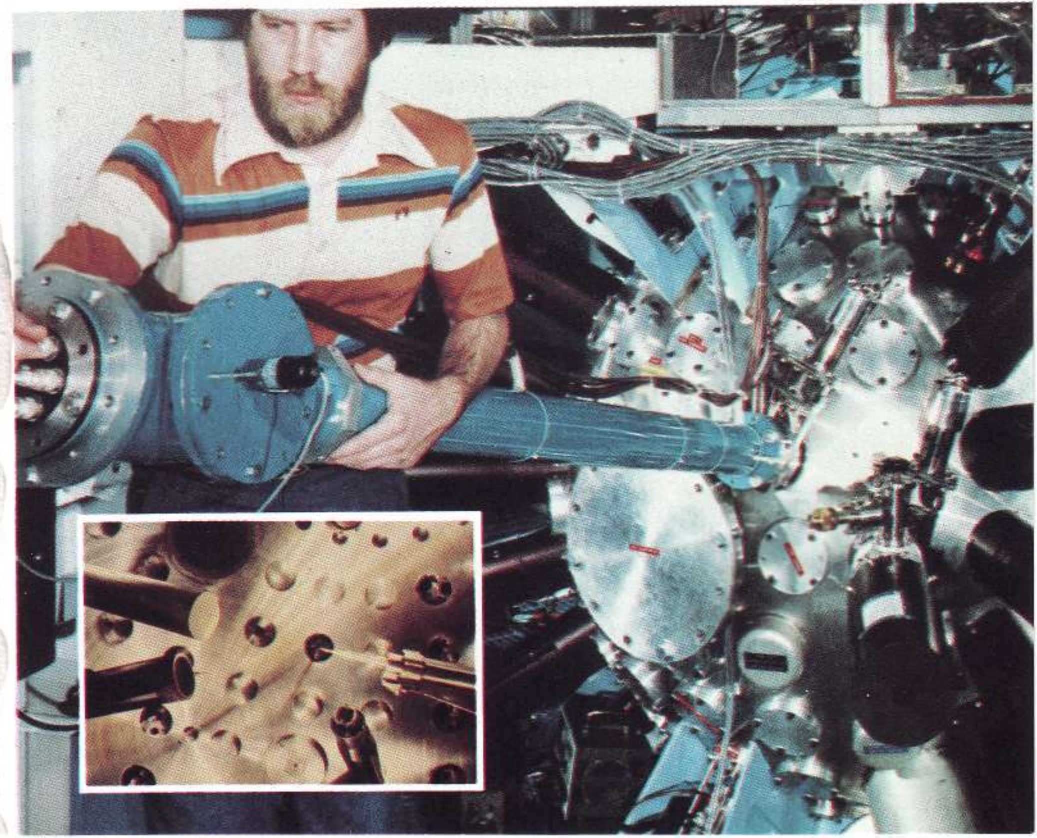
Plate 6.

NASA

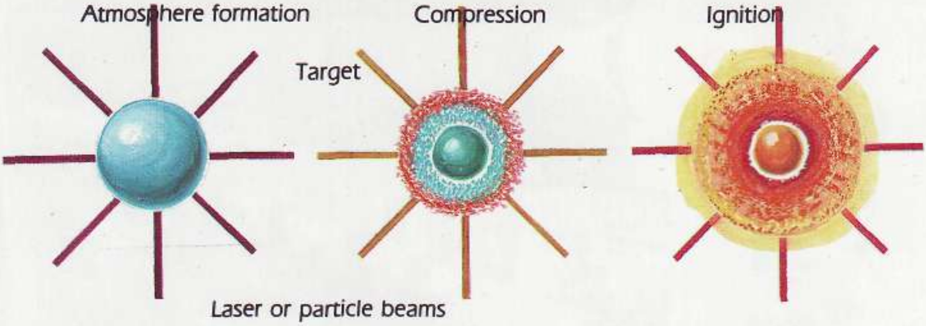


LLNL Plate 7.

Plate 8. LLNL



INERTIAL CONFINEMENT FUSION—HOW IT WORKS



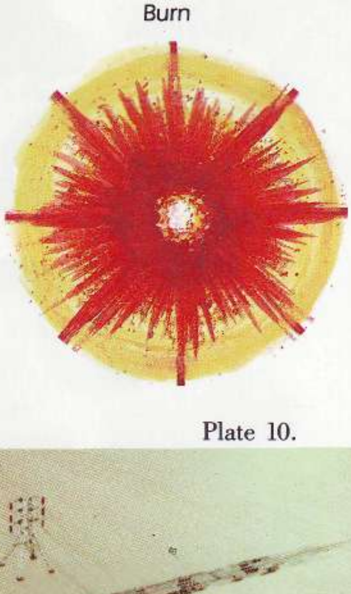
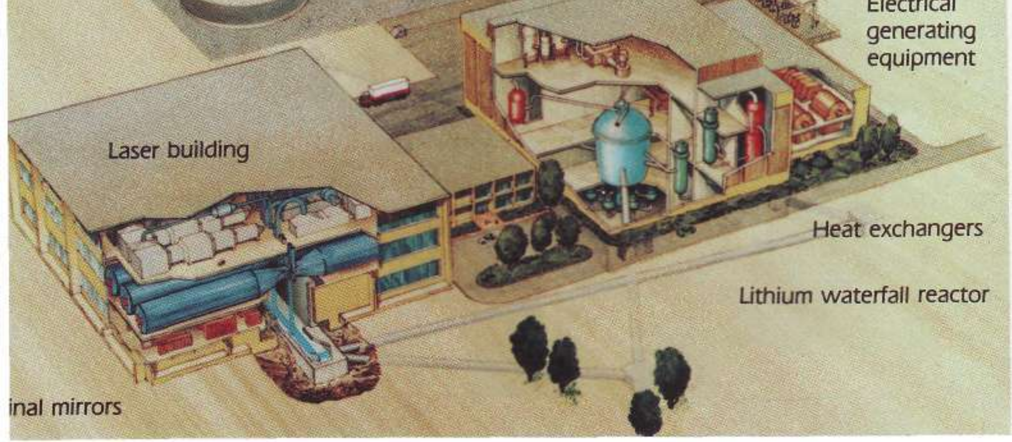


Plate 9. *In inertial confinement, beams of light or particles are focused onto tiny target pellets filled with fusion fuel. First, the laser or particle beams rapidly heat the surface of the fusion target, forming a surrounding plasma envelope. Then the fuel is compressed by rocket-like blow-off of the surface material. With the final driver pulse, the full core of the fuel pellet reaches 1,000 to 10,000 times liquid density and ignites at 100 million degrees Celsius. Thermonuclear burn spreads rapidly through the compressed fuel, yielding many times the energy of the driver input.*

Plate 10.



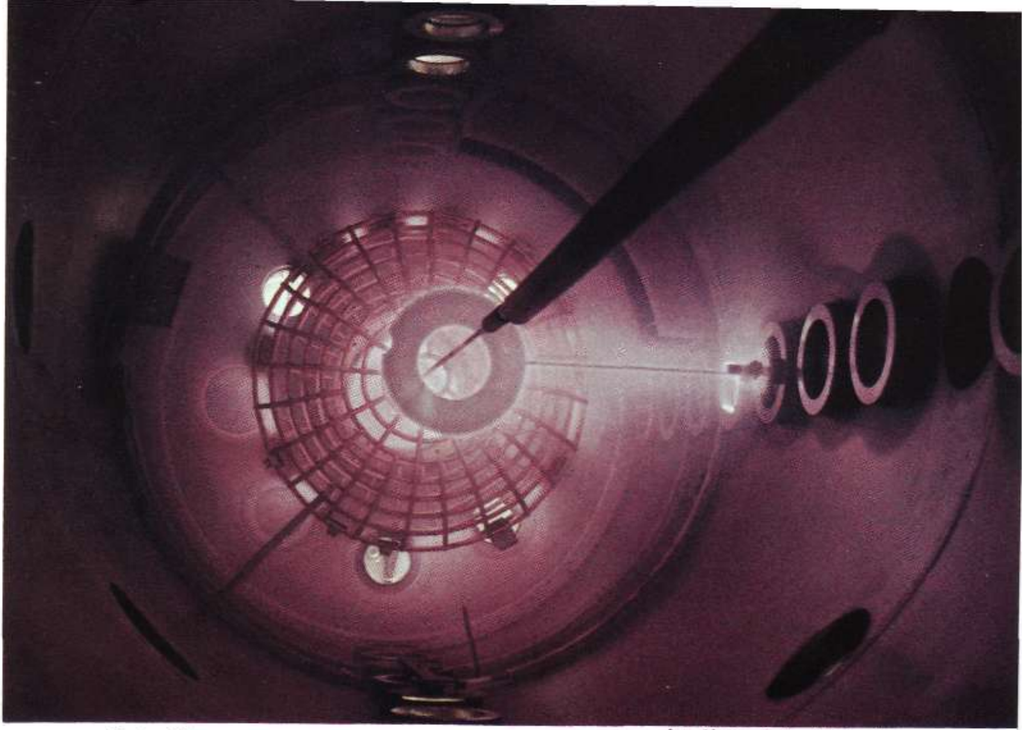


Plate 11.

Los Alamos National Laboratory

Steven Bardwell

Plate 12.

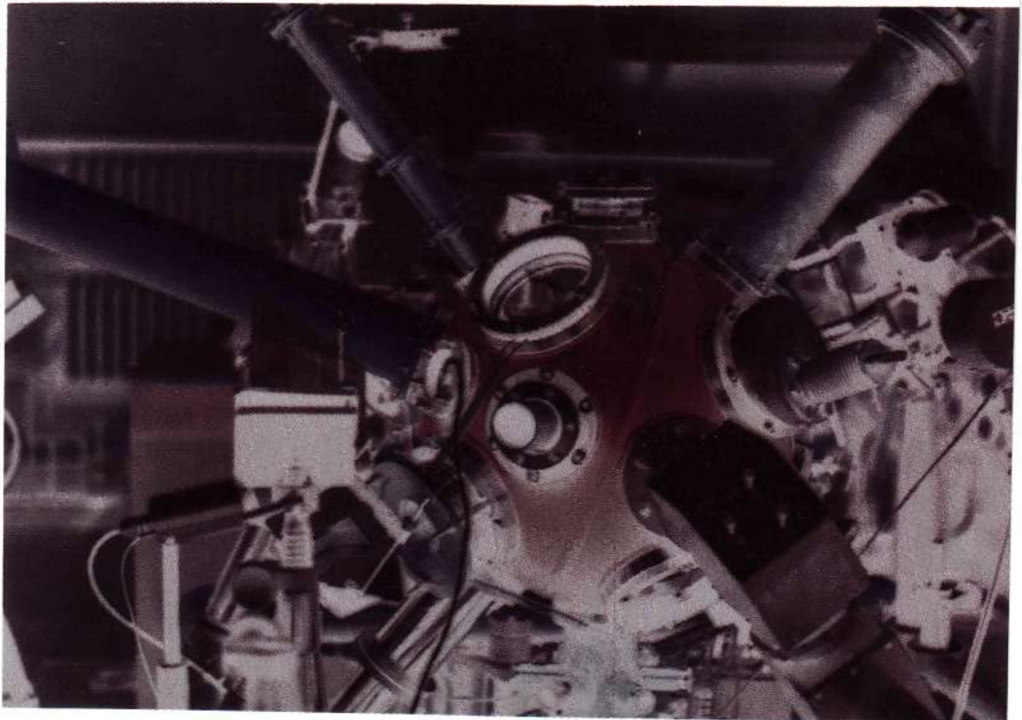
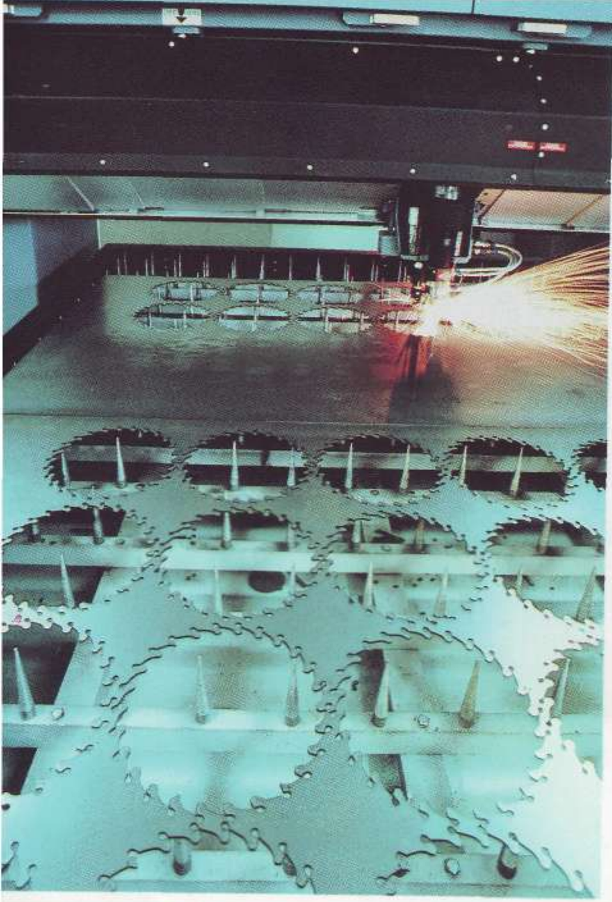


Plate 15.

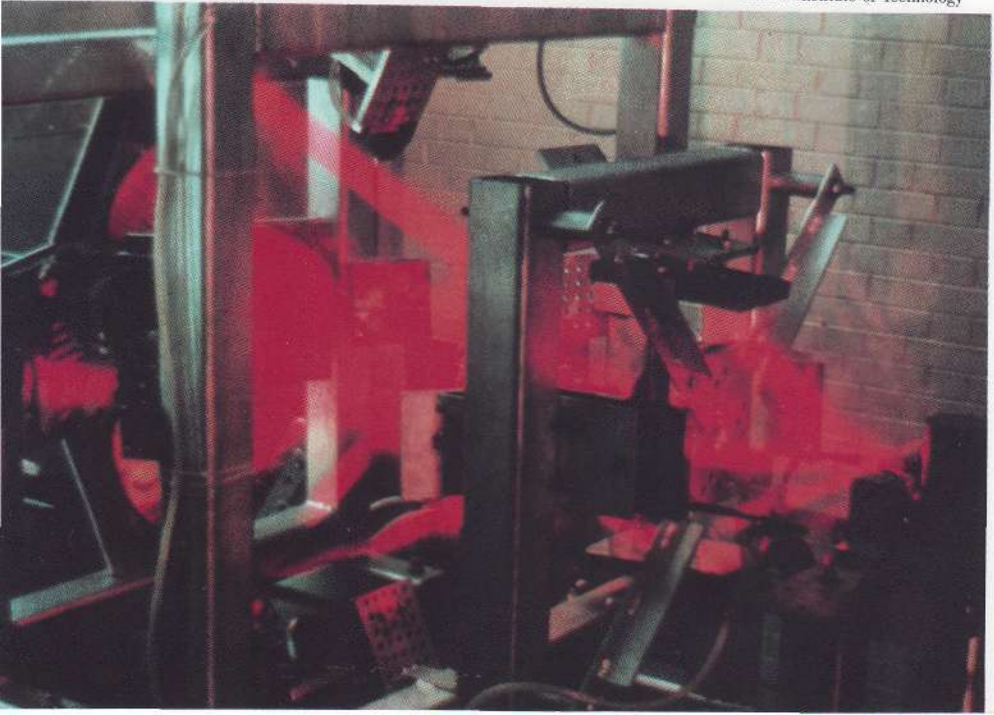


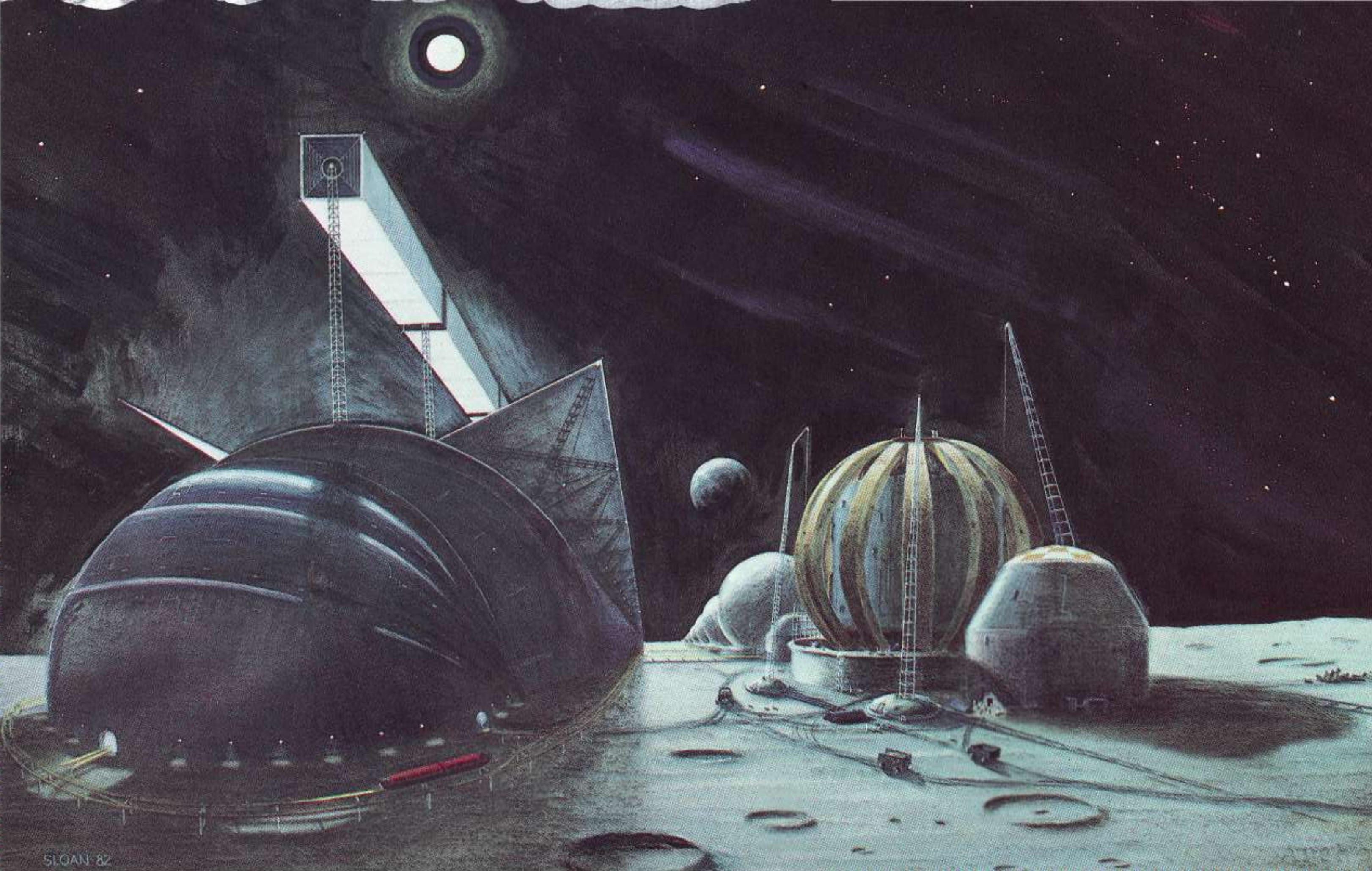
Courtesy of Coherent, Inc.

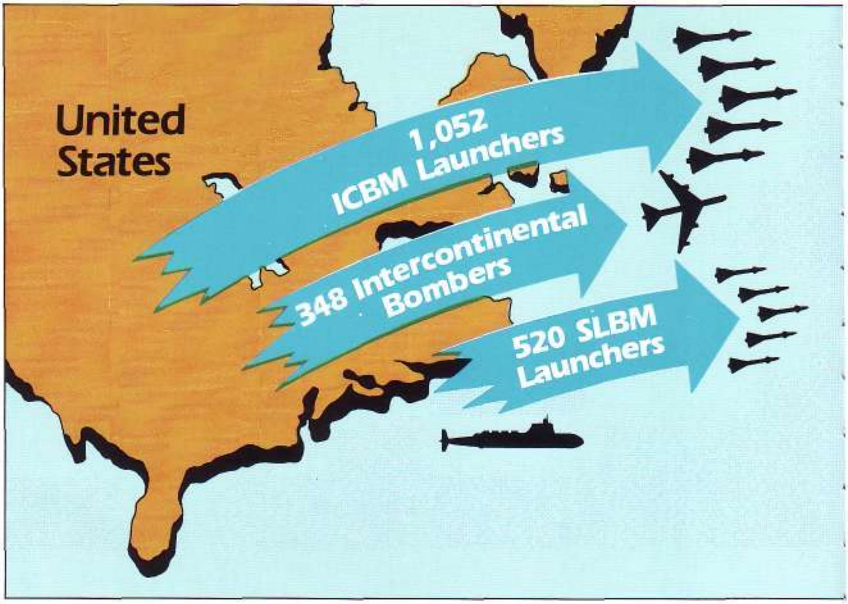
Plate 13.

Plate 14.

Illinois Institute of Technology




SLOAN '82



The Superpower MAD Scenario

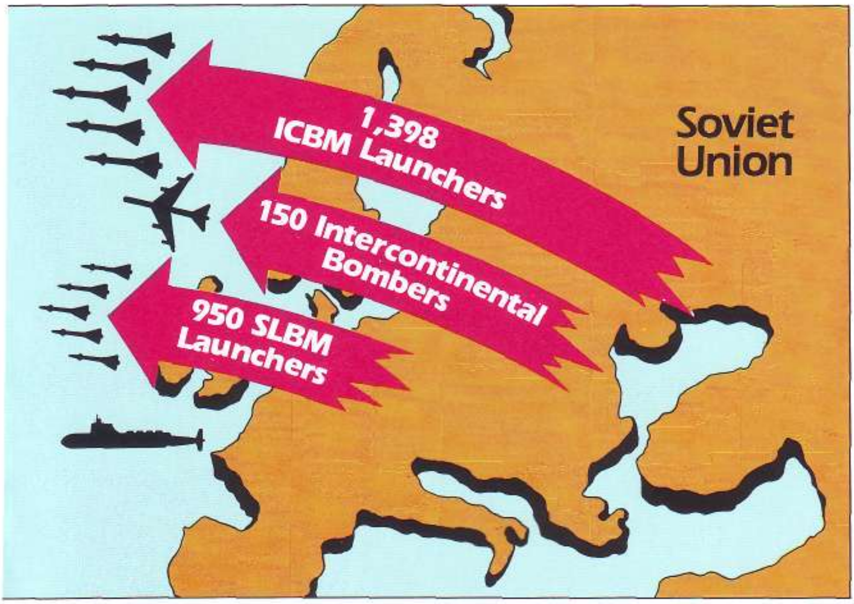
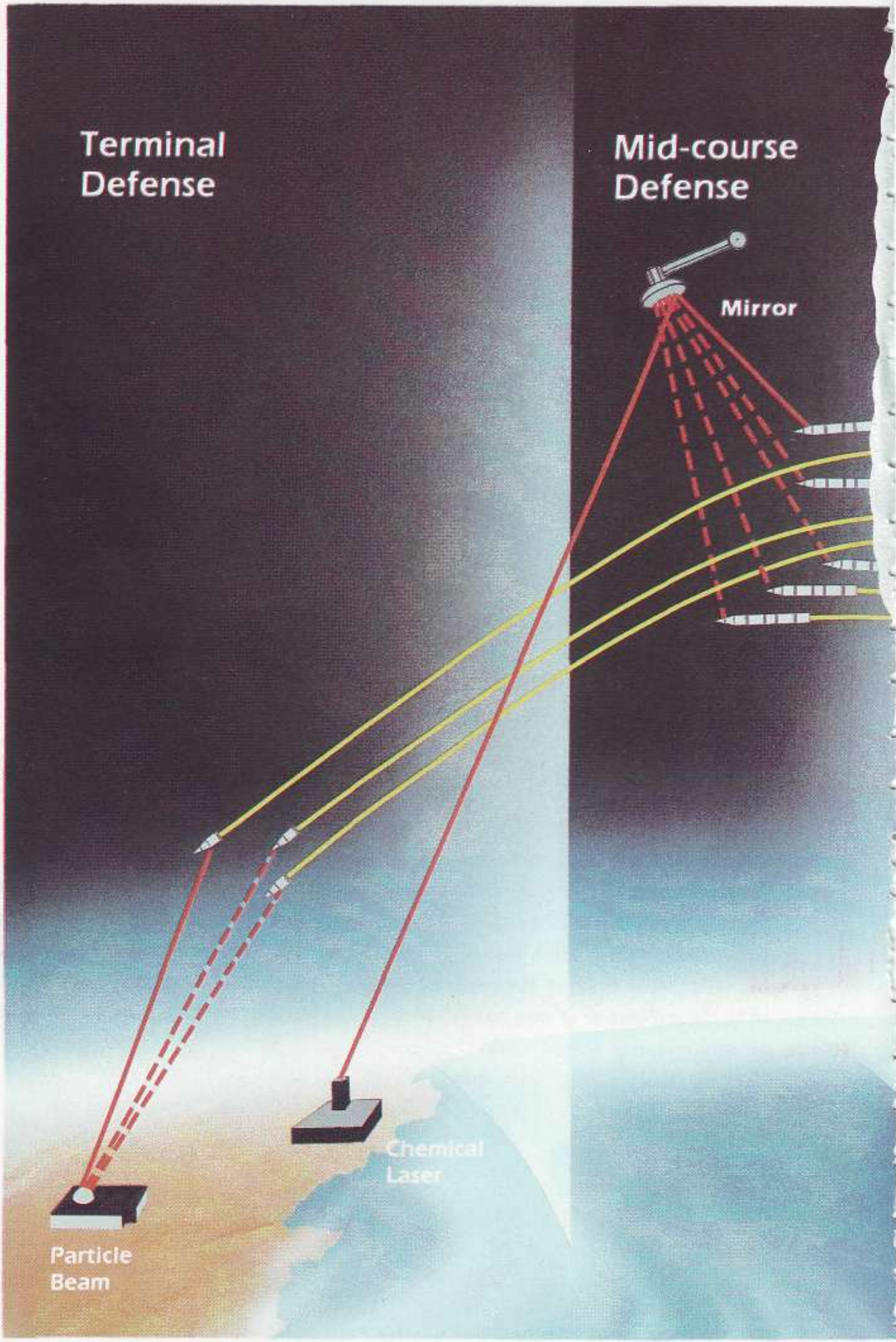
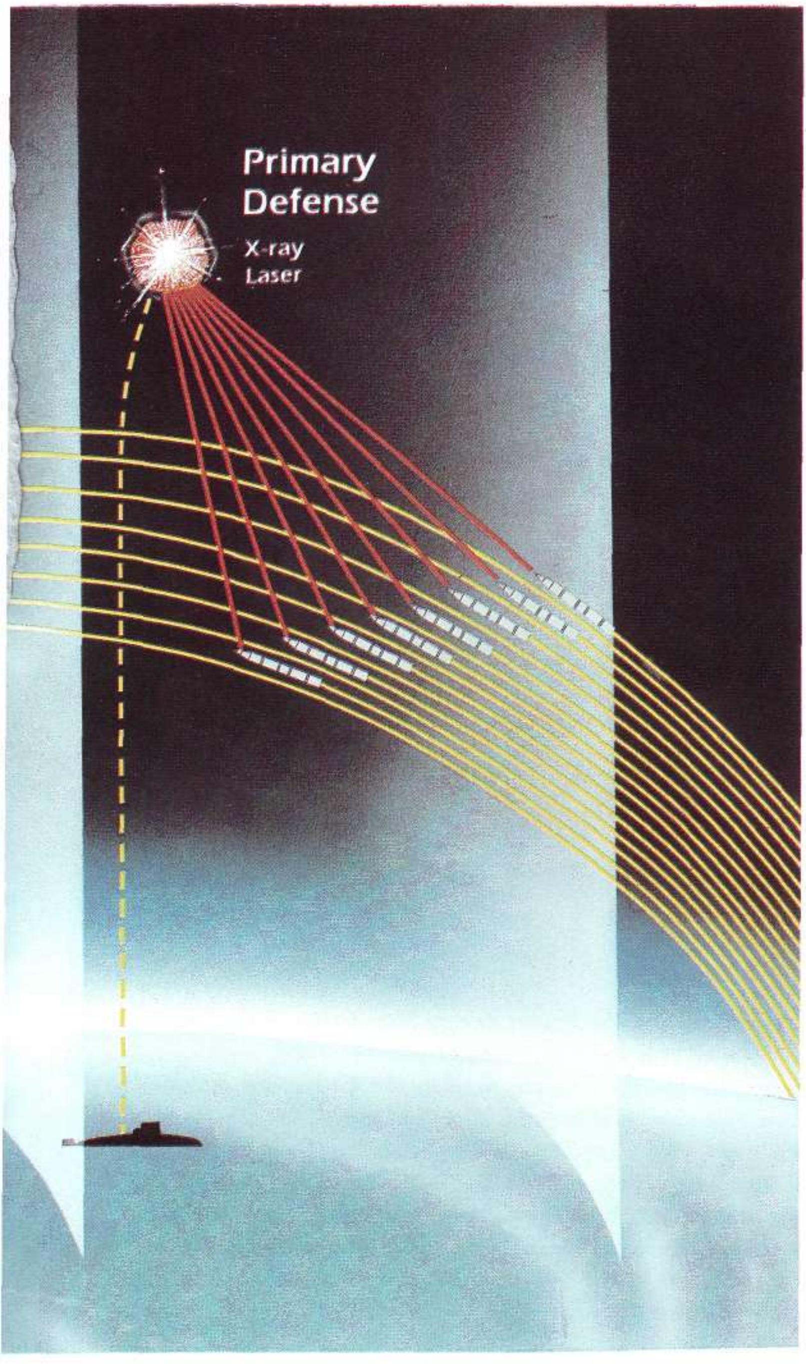


Plate 16. *The strategy of mutually assured destruction, MAD, is based on the idea that there is no rational military use for nuclear weapons except in so far as their existence deters one's adversary from using its nuclear arsenal. In this view, the deterrence capability rests on a nuclear force being able to survive any enemy attack with sufficient "second-strike" capability to then devastate the other side. Each of the weapons listed here has such large destructive power that the explosion of one would be sufficient to destroy any city in the world or any military target.*



Total Defense in Three Stages Plate 17.


Primary
Defense
X-ray
Laser

How Beams Work

Particle Beam

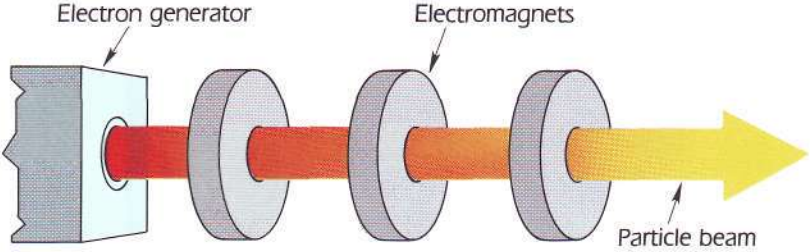


Plate 18. *Electrons in an accelerator are forced by a series of powerful electromagnets to emerge as a beam much like a lightning bolt.*

X-Ray Laser

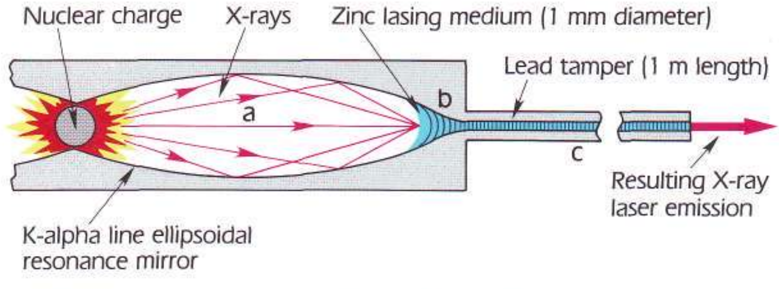


Plate 19. *In this design by the Fusion Energy Foundation, X-rays from a bomb blast are focused by a set of ellipsoidal cavities (a). Using multilayered K-alpha dielectric mirrors, these cavities focus all the X-rays from the spherically symmetric explosion on to the ends of the lasing rod. These rods use a conical assembly of lasing material to further focus the plasma produced by the X-rays along the axis of the rod (b). The lasing medium is embedded in a heavy metal tamper, which provides mechanical stability as well as an inertial focusing of the lasing medium (c). In addition, a very intense photoelectric current generated by the X-rays in the lasing material confines and focuses the X-ray producing plasma.*

Chemical Laser

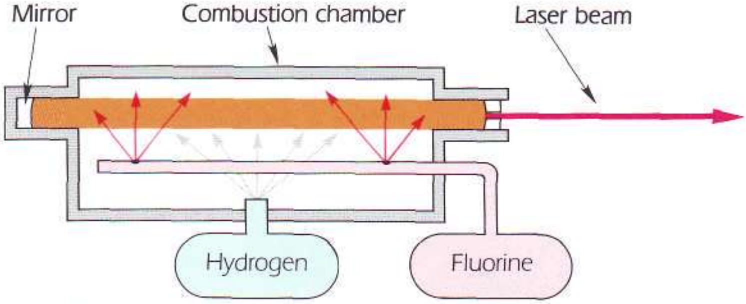


Plate 20. *In this chemical laser, hydrogen and fluorine gas are pumped into a combustion chamber where they react violently. The light emitted from the excited electrons is collected and concentrated by the mirrors and emerges as an infrared laser beam.*

Nuclear Powered Laser

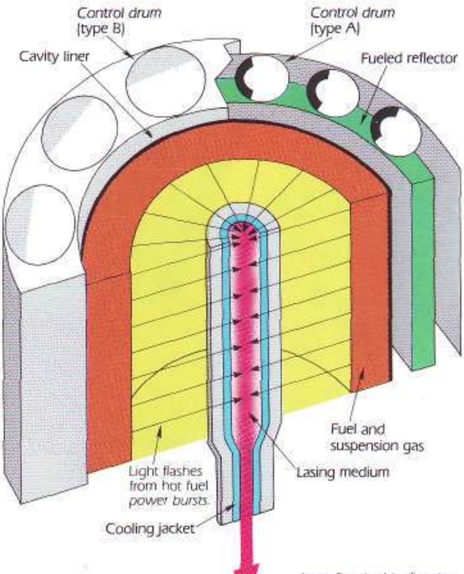


Plate 21. *In this nuclear power radiant transfer laser, blackbody-type light from a uranium carbide reactor enters the lasing medium, an inorganic liquid, causing excitation and lasing. The reactor operates with a mixture of helium gas and small suspended solid particles of uranium carbide fuel swirling around the reactor vessel. The reactor power bursts are controlled by rapidly rotating drums.*

Free Electron Laser

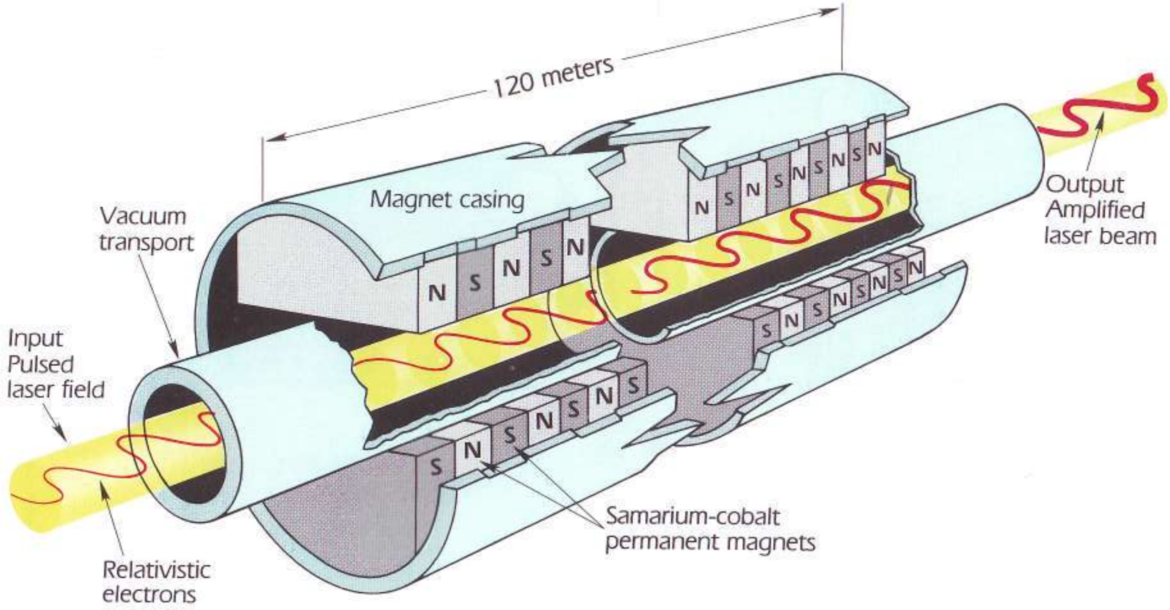


Plate 22. *A beam of high energy (relativistic) electrons enters the free electron laser together with a pulsed laser field. Magnets arrayed in alternating gradients (north and south) on the device cause the electrons to "wiggle," releasing energy to the beam. At a certain distance along the device, the kinetic energy of the electrons is transferred to the input laser beam, thus amplifying it.*

Plate 11. *Inside view of the Spheromak experimental fusion device at Los Alamos National Laboratory, looking toward the copper cage.*

Plate 12. *Target chamber of a laser fusion experiment in the laboratory of N. Basov at the Lebedev Institute in Moscow.*

Plate 13. *Laser cutting machine at work.*

Plate 14. *A ruby laser at the Illinois Institute of Technology's Laser Center, which is developing the ability to do flexible laser machining. Each of the four beams of the laser can perform a different operation on a piece of metal, such as welding, cutting, heat treating, and alloying.*

Plate 15. *Fusion reactor (right) on the Moon, from a design by space scientist Krafft Ehricke. At left is a module of "Selenopolis," the living environment designed by Ehricke, and its monorail transportation system.*

Plate 17. *Experts agree that no single antimissile system can be 100 percent effective against ballistic missile bombardment. But, by combining three different systems, each with 90 or 95 percent effectiveness, a total system can be built that provides almost complete protection against ballistic missiles. The first layer must destroy 90 percent of the missiles as they are launched. This space-based system might be launched as soon as the missiles are detected (as shown in the figure) or might be permanently based in space. An X-ray laser station is shown in the figure. The second stage has only to deal with the 10 percent of the remaining missiles, a more modest role of which a space-based mirror and ground-based optical laser would probably be capable. The third, terminal, stage of the system would be a ground-based particle or laser beam designed to intercept the warheads themselves, after they had been released from the ICBM. Because only 1 percent of the original targets would be left after the protection of the first two layers, the last stage can be more expensive and complex, as a particle beam system would be.*

Chapter 7

The Missile Crisis of the 1980s

The world and its human population is today threatened with extinction by the existence of a massive arsenal of nuclear weapons whose use, even in small numbers, would guarantee the destruction of most of humanity. Each of these weapons has such large destructive power that the explosion of one would be sufficient to destroy any military or civilian target; any city in the world would be totally destroyed by a single one of these weapons.

It is the combination of these explosive devices with the intercontinental ballistic missile, ICBM, that underlies the current missile crisis. ICBMs provide the capability for launching thousands of these devices at distances of more than 7,000 miles and for assuring that they arrive within 100 yards of their target. Given the destructive force carried by one of these devices, there is no target so well protected ("hardened" in military parlance) that it is not today threatened by nuclear incineration within approximately 30 minutes, the flight time of a nuclear-armed ballistic missile.

The combination of these two facts has created a military situation without precedent in modern times: An offensive weapon has existed (nuclear-armed ICBMs) of incredible destructive power for which only local defense was possible; it has been impossible to protect a whole country from nuclear destruction. While the approach to this situation has been fundamentally different on the part of each superpower over the past 35 years, such a situation has been inherently unstable. Long-term peace in the face of such a military situation is almost impossible.

The two "superpowers" and their immediate allies are now no longer the only nations possessing nuclear weapons and their delivery capability. According to very reliable sources, Israel, Pakistan, and South Africa all already possess nuclear weapons (and it is very likely that Israel possesses thermonuclear weapons), and they are all on the verge of acquiring missile delivery capabilities for these weapons.

The New Generation of Nuclear Weapons

While the doctrine of deterrence is being shaken politically, the new generation of nuclear-armed ballistic missiles now being deployed—the Pershing 2 missiles by the United States and the SS-20 by the Soviet Union—is collapsing the "balance" of terror militarily. These new weapons have exceedingly accurate guidance and maneuverable reentry vehicle (MARV) capabilities, as well as short trajectories. Their deployment eliminates the possibility of any *passive* defense for land-based missiles.

Under this kind of "fire," ICBMs can no longer act as a deterrent because they would be destroyed in their silos if not launched as soon as the other side's missiles were detected. Thus, as the deployment of new weapons proceeds over the next several years, the threshold for war will drop dramatically and the dangers of accidental nuclear exchange will become larger and larger.

Both superpowers are now following a course that is rapidly raising the premium on making a preemptive strike. A simple numerical comparison of warheads and missiles along with some of their characteristics shows that the Soviet Union has a significant advantage and has used that advantage to increase its ability to launch a preemptive strike. The Soviet Union has a great advantage in the number of high-yield ICBM warheads and powerful ICBMs. The U.S. advantage is in the number of low-yield submarine-launched warheads. (See accompanying table.)

To realize the significance of this difference, it is important

Comparison of U.S. and Soviet Strategic Nuclear Forces

Launchers	Warheads-Yield	EMT[1]	Throw-Weight[2]	CEP[3]
	UNITED STATES			
ICBM	900 × .33 mt[1]	430	600	.10 nm
550 Minuteman III	750 × .17 mt[5]	230	500	.14 nm
450 Minuteman II	450 × 1 mt	450	675	.30 nm
52 Titan II	52 × 9 mt	224	390	.50 nm
1,052	**2,152**	**1,334**	**2,165**	
SLBM				
80 Polaris A-3	240 × .2 mt	81	80	.50 nm
432 Poseidon C-3	4,320 × .05 mt	582	864	.25 nm
64 Poseidon C-4	512 × .1 mt	110	160	.25 nm
576	**5,072**	**773**	**1,104**	

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1. Equivalent megatonnage (EMT) accounts for the disproportional hardness of Soviet and U.S. targets.
2. × 1,000 lbs

to understand that ballistic-missile throw-weight is the single most useful index of strategic capability. Throw-weight measures total weight (including weight of the reentry vehicle and guidance unit) that a missile can deliver at a stated range and trajectory. Throw-weight is an important factor determining the potential of a missile system to "cover" its targets and destroy them. A high throw-weight allows a variety of reentry packages, from one very large high-yield weapon such as the Soviet SS-18's 25-megaton warhead, to the ten 2-megaton warheads of the SS-20.

The modest throw-weight of the U.S. systems does not permit this choice. The low throw-weight of the American Minuteman III allows a single high-yield warhead, or a small number of relatively low-yield weapons; that is, three 170-kiloton warheads.

Recent studies by the U.S. Department of Defense have analyzed the consequences of confrontation of these two arsenals.

Launchers	Warheads-Yield	EMT[1]	Throw-Weight[2]	CEP[3]
	SOVIET UNION			
ICBM				
480 SS-11	180 × .30 mt	84	1,160	.50 nm
	520 × 2 mt	822		
60 SS-13	60 × 1 mt	60	60	.70 nm
150 SS-17	600 × .90 mt	558	1,200	.24 nm
208 SS-18	3,080 × 2 mt	4,869	5,143	.14 nm
800 SS-19	1,800 × .75 mt	1,485	2,400	.14 nm
1,398	**6,240**	**7,138**	**9,963**	
SLBM				
18 SS-N-5	18 × 1 mt	18	27	1.5 nm
453 SS-N-6	453 × 1 mt	453	679	1.0 nm
291 SS-N-8	291 × 1 mt	291	436	.5 nm
12 SS-NX-17	12 × 1 mt	12	36	.3 nm
176 SS-N-18	528 × 1 mt	528	880	.3 nm
950	**1,302**	**1,302**	**2,058**	

3. Circular error probability (in nautical miles)
4. Mark-12A warheads
5. Mark-12 warheads

The result is that as the decade proceeds, each side is pushed more and more toward a preemptive use of its nuclear weapons, because these weapons are of such high accuracy that failure to use them first in a potential confrontation would result in the destruction of those missiles in their silos. This is the "use them or lose them" paradox.

At present, the United States is less capable of effectively attacking hardened targets such as ICBM silos, which is dependent upon the proper combination of a relatively high warhead yield and excellent guidance systems. However, this imbalance will be changed with the current generation of missiles being deployed by the United States, the Pershing 2 in Europe and the MX missile with its improved guidance performance.

The Soviets in turn have responded to the Pershing 2 siting in Europe by making clear that they will deploy short range, low-trajectory missiles very close to the U.S. coastline. Among other possibilities, this undoubtedly refers to submarine deployments. The "bottom-crawling" submarines that the Soviets provocatively tested in Swedish and Norwegian waters during 1983 may be a clue to this new type of deployment. Missiles launched from fixed undersea platforms would be more accurate than those launched from ordinary submarines. In any case, it is clear that the Soviets intend to respond by putting the latest generation, most accurate missiles very near to the United States. Thus the countdown toward the launch on warning trigger accelerates.

Such a capability that exists now on the Soviet side and that will exist in the next several years on the U.S. side means each superpower can destroy the other's ICBM force with a fraction of its own force—*provided* it strikes first. In a confrontation in which either superpower perceives war to be inevitable, each side, possessing the ability to disarm its adversary, may launch its attack preemptively to do so.

Thus, the pressure toward first use of nuclear weapons is becoming greater and greater. As many strategic analysts have noted, this technological development means that deterrence and the idea of mutually assured destruction have on their own terms become unrealistic.

In this situation, the installation of new, highly accurate missiles in East and West Europe, only a few minutes' flight-time from their targets, and the movement of submarines with similar intermediate-range, low-trajectory missiles near the coasts of each superpower, is a countdown to a new, more deadly Cuban missile crisis.There is only one solution to this problem: the development of a technology to neutralize the nuclear-armed ICBM. The construction of new offensive weapons will make the situation worse; the attempts at disarmament have been fruitless over the last 25 years, except to stop attempts to develop anti-missile defenses, and voluntary restraint has been impossible. The only solution is an active defense, centered around anti-missile energy beam weapons.

Chapter 8

How Soon Can We Have Beam Weapons?

An intense debate has raged for the past five years in the scientific community over the possibility of ever building the first beam weapon. Before 1978, almost all scientists believed that a complete defense against ballistic missile attack was impossible. This evaluation meant that almost all military strategists were calculating that the offense in a nuclear confrontation had the complete upper hand. Strategic defense was impossible.

Today, there is no scientist who doubts the possibility of building a beam weapon system for destroying ballistic missiles. However, the debate now continues over how soon such a system could be built and how practical the first beam weapons will be. On the one side, some scientists argue that a beam weapon *could* be built (the laws of physics do not prevent it), but that such a weapon would be so vulnerable to one's adversary, it would never provide a good defense. These scientists go on to argue that such fragile devices would be expensive, difficult to use and repair, and ineffective in actual battle conditions.

Other scientists have effectively refuted these claims. They point out that beam weapons are more promising today, at the very start of their development, than airplanes were even two decades after their invention. The flexibility of the beam technologies, the wide range of possibilities among beam weapons, and their recent rapid progress all justify tremendous optimism. As one scientist working on beam weapons said: "I don't consider the arguments of the critics as insoluble problems, but rather as a challenge to be met. I am not interested in finding reasons we can't make a beam weapon; I am interested in making one."

Spectacular scientific and engineering progress has convinced most scientists of the possibility of beam weapons and has opened up two major paths toward near-term realization of beam weapons. Both development strategies could, according to experts, result in a beam weapon system deployed in the next five years to defend military or population concentrations against missiles.

Ground-based Chemical Laser With Space-based Mirror

A ground-based beam weapon system would provide limited area defense as well as point defense. In this design, a laser beam weapon system is built on a mountaintop, and a relay mirror in orbit around the Earth provides aiming and tracking for the beam weapon. (See Figure 4-1.)*Using an intense beam of optical light (infrared or visible radiation), the ground-based laser generates a pulse of energy sufficient to destroy missiles as they are launched or, later, as they reenter the atmosphere toward their target.

The generation of the beam is accomplished totally on earth, eliminating any problems of weight, remote maintenance, or launch capability associated with space-based weapons. By situating the weapon above the bulk of the atmosphere (for example, on a 12,000-foot mountaintop), almost perfect transmission of

*Page 29

the laser light can be achieved using long-wavelength chemical lasers.

Part of the aiming and tracking equipment is ground-based and part is in space—namely, the orbital mirror. Thus, the beam could be reaimed at targets after their boost phase, at the point they are entering the atmosphere above the horizon of the beam weapon. This mode of direct engagement would provide *point defense* for the region immediately surrounding the beam weapon. Or, the beam could be reflected off the orbiting mirror to provide *area defense,* hitting ballistic missiles much farther away and earlier in their flight. The set of orbiting mirrors, each up to 30 feet in diameter, would be equipped with sensing and guidance capabilities. The mirrors would refocus the diffuse beam that hits them, aiming that beam onto the targeted missile.

All the components for such a device are well within our present engineering capabilities, as the table shows. Experimental devices such as the Space Telescope are able to point their optics on targets smaller than those for beam weapons. The accuracy of this pointing is greater than required for boost-phase destruction of ICBMs. Mirrors within a factor of two of the required size have already been constructed, and several aerospace companies have made a public offer to make a fixed-price bid for construction of a 5-meter mirror for a beam weapon. The ability of these mirrors to withstand the laser energy is sufficient for a beam weapon.

The most difficult problem remaining is to integrate these components into a working device. Some scientists believe that this problem will be nearly as difficult as building any one of the individual parts of a successful beam weapon. However, none of these parts has to be invented; all the pieces of a beam weapon are close to being ready.

The cumulative impact of these developments is that a system could be deployed using already developed laser technologies, as soon as these are integrated into a beam weapon system.

Several defense industry specialists have collaborated on a study of the possible timetable for the construction of such a beam weapon system and have concluded that the first unit of such a system—a "prototype"—could be in orbit around the Earth in 1987. This device could, they concluded, be either the Earth-based laser with an orbiting mirror described here, or a smaller, completely space-based chemical laser. These industry specialists have presented their study to the Defense Department and the White House, where it has been the basis of intense discussion and lobbying.

Such a system would be capable of providing a limited de-

Comparison of Required and Achieved Parameters for a First-Generation Beam Weapon System

Technology	**Required**	**Achieved**	
		Deployed	Laboratory
Pointing (μ radians)	0.05–0.1	0.048	
Tracking accuracy (μ radians/at 0.01 radians/second)	0.01	0.1	0.01
Mirror size—diffraction limited (meters)	5–10	2.4	5–6
Thermal stability (kw/cm²)	1	3	
Laser power (megawatts)	5–10	2.2	1,000,000

The specifications for a laser beam defensive weapon system capable of destroying ballistic missiles in their boost phase at a distance of several thousand miles can be achieved based on the recent advances in these technologies.

fense—limited by the expense and low energies inherent in chemical laser systems. While no expert proposes that a complete defense of the whole United States against an all-out attack could be based on the use of these chemical lasers, the development and deployment of a beam weapon based on these technologies would solve a host of problems in preparation for a complete defense system.

First, a ground-based chemical laser beam defense system would remove the situation of total vulnerability under the mutually assured destruction (MAD) doctrine; an accidental launch of even a single missile, which would be a total catastrophe today, could be prevented. Similarly, such a system would provide a complete defense against a small nuclear launch by a nation other than the United States or the Soviet Union, anywhere on the globe, thus preventing nuclear blackmail. Such a system would also provide point defense of ballistic missile emplacements, guaranteeing the survival of both sides' missiles during a conflict; this would remove the tremendous pressure to strike first, a pressure that exists, as discussed in Chapter 7, as a result of the new generation of missiles that must be used before they are destroyed by one's adversary. This laser beam weapon would accomplish all this. But this hybrid system cannot provide a complete defense.

Space-based X-ray Laser System

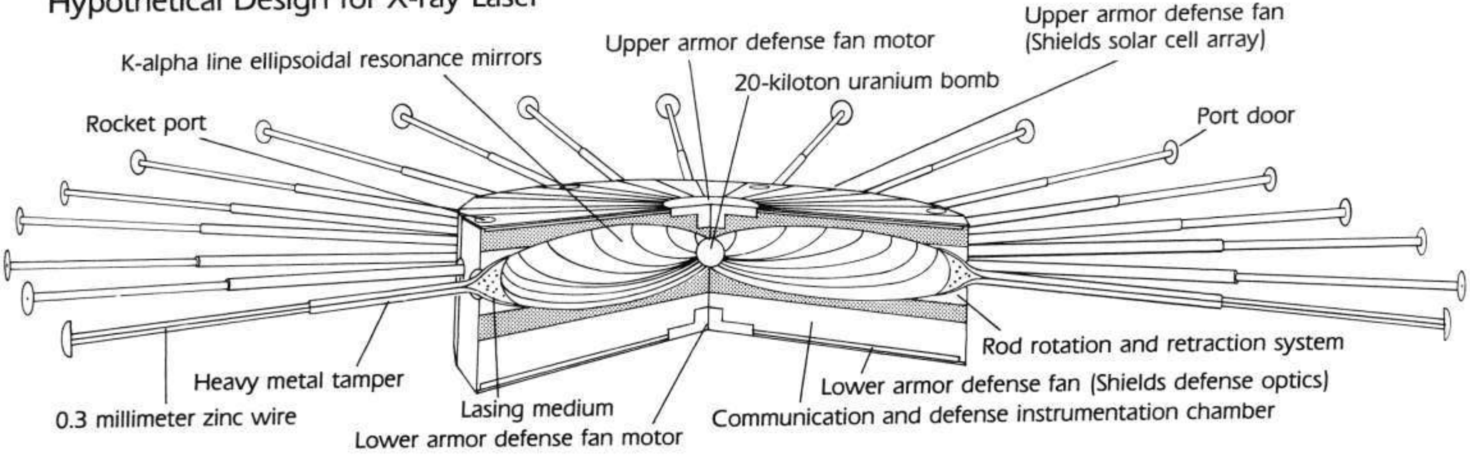
The X-ray laser, because it is smaller, cheaper, longer range, and high-powered, can provide a complete defense. Recent scientific evidence indicates that successful development of an X-ray laser is much closer than is commonly thought. The X-ray laser concept, and its scientific proof-of-principle demonstration over the past two years at an underground Nevada test site and elsewhere, is the central new feature of ballistic missile defense. Until the X-ray laser solved the "arithmetic" problem of ballistic missile defense, the idea of a complete defense against nuclear war had almost no adherents, because, the argument went, all known defense systems required at least one defensive missile and one defensive warhead to destroy each offensive warhead. Since a single offensive missile is capable of delivering up to 15 offensive warheads, any engagement had an automatic 15 to 1 advantage on the side of the offensive.

The X-ray laser changes all that for two reasons: First, it is able to intercept the missile in the boost phase, in which each missile still has its payload of many warheads intact. Thus, a single bolt from an X-ray laser can destroy up to 15 warheads. Second, each X-ray laser satellite uses one defensive warhead to produce up to 100 X-ray pulses. Even if only one tenth of these pulses hits a missile, a single defensive warhead in an X-ray laser would be capable of destroying 150 offensive warheads. This gives the defense a very great advantage, and reverses the arithmetic that for 25 years seemed to make ballistic missile defense a hopeless task.

X-ray laser technology combines small size and weight (because of the great efficiency of nuclear pumping) with relatively low cost and a wide range of deployment modes. The current thinking is that one component of the X-ray laser system (perhaps 300 satellites) should be permanently based in low-Earth orbit. These "early warning" defense satellites would be vulnerable to antisatellite destruction (although this danger is minimized by the small size and large number of the satellites). Behind this component would be a "pop-up" capability of another several hundred satellites, based on submarines, on land near the direction of missile threats, or in the continental United States. These satellites would be launched into low-Earth orbit on warning.

Fusion Energy Foundation experts think the X-ray laser system may become the "show stopper" in *as little as three years,* and scientists in charge of the X-ray laser system have repeatedly

Figure 8-1
Hypothetical Design for X-ray Laser



This design solves the problems of the inefficiency and large beam divergence of conventional X-ray laser designs, by combining several techniques well known in the construction of advanced nuclear weapons. First, the X-rays from the bomb blast can be focused using a set of ellipsoidal cavities arrayed around a spherically symmetrical explosion. These cavities focus all the X-rays from the nuclear explosion on to the ends of the lasing rods. The rods use a conical assembly of lasing material to further focus the plasma produced by the X-rays along the axis of the rod. The lasing medium itself is embedded in a heavy metal tamper, which provides mechanical stability as well as an inertial focusing of the lasing medium. In addition, a very intense photoelectric current generated by the X-rays in the lasing material confines and focuses the plasma that produces the X-rays. These techniques increase the efficiency of the conventional design by 2 to 3 orders of magnitude and decrease the beam divergence by perhaps a factor of 10.

hinted that the scientific and engineering progress has been so rapid that they expect to "present the next President" with a working system for ABM defense.

There have been three independent reports of very successful tests of different components of the X-ray laser. The first was the 1981 Dauphin test, underground in Nevada, which demonstrated the scientific proof-of-principle of the X-ray laser. Reportedly, it was so much more successful than expected at producing a monochromatic, collimated beam of X-rays that the diagnostic equipment installed for the experiment was vaporized by the pulse of X-rays.

There were two subsequent reports of tests in 1983, one (in space) of the sensing and pointing system for an X-ray laser, and the second (underground) for other components of the system. These tests indicate that the three largest problems of the X-ray laser are being solved:

(1) Energy output efficiency. The reported pulse energy of the first experiment was 1 megajoule (1 million joules, or watts per second) on the target. This means that if the beam stayed on the target for one second, it would deliver the power equivalent of 1 million watts, or 1 megawatt, onto the missile. In fact, the X-ray laser delivers its power much more rapidly than that.

A 100-fold to 1,000-fold effective increase in energy is necessary above this 1-megajoule level. This energy increase can be obtained simply by using present bomb designs to better *focus the bomb energy* on the lasing medium. A hypothetical design for this is shown in Figure 8-1.

(2) Beam divergence. Until now the only known way to focus the beam was to use rods with a very small diameter (really wires) and several meters in length as the lasing medium. This produces a very thin, brightly focused beam. The only way to make a bigger beam to irradiate a larger area was to let the beam spread.

Therefore, it had appeared that a brightly focused beam would be of low power, while a high power beam would spread over a large area.

This problem can be solved by using several technologies well known in the weapons community for focusing first the bomb blast, then the zinc plasma shock wave, and finally the lasing medium, shown as *a*, *b*, and *c*, respectively, in Plate 19 following page 56.

(3) Pointing. The difficulty of pointing an X-ray laser beam that has only 1 megajoule pulse energy (as in the first test in 1981) at a single missile is roughly the same as for a chemical laser system. This is a challenging task that would require several years to solve. However, if the power is increased by 100 to 1,000 times as discussed above, the pointing accuracies for such a bigger, more powerful beam would not have to be so precise; they would fall within *present* technological capabilities. The bigger, more powerful beam could disable any missile passing through its area, requiring much less precise pointing and permitting the operators to deliberately spread out the beam to cover a larger area of attack in space.

Particle beam defense systems, capable of defending even against small, maneuverable warheads that have separated from the missiles and are nearing their targets, will be the next challenge. But all the beam weapon systems are "much closer than most people think"—realizable not only in this century, but some of them in this decade.

Chapter 9

The Russians Are Doing It!

No matter what the Russians say, within the next 10 years they will have space-based antimissile beam weapons. For at least 20 years, scientists in the Soviet Union have been working on the technical problems involved in using beam weapons to protect their nation from nuclear attack. Estimates from scientific and military experts indicate that the Soviets have now solved most of these problems.

Soviet leader Yuri Andropov may say that beam weapons are an aggressive U.S. policy. Soviet officials may deny that they are readying beam weapons for their own defense. Soviet scientists may say that such weapons are an "illusion." Don't believe it!

Here are the facts, going back 20 years:

- In 1962, in the book *Military Strategy*, Soviet Marshal V.D. Sokolovskii discussed "antirocket screening systems" based in space. Sokolovskii said: "Possibilities are being studied for the use, against rockets, of a stream of high-speed neutrons as small detonators for the nuclear charge of a rocket. . . . Various radiation, anti-gravity and anti-matter systems are also being studied as a means of destroying rockets. Special attention is devoted to lasers; it is considered that in the future, any missile and satellite could be destroyed with powerful lasers."

- In 1967, Soviet researchers discussed at an open scientific conference the fact that X-rays from hydrogen bomb explosions could be used to disable ICBMs. A U.S. authority attending the conference stated, "the Russians not only had something, and were years ahead in theory, but had already tested it out in space and probably were starting to build their antimissile system around it."
- In 1971, scientists at the main Soviet laser laboratory, Lebedev Institute in Moscow, announced that they had succeeded in generating 300-billion watt pulses from a high-energy laser. This breakthrough was based on a new chemical laser, using hydrogen and fluoride, developed by V.L. Tal'roze at the Soviet Chemical Physics Institute.
- A Soviet book published in 1974 by N. Sobolev featured a diagram of what a land-based laser antiballistic-missile system (ABM) would look like. Pointing out the advantages of a laser ABM system, Sobolev stated that the laser propagates at the velocity of light, "tens of thousands of times exceeding the speed of antimissiles," does not scatter in space, and uses less sophisticated ground support equipment than that required by missile ABMs.

  "Another possible antimissile laser defense system is a project of an orbital space station equipped with target-detecting and tracing radars," with a laser system on board, Sobolev concluded. (At this time, the Soviets had a near-permanent orbiting space station.)

It may seem unusual that Sobolev's recommendations were written a decade ago, and *immediately after the signing of the*

1972 U.S.-Soviet Treaty on ABMs, which has always been taken in the West to be a ban on all ABM deployment. For an explanation, see the short report on that treaty at the end of this chapter.

On what basis, then, are the U.S. beam skeptics denying that the Soviets are developing directed energy beam weapons, when the Soviets themselves have said not only that they are doing it, but that it's a good idea!

But Andropov Says, 'Nyet'

Despite all the public evidence—certainly available to top scientific, military, and intelligence experts in the United States—that the Soviets are developing beam weapons, Soviet leader Yuri Andropov somehow thinks that by bellowing as loud as he can about President Reagan's bellicosity, he will stop the U.S. defensive beam weapon program.

The day after President Reagan's March 23 speech proclaiming a stepped-up U.S. beam effort, the official Soviet news agency, TASS, said, "What is being talked about is a new attempt by the United States to achieve superiority in strategic arms over the Soviet Union and to upset the existing rough balance of power."

The naive might be fooled into thinking that the Soviets were not already ahead of the United States in developing these same defensive systems, and not spending at least three times as much per year on their development.

Three days after President Reagan's speech, General Secretary Andropov said in an interview with the Soviet daily *Pravda* that Reagan's statements about beam weapons keeping the peace were "untruths." Andropov accused the American President of proposing the upgrade of "the strategic offensive forces of the United States" to acquire a "nuclear first strike capability." The entirety of the Reagan speech, or even long excerpts of it, was never published in the Russian press to let the population see what Reagan had actually said.

Georgi Arbatov, the Soviet director of the USA-Canada Institute, went even further, telling the *Washington Post* April 8 that what the President had proposed were "some useless and exotic weapons" that would be a "heavy blow to stability even though these weapons do not exist." Two days later, a statement from 244 Soviet scientists was released saying, "proceeding from the understanding of the basic nature of nuclear weapons, we declare in all responsibility that there is no effective defensive means in nuclear war, and their creation is not practicably possible." Some of the scientists who signed that statement are themselves known to be intimately involved in their country's beam weapon program.

At the same time, the Soviets have been great backers of the new "peace movement"—not in Mother Russia, of course, only in the West. The nuclear freezers in the United States, with Soviet support, have proposed throwing away U.S. strategic arms, even with no comparable reduction by the Soviets. Why shouldn't the Soviets support this new "peace" movement?

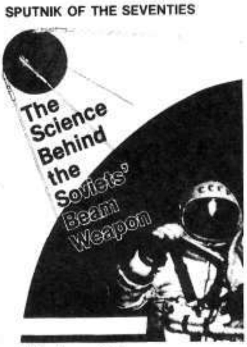
This is a clear case of the Soviets trying to convince the United States to "do as I say, not as I do." The question is, is the United States stupid enough to have its strategic military policy made in Moscow?

What Are the Russians Doing?

Over the past 30 years, Soviet scientists have been doing experiments that will lead to an operational beam weapon capability. Periodically, their scientists have discussed these experiments with their U.S. counterparts, since the weapons research also has widespread applications for commercial fusion energy development, new industrial technologies, and other civilian fields.

Over the past five years, the Soviets have reached the point where they have actually tested some of the techniques needed to deploy beam weapons, and they have succeeded in destroying missiles and aircraft in flight using high-energy lasers. Here are some of the experiments the Soviets have done:

Sputnik of the '70s



In a 1977 pamphlet titled "Sputnik of the '70s: The Science Behind the Soviets' Beam Weapon," the Fusion Energy Foundation compiled the technical evidence to back up the claim that the Soviets were ahead. Here is a sampling of what the pamphlet said:

"The real story of the Soviet Union's weapons development is not a military one at all, but, rather, a scientific and industrial one. . . . Each of the technological ingredients which went into making such a 'death ray' possible were the result of the Soviet Union's crash program for fusion [energy] development, a commitment to basic science research many times larger than that of the United States, and a continuing aggressive policy of industrial development.

"If all these technologies have been integrated by the Soviets, as all available information indicates is the case, the Soviet Union is near to perfecting a weapon which is capable of being deployed to destroy any offensive capability of U.S. ICBMs."

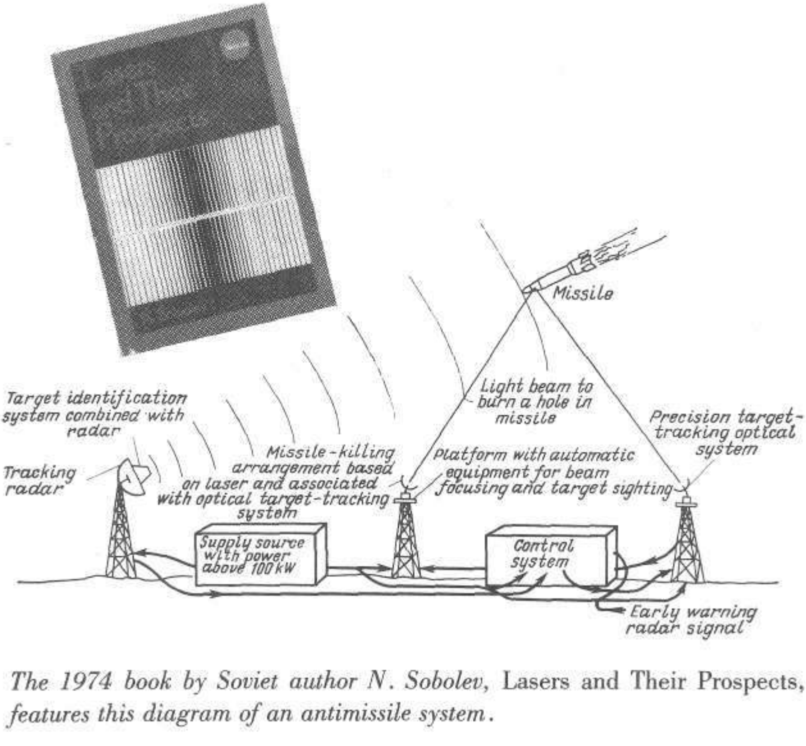
Significantly, many of the technologies that were required to develop a U. S. beam weapon system that were not available here in 1977 have been developed within the last two years. It is these recent advances in computer processing and aiming and tracking that allow scientists today to say that a laser beam weapon system could be operational in the next five years.

Generating High Energy Laser Beams

- In 1971, scientists at the Lebedev Institute announced that they had generated laser pulses of 300 billion watts. This followed an earlier breakthrough in the development of advanced hydrogen fluoride lasers.
- Last year, a Soviet battleship fitted with a high-energy laser downed a pilotless subsonic aircraft, demonstrating how the Soviet military will deal with the U.S. cruise missile.
- Recently an advanced iodine laser was tested that brought down a ballistic missile, demonstrating the use of a laser as a *strategic* weapon. U.S. intelligence sources report that there are downed reentry vehicles scattered near Soviet test sites, indicating they have been successful in downing test ballistic missiles they launch as targets.
- The Soviets have developed land-based laser systems capable of "blinding" U.S. military surveillance satellites. The effect is to overload the sensitive cameras on the satellite, or even destroy the satellite's delicate optics. U.S. intelligence sources report the Soviets have had this technology available for about four years.

The fact that the Soviets are developing advanced laser technology is certainly no secret. As a matter of fact, much of it is for civilian industrial use. In a cover story in the Communist Party weekly economic magazine in April 1983, the nation's top laser scientist, E.P. Velikhov, writes at length about how "The Laser Beam Is Working." In the article, Velikhov enumerates the industrial applications of the latest laser technologies from the military development program. Velikhov is vice president of the Soviet Academy of Sciences and has headed the Soviet nuclear fusion program as well as Soviet work in magnetohydrodynamics and laser development. All three areas have important civilian as well as military applications.

"In a little more than two decades," Velikhov states, the laser has gone through "all the stages of development and emerged into the open range of multipurpose utilization in the national economy." In the current Five Year Plan, he explains, "work is being done in the following major directions: development and creation of lasers of more than a kilowatt of power; organization of experimental laboratories" at scientific research institutes and in industrial facilities; "creation of an industrial base for the widespread mass production of lasers and laser technology equip-



The 1974 book by Soviet author N. Sobolev, Lasers and Their Prospects, *features this diagram of an antimissile system.*

ment"; and the further use of low-energy lasers and more areas of application.

Generating Other High-Energy Directed Beams

- For many years the Soviets have had a broad-based approach to beam weapons, conducting scientific work and experiments not only in the development of laser beams, but also in charged particle, microwave, and other beams.
- The Soviets have performed experiments using microwaves propagated in the ionosphere of the Earth's atmosphere to black out radio transmissions, destroy radar reception, and in general, conduct electronic warfare on a global scale. This is a critical capability, since one of the important questions in a nuclear exchange is the ability of each side to continue to communicate with its communications and reconnaissance satellites.
- Microwaves, which can be produced by an electron beam passed through a plasma, can be targeted at missiles to destroy delicate electronic equipment or even cause mechanical failure. Experts estimate that the Soviets are at least two or three years ahead of the United States in microwave technology.
- The Soviets, almost exclusively, have been investigating the use of highly organized plasmas (high-temperature gases whose particles are charged) as "projectiles" against missiles. They have also done research using positively charged proton beams for ballistic missile defense.
- As early as 1967, the Soviet scientist Gersh Budker, now deceased, described his method of accelerating protons at an open scientific meeting. Since protons are 2,000 times heavier than electrons, if they could be accelerated to great speeds, they could do potentially greater damage than electron beams. At the time, U.S. participants reported that the U.S. scientists "laughed."

Budker developed a method of accelerating proton and electron beams together. (When protons alone are accelerated, the like-charged protons would repel each other, making the beam very dispersed.) This method involves the transfer of energy from magnetic accelerators to the protons, and it solved the problems of using proton beams. Now the United States is trying to catch up in this research, too.

- The Soviets, in joint experiments with the French, have also been studying the propagation of electron beams through the atmosphere. They have shot streams of electrons into the ionosphere and created "artificial auroras" or showers of electrons. These experiments demonstrated the fact that the plasma ionosphere can act as an "amplifier" when energy is put into it. If this amplifying effect could be controlled, it would have potential as an antimissile device.

Generating Pulsed Power

Beams of plasma or charged particles used as strategic ABM weapons will require rapid pulses of enormous amounts of power, and the Soviets have already tested two methods of producing such bursts of electrical power; both involve the use of a nuclear explosive to generate the needed energy.

Magnetohydrodynamics, or MHD, is one of these methods. MHD turns heat and plasma energy into electrical power almost instantaneously and without any large, bulky moving parts. It directly converts heat into electricity using a supercooled, powerful magnet. This is a process that the Soviets have been pursuing for the last 20 years. Although the United States was actually ahead in this type of research until recently, the program here has been slowed to a halt since 1979 as electricity demand has collapsed in the wake of "conservation" policies and industrial bankruptcies. Now the Soviets lead the world MHD effort. In fact, an MHD generator helps power the Moscow subway. But the technology's main mission in the Soviet Union is military.

Since the late 1970s near the town of Semipalatinsk, the Soviets have operated two huge spherical chambers, 70 feet in diameter, attached together like a huge dumbell, with walls 3 to 4 feet thick. Small hydrogen bombs have been exploded inside these chambers, which the Soviets have used, via the MHD process, to create enormous pulses of electrical energy. The only possible uses for such billion-watt electrical pulses are military.

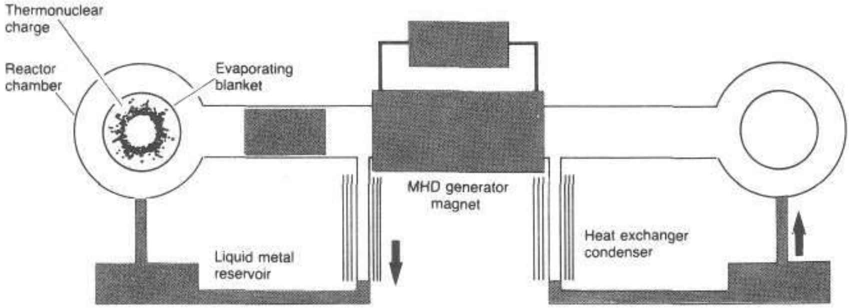


Figure 9-1
MHD Generator for Pulsed Thermonuclear Reactions

This dumbell-shape design for MHD direct conversion with a fusion reactor was suggested in 1974 by Soviet Academician E.P. Velikhov, who directed the Soviet MHD program. When the fusion reaction takes place in one of the two reactor chambers of the dumbell, it evaporates the blanket of a liquid metal like lithium around the reactor chamber. The accelerated hot vapor then pushes a metal piston past a solenoid to the other reactor chamber. The kinetic energy is transferred into electrical power, which is drawn off through the solenoid, or load, that separates the two reactor chambers. Another fusion reaction in the second reactor chamber then sends the piston back. In this closed-cycle system, the liquid metal vapor is caught, condensed, then recycled through the liquid metal reservoir back into the reactor blanket to be revaporized.

The design for the Semipalatinsk MHD chambers was first discussed in the open literature by Academician Velikhov in a paper in 1974. He described a system where a trillion joules of energy, equal to about 250 tons of TNT, would be produced from a hydrogen fusion bomb ignited in one of the two chambers. That energy would be used to vaporize a liquid metal surrounding the nuclear charge. This would provide the mass to move an electrically conducting piston toward the second chamber.

In the center of this dumbell, the piston would pass a large magnet that would slow it down and extract some of its energy in the form of electrical power. Velikhov estimated that this kind of "dumbell" design could produce pulses of 15 billion watts of power each.

Three years later, in 1977, General George Keegan, then head of Air Force Intelligence, revealed that reconnaissance satellites had shown the Soviets constructing these chambers. "Impossible," U.S. scientists said. "No one could weld the 3 to 4 foot thick steel chamber pieces for such a device."

Indeed, in the United States no such welding technique is in use. However, scientists at the Hydrodynamics Institute in Siberia had devised such a welding technique when perfecting "explosion flux" welding, using chemical explosives. When two pieces of metal were welded together by this explosive method, the weld was stronger than the metal itself! There is no doubt that explosion welding was the way the MHD chambers were created.

The second method of pulsed power production under Soviet development is the use of so-called *liner generators*. Here, conventional explosives are used to crush a metal liner, which supercompresses a plasma that has a magnetic field inside it. As the metal liner cylinder crushes the plasma and compresses the magnetic field, an enormous pulse of energy is produced. Experiments on liner generators began in 1980 in Kazakstan and are another possible method for producing large pulses of energy for beam weapons.

Driving Ion Beams

The common objective of all of these explosive experiments is the generation, storage, and release of enormous pulses of electrical power, compressing more and more electrical energy release in a shorter and shorter instant of time. No conceivable electricity grid could store, and then release, many hundreds of times in a period of minutes, the large pulses of power that generate strategic antimissile energy beams. The requirement can be met, however, using explosions and the special properties of strong magnetic fields and of plasmas.

In all of this pulsed power development, the Soviets have pursued the objectives of military use for beam weapons: "higher output energies; reduced size and weight of the equipment; operational reliability; . . . explosive energy sources," to quote a 1978 report. The report, by the Rand Corporation, draws a striking conclusion: "[The Soviet work] is to a large extent aimed at showing that the theoretical limits, established by Western researchers, of energy and power that can be developed by pulsed MHD generators, are invalid."

These, of course, are precisely the theoretical limits that are supposed to make beam weapons impossible, according to the Soviet scientists' statements for circulation abroad!

The specific objectives of this Soviet research are particle beams—beams of electrons, protons, and neutral particles:

- Since 1971, Soviet military-science teams have been generating intense *electron beams* of increasing brightness and coherence. These beams propagate well through the atmosphere, actually using the atmosphere and the ionosphere to increase the coherence and focus of the beam. They are therefore developed for ground-based defense of areas of Soviet territory against reentry vehicles.
- Since 1967, as reported above, Gersh Budker and other Soviet

scientists have worked on developing *proton beams* from the same type of experiments. Proton beams would have an atmospheric use similar to electron beams—but since protons are much heavier, these beams will be much more destructive against reentry vehicles and warheads.

- High-energy electron beams can be used, by interaction with plasma gases, to generate *neutral particle beams*. These also will pack greater power than electron beams. In addition, because they are unaffected by the Earth's magnetic field, these neutral beams are for long-range, space-based use.

More Evidence?

The Soviets have demonstrated that they can produce billions of watts of electricity to power beam weapons; they have researched and experimented on the production and propagation of several possible types of beams for military applications, and they have used laser weapon systems to destroy tactical and strategic weapons. How much more evidence does the United States need before we decide it is time for us to catch up?

Further, the Soviets are not waiting for these technologies to be perfected before putting up defenses. For years they have been testing their surface-to-air missile system as an ABM system for "perimeter defense" of the country. The latest SA-5 surface-to-air missiles have a range of at least 150 miles and multiple boosters and radars; they can intercept at up to 100,000 feet missiles traveling at speeds up to 19,000 feet per second. That is as fast as submarine-launched missiles travel, and not much slower than land-based missiles at top reentry speed.

To guide this system, the Soviets have built and deployed very large phased-array radars, which can reach out thousands of miles to acquire U.S. ICBMs as targets. Five have been built, and there is evidence that ten huge radars, in total, are planned.

They have also developed a mobile ABM radar, the ABM-X-3, as it is called in the West, for the same purpose.

These radars are the infrastructure for a beam weapon defense system.

The total Soviet military budget, according to the a 1981 study by the Fusion Energy Foundation, is now about 50 percent larger than the U.S. military budget. While that conclusion was not what most Western researchers believed at the time, the most recent official estimate of the Defense Intelligence Agency now agrees that the Soviet military budget consumes 17 to 19 percent of that nation's GNP. Soviet investment in research and development has been about $100 billion over the last decade. Even the Defense Department has admitted the Soviet beam weapon program is between three and five times the size of the U.S. effort.

The Russians are definitely doing it—and they are ahead for now.

What About the ABM Treaty of 1972?

Immediately after President Reagan's March 23 speech, his critics were quick to state that his proposal violated the 1972 U.S.-Soviet Treaty on ABM systems. The treaty itself says otherwise. The treaty *specifically excludes* beam weapons from its ban on the deployment of ABM weapons, by very narrowly defining ABM systems. Article II of the treaty reads:

> For the purpose of this Treaty an ABM system is a system to counter strategic ballistic missiles or their elements in flight trajectory, currently consisting of: a) ABM interceptor missiles, which are interceptor missiles constructed and deployed for an ABM role, or of a type tested in an ABM mode; b) ABM launchers, which are launchers constructed

> and deployed for launching ABM interceptor missiles; and c) ABM radars, which are radars constructed and deployed for an ABM role, or of a type tested in an ABM mode.

This definition is based on the characteristics of the old U.S. Safeguard and the Russian Galosh ABM systems. It covers only a fraction of the Soviet antimissile missile system. (For example, it does not cover the perimeter defense system described above.)

Far more important, it does not restrict the development of "new physical principles" for antimissile defense, namely the laser and the plasma physics principles of relativistic beam weapons, which scientists on both sides knew were the real "firepower" to defeat missiles. "Agreed Statement D" states:

> The Parties agree that in the event ABM systems based on other physical principles [other than those specified in Article II] and including components capable of substituting for ABM interceptor missiles, ABM launchers, or ABM radars are created in the future, specific limitations on such systems and their components would be subject to discussion in accordance with Article XIII and agreement in accordance with Article XIV of the Treaty.

Did President Nixon know this? Evidence indicates he was not given this assessment by Henry Kissinger who negotiated the treaty for him. The Soviets, however, certainly did understand that beam weapons were not affected. On September 29, 1972, after emerging from the meeting of the Supreme Soviet that ratified the 1972 ABM Treaty, Soviet Defense Minister Marshal Andrei Grechko emphasized that the treaty did not constrain research and development. The treaty, he said,

> does not place any limits on carrying out research and experimental work directed towards solving the problems of defense of the country from nuclear missile attacks.

Chapter 10

Answering the Critics

The critics of beam weapons have been taken by surprise by the rapid-fire scientific breakthroughs, especially those of the past two-and-a-half years. These "flat earth" critics used to say that a workable beam weapon defense system could not be built with currently available science and technology—as if that made it distant or even impossible. Meanwhile, science was passing them by. With the testing of the X-ray laser and advances in pinpoint aiming provided by NASA's Space Telescope, we are on the threshold of success—if we push forward relentlessly. Did scientific progress win over the critics? No, they became only more vocal in demanding that we should not push forward.

The accompanying table summarizes the major criticisms of beam weapons and answers each point for both first and second generation beam weapon systems.

The center of opposition is a group of scientists at the Massachusetts Institute of Technology—led by Victor Weisskopf, Bernard Feld, Kosta Tsipis, Jack Ruina, and political scientist

George Rathjens—and at the University of Chicago and the California Institute of Technology. These same critics of beam weapons are also the "brains" behind the nuclear freeze movement. Their literary outlet is *The Bulletin of the Atomic Scientists*.

Let's hear what one of the most famous of these critics, Dr. Richard Garwin, a research fellow at IBM and a longtime government military advisor, had to say in a debate with beam weapon proponent Dr. Steven Bardwell of the Fusion Energy Foundation in April 1983:

> I think it's highly improbable these systems can be built. I would prefer that the Soviets tried to do so and we deployed against them. If the Soviets somehow succeeded in spite of everything, we should go to launch on warning [of our ICBMs].

And another beam weapon critic, MIT's Dr. George Rathjens, also debating Bardwell:

> What I really object to about this beam weapon thing is the degree of technological optimism involved. That is something I just don't share.

A third, very influential critic is Dr. Alan Din of the European Center for Nuclear Research (CERN) in Geneva. In May 1983, Din wrote an article in the European *Journal of Peace Research* in which he shocked some of his cothinkers. The article, "Prospects for Beam Weapons," admitted quite bluntly that beam weapons could be developed and deployed *during the 1980s*. We'll never stop them, he advised his fellow critics, by claiming they are not feasible—they are, and quickly.

Why, then, does Din argue for stopping beam weapon development and not deploying this split-second defense against missiles? Din claims that the split-second operating characteristics of this new level of firepower will put decision-making power in warfare entirely in the hands of computers, and thus increase the danger of war!

This "flat earth" school of thought has a long history in resisting powerful scientific and technological innovations. Edison's light bulb was only one of many famous developments this faction hoped to wish away (see below). Since 1957, the elite of this tendency has called itself the Pugwash Conference on Science and World Affairs. In that year Western and Soviet scientists were brought together for the first of a continuing series of conferences at the instigation of Lord Bertrand Russell. Millionaire Cyrus Eaton financed the meeting, which convened in the village of his birth, Pugwash, Nova Scotia. The name has stuck, even though the meetings have been held in many locales around the globe.

Recently, even many of these same critics have admitted that at least one beam weapon system defeats even most of their *technical* objections—the X-ray laser.

In November 1980, scientists at Lawrence Livermore National Laboratory exploded a miniature fission bomb at an underground test site in the first test of a U.S. X-ray laser. This laser produces a beam so intense that no "dwell time" is necessary to knock out the target—the beam does not have to be held on the target until it burns through its skin. Similarly, the beam is so intense that it does not have to be focused with pinpoint sharpness to achieve a kill; this means that aiming does not have to be so exact. The X-ray laser's fuel—a tiny fission bomb—is light in weight (a few hundred pounds) as is the assembly as a whole. Several can be lofted by one rocket, and a single Space Shuttle could carry many (as shown in Plate 1 following page 56). No mirrors are required because the X-ray laser can be based in Earth orbit.

There are indications that an ABM system based on X-ray lasers may be ready for deployment within as little as three years—

Beam Weapons: Fact Versus Fiction

Summarized here are the most frequently mentioned objections to the development of beam weapons, and their scientific refutation. It is useful to note that scientists who claim that beam weapons are impossible are at least five years behind in terms of the scientific literature and current experimentation.

	Objection	**Reply**	
		First-generation system	**Second-generation system**
1	**The power levels required for a laser cannot be produced** today either economically or efficiently. The fuel is too expensive or too heavy.	A 2.2 megawatt chemical laser already exists. To scale it up to 10 megawatts is a straightforward engineering task, and there is no laser scientist who believes that this cannot be done. Ten megawatts is the power level recognized in general, and by Tsipis, as the minimum required for a laser beam weapon. *For a ground-based system, the amount and mass* of the fuel required are irrelevant, since the laser does not have to be put in orbit.	Short wavelength lasers, specifically the free-electron laser and the X-ray laser, have inherently high power densities, their brightness being about 2 or 3 orders of magnitude greater than the minimal chemical laser. The fuel is *neither expensive nor heavy since* nuclear power sources are used to pump both these lasers.
2	**A laser beam of the type required cannot be propagated,** because the beam would be so greatly attenuated by either moisture in the atmosphere or dust clouds generated in the course of a military engagement that the energy from the laser would never reach the target.	If the laser is based on a mountaintop above 12,000 feet, less than 10 percent of the beam will be lost. The critical point to be made is that there are numerous laser frequencies that will propagate through the atmosphere and other media. To flatly assert that lasers cannot propagate through the atmosphere *ignores the results of experiments with plasmas* during the past five years.	This objection is irrelevant here.
3	**It is impossible to produce a mirror good enough and accurate enough** to be capable	The generally agreed specification for a first-generation mirror is between 5 and 10 meters in di-	These systems have no optics.

	of focusing a beam that is powerful enough to destroy a missile. And even if such a mirror could be produced, it would be so delicate and so vulnerable that it would be unusable in a military system.	ameter. This is within our technological capabilities today, and United Technologies offered to build such a mirror at a fixed price. As to the fragility of such a mirror, the basic point is that a first-generation system would not be subject to countermeasures by a technologically capable opponent. The system is no threat to the Soviets and it would be pointless for them to try to destroy it, since the only function of such a system is to prevent an accidental or third power launch.	
4	**There are no technologies available that can point such a mirror accurately enough** to hit a target at a range of 1,000 to 2,000 kilometers (the range required for the strategic task of destroying missiles).	The mirror has to be pointed with the accuracy of 0.1 microradian in order to hit the target. This is done routinely with space satellites, and will be done with the existing Space Telescope.	The same applies to the pointing of the X-ray lasing medium.
5	**Even if such a mirror could be aimed accurately, the technologies do not exist to track missiles long enough** for the beam to destroy them—a tracking accuracy of 0.1 microradian per radian per second.	The required tracking capability has been demonstrated by fourth generation gyroscopes in the laboratory. It is now an engineering problem to put these on a telescope and make them usable for a laser system.	The problem of tracking is irrelevant for these systems, because the lasers are so bright that they blast the target in microseconds, virtually without any dwell time.
6	**The sensing technologies do not exist to distinguish between decoys and armed missiles.** Since decoys are lightweight, cheap, and easy to build, this gives the advantage to the offense, which can saturate the defense with decoys, thus aiding the penetration of the armed missiles.	The technology exists—long wavelength infrared telescopes—to distinguish the infrared emission of missiles at several thousand kilometers. This emission is dependent on how heavy the missile is, and therefore provides the capability of distinguishing between decoys and armed ICBMs in the boost phase, which is the purpose of these first generation systems. With reentry vehicles, the task is much more difficult.	The same applies.

Objection	Reply	
	First-generation system	**Second-generation system**
7 **Given the constraints of focusing and tracking, there are a series of simple and cheap ways to defeat beam weapons,** such as using missiles with a reflective coating, or burn-off coating, or rotating the missile so that the laser energy is spread out so much that it will not be able to destroy the missile.	The various countermeasures that have been proposed to defeat a first-generation beam weapon system are strategically irrelevant at this point since the Soviet Union is not going to retool its existing missiles to defend them from a weapon that does not threaten them. In the future, scaling up the power density of the laser beam by a factor of 10 would defeat all passive defense systems mentioned—such as reflective coatings, burn-off surfaces, and space mines.	Passive defenses are totally helpless because of the intense brightness of the short wavelength lasers, which can burn through anything.
8 **The cost of developing a beam weapons system** for protection against all-out attack is so great as to make it impossible.	As we have proposed it, to develop a first-generation system would cost no more than $20 billion, and the deployment of such a system would be a small multiple of this.	The X-ray laser is smaller, more efficient, and much less costly to deploy for protection against an all-out nuclear attack than would be a scale-up of a chemical laser system to achieve this goal.
9 **Beam technologies would be used for offensive purposes.**	The amount of energy that the beam delivers is actually tiny; it could never be a weapon of mass destruction, but might perform a selective surgical delivery of energy.	These systems could be used offensively. Their technological superiority shifts the advantage to the defensive, however.

earlier than the most optimistic estimates for chemical lasers. Tests of the sensing, aiming, and other systems for an X-ray laser have already been performed in space.

The more immediate development of the X-ray laser, however, in no way lessens the need for a chemical-laser-based system, which will provide one tier of a multilayered antimissile defense system; X-rays cannot propagate through the atmosphere, but wavelengths provided by chemical lasers can. For chemical lasers, there are scientific advances to be made and engineering problems to be solved at several stages. The critics have sought to make a mountain out of each of them. The table, however, shows how close we actually are to solutions.

The 'Flat Earth' Opposition: A Shameful Record

The United States was founded on the premise of promoting scientific progress for the benefit of all mankind, as exemplified in the work of Alexander Hamilton and Benjamin Franklin. From the beginning, however, there have been powerful interests opposed to the application of science to material and moral advance. They have been the sponsors of our "flat earth" scientists, or what one scientist recently named "the League for Cultural Stagnation."

A sample of scientific expertise from this school of thought over the past 100 years follows. What is most clear is the influence this tendency has had on the opinions of those making science

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Several of these facts may be found in *Facts and Fallacies: A Book of Definitive Mistakes and Misguided Predictions* and are reprinted here by permission of the publisher, St. Martin's Press, Inc., Copyright © 1981 by Chris Morgan and David Langford.

and technology decisions for governments. In every case where the launching of a crash program was at question, the flat earth view has held a majority among policy-makers, and the minority, including U.S. Presidents, has had to mobilize the optimism of the American citizenry directly to overcome the resistance.

1875—The automobile. From the *Congressional Record* of 1875 on the "so-called internal combustion engine": "Gasoline in the hands of people interested primarily in profit would constitute a fire and explosive hazard of the first rank. Horseless carriages propelled by gasoline engines might attain speeds of 14 or even 20 miles per hour. . . . The development of this new power may displace the use of horses, which would wreck our agriculture. . . . The discovery with which we are dealing involves forces of a nature too dangerous to fit into any of our usual concepts."

1880—The electric light. In a January 6, 1880 article, the *New York Times* "proved" that Edison's electric light could never compete with gaslight. It took one generator to power eight light bulbs, the *Times* argued, so at least 250,000 generators would be needed to light New York. At $3,000 per generator, this implied a mammoth investment of $750 million that was obviously out of reach. *Scientific American* adopted the *Times*'s line of argument.

Ten days later on January 16, in a front-page expose of Edison, the *Times* cited a "noted electrician" as the authority for the conclusion that "after a few more flashes in the pan, we shall hear very little more of Edison or his electric lamp. Every claim he makes has been tested and proved impracticable."

By fall 1881, Edison had opened up generating stations providing electricity to parts of New York and Philadelphia.

1895—X-rays. Lord Kelvin, a leading British scientist and president of the Royal Society: "X-rays will prove to be a hoax." Years later, Kelvin declared, "Radio has no future."

1902—The airplane. Professor Simon Newcomb, a leading American astronomer, mathematician, and naval advisor on scientific matters, wrote, "Flight by machines heavier than air is unpractical and insignificant, if not utterly impossible." This was also a view expressed earlier by Lord Kelvin.

After the failure of one of Samuel Langley's experiments in powered flight, a *New York Times* editorial on December 10, 1903 proclaimed that man's attempts to fly had always been fruitless: "We hope that Professor Langley will not put his substantial greatness as a scientist in further peril by continuing to waste his time, and the money involved, in further airship experiments."

Seven days later, on December 17, the Wright brothers, who were in correspondence with Langley, made their dramatic maiden flight at Kitty Hawk, N.C. This the *Times* did not report. On December 26, however, the *Times* wrote, "inventors of a North Carolina box kite machine want the government to purchase it." Despite scores of successful flights, witnessed by hundreds, the success of the airplane was almost totally blacked out of the American press from 1903 until 1908 when the U. S. Army signed a contract with the Wrights.

So little information appeared in print that British intelligence—which may have had a hand in the blackout—had to send an agent to Ohio to spy on the Wright brothers. As late as 1907, the British Secretary of State for War, Lord Haldane—who was well informed concerning the Wright brothers' achievement—bluffed that the airplane would never fly.

With the Army contract in 1908, the Secretary of the British Aeronautical Society, Major B.F.S. Baden-Powell, had to concede that "Wilbur Wright is in possession of a power which controls the fate of nations."

1910—Transatlantic flight. American astronomer William Pickering wrote in 1910: "The popular mind often pictures gigantic flying machines speeding across the Atlantic carrying innumerable passengers in a way analogous to our modern steamships . . . it seems safe to say that such ideas are wholly visionary."

1920—Space travel. Unlike the airplane, rocket propulsion functions also in space. Robert Goddard, the American pioneer in rocketry, thought in terms of eventual space travel from the outset, even though it took him years to achieve an altitude of 300 feet. The *New York Times* ridiculed Goddard and his work in a Jan. 13, 1920 editorial: "For after the rocket quits our air and really starts on its longer journey, its flight would be neither accelerated nor maintained by the explosion of the charges it then might have left. . . . That Professor Goddard . . . does not know the relation of action to reaction, and of the need to have something better than a vacuum against which to react—to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in our high schools. But there are such things as intentional mistakes. . . ."

Today the *Times* leads the American press in largely opposing beam defense.

1923—Nuclear energy. Robert Millikan, the American theoretical physicist who received the Nobel Prize in 1923, also said in that year: "There is no likelihood man can ever tap the power of the atom. The glib supposition of utilizing atomic energy when our coal has run out is a completely unscientific Utopian dream, a childish bug-a-boo. Nature has introduced a few foolproof devices into the great majority of elements that constitute the bulk of the world, and they have no energy to give up in the process of disintegration." Lord Haldane's brother, the world famous scientist J.B.S. Haldane, expressed the same view.

Once it was established that atomic nuclei *did* have energy to give up, Sir Ernest Rutherford—also a Nobel laureate in theoretical physics—insisted repeatedly during the 1930s: "The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who looks for a source of power in the transformation of the atom is talking moonshine."

Nuclear power *was* feasible, said the University of California's Ernest O. Lawrence in answer to Rutherford. "I don't know how, but I'm going to find out," Lawrence said.

1933—Strategic bomber. Secretary of War George Dern argued against construction of a long-range bomber in 1933 saying, "The best protection is to accept and build upon American tradition and not try to purchase freedom with gadgets." He denounced the concept of a strategic air arm as the "fantasy of a dreamer." Hitler was already in power.

1937—Limits of the cyclotron. In 1931, Ernest O. Lawrence and M. Stanley Livingston had demonstrated the "cyclotron" circular particle accelerator, generating a beam of protons at 1.2 million electron volts. In a series of papers in *Physical Review* in 1937-1938, Hans Bethe—a young theoretical physicist opposed to geometric methods in physics—argued that the cyclotron could not achieve higher power levels than already demonstrated by Lawrence: "We see that either the resonance or the focusing is destroyed by the relativistic change of mass irrespective of the special choice of the magnetic field. . . . Thus it appears that the cyclotron cannot be made to give much higher energies than those obtained thus far." British Nobel laureate James Chadwick—discoverer of the neutron—echoed Bethe's argument in a 1938 *Nature* article.

Four months after Bethe announced his limits to particle accelerators, L.H. Thomas produced a design for a cyclotron with alternating magnetic field gradients. When machines incorporating this principle were finally built in the 1950s, Bethe's limits were exceeded five times over. Today, Nobel laureate Bethe opposes beam defense.

1939—Crash expansion of aircraft production. World War II had broken out in Europe, and Roosevelt—knowing we would have to help defeat the Nazis—proposed a crash program for building 50,000 planes a year. That was a huge figure; at the time the aircraft industry was working hard to supply the air force with 2,000 planes a year, an all-time high for the United States. Army Chief of Staff Gen. George C. Marshall urged the President *not* to go ahead with his crash program because, he said, it was so far beyond current production capacity that it would result in chaos. Roosevelt ignored Marshall's advice. In 1942, the nation produced 48,000 planes—equal to the combined production of Germany, Japan, and Britain that year. In 1943, we produced 86,000 planes and in 1944, 96,000—again more than the combined production of Germany, Japan, and Britain in each year.

1945—Atom bomb. Admiral William Leahy, naval aide to President Roosevelt: "[It's] the biggest fool thing we've ever done. The atom bomb will never go off and I speak as an expert on explosions."

1945—ICBM. Dr. Vannevar Bush, President of the Carnegie Institution in Washington, headed the American wartime scientific effort as director of the Office of Scientific Research and Development. He was also chairman of the Joint Committee on New Weapons of the Joint Chiefs of Staff: "These people who have been writing these things that annoy me, have been talking about a 3,000 mile high-angle rocket shot from one continent to another, carrying an atomic bomb and so directed as to be a precise weapon which would land exactly on a certain target, such as a city. . . . I feel confident that it will not be done for a very long period of time to come. . . . I think we can leave that out of our thinking."

1950—Fusion energy. Dr. Louis Ridenour, chief scientist for the U.S. Air Force, wrote in the March 1950 *Scientific American:* "We cannot find in the development of the fusion bomb any such peacetime values as are inherent in the development of nuclear fission. . . . Thus when we discuss the 'hydrogen bomb' we are clearly speaking of a weapon, and a weapon only." Project Sherwood—to develop controlled thermonuclear fusion—began in 1953.

1956—Space travel. Sir Richard Woolley, Britain's Astronomer Royal: "Space travel is utter bilge." A year later, the Soviets launched Sputnik.

Chapter 11

Beam Weapons on the Battlefield

National discussion of beam weapons has focused on the strategic defense of the nation against nuclear missile bombardment. President Reagan's initiative has also received great press coverage and discussion in Western Europe. There, however, near the borders of the Warsaw Pact, the equally dramatic battlefield applications of beam weapon technologies against tank assaults, cruise missiles, planes, and so on are considered crucial. This is also true for the U.S. armed services, in particular the Navy.

The Soviet Union has a very definite lead over the United States in developing the battlefield and naval beam weapons that can revolutionize land-warfare strategy. The U.S. effort to develop high-energy lasers for the battlefield has been increased by 60 percent recently, but is still not nearly as large as the Soviet programs.

In the scenarios of the MAD doctrine, as described above, all warfighting becomes reduced to one function—artillery. Rockets, submarines, bombers and their escorts, surface ships, and even licly, Dr. Edward Teller in an April 13, 1983 debate at Los Alamos National Laboratory—insist that the age of "invulnerable" submarine-based missiles is ending.

High energy lasers of this KIROV type are ideally suited to defense against cruise missiles, which are slow moving, low al-

The second unit of the 23,000-ton KIROV-class cruiser—the first Soviet nuclear-powered warship—will have a significantly improved surface-to-air missile defense capability because of its high-energy infrared laser for defense against "smart" missiles.

U.S. Department of Defense, *Soviet Military Power*, 1983 titude craft with a light, unhardened surface material. The U.S. Navy has a program to develop the same type of ship defense—a 2.2 megawatt infrared laser known as Sealite—but that program is lagging behind the Soviet timetable by at least five years.

However, in the late 1970s, tests demonstrated that the Navy can begin to deploy prototype weapons on its vessels. In 1978, a 400 kilowatt deuterium fluoride laser, with a pointing and tracking system designed by Hughes Aircraft for the Navy, destroyed a TOW wire-guided antitank missile launched against it by Army personnel. This TOW missile is a more difficult target to hit than the type of cruise missiles and interceptor aircraft targets involved in defending ships, because it moves faster. In late 1983, test firings of the Sealite laser, the most powerful single-beam laser in the NATO countries, should begin. Meanwhile, in May 1983, the Airborne Laser Laboratory of the Air Force demonstrated that Sidewinder missiles can be shot down from a plane with a similar 400 kilowatt laser at a 5 to 10 mile range, by disabling all of the five Sidewinders launched at it. (The Airborne Laser Laboratory is shown in Plate 4, following page 56.)

Over the European battlefield, the importance of laser weapons, and eventually particle beam weapons, will be to "clear the air," just as over ships at sea. Beam weapons, even before they reach the power density to penetrate heavily armed tanks and so forth, will use more concentrated energy traveling at much higher speeds than missiles, high-performance aircraft, "smart" rockets, and shells. They will also be guided by more advanced radars, which themselves will use lasers and infrared sensors. Such beam weapons will eclipse existing battlefield technologies strategically, first in the air, because they are an inherently more powerful technology.

The ship-based defensive lasers described above can also, of course, be based on land, as a "perimeter defense" against cruise-type missiles. Lasers operating from space or from aircraft will be the "equalizer" against large assaults of high-altitude aircraft, as well as ballistic missiles. In fact, even very long-range beam weapons designed to disable ballistic missiles can be used to force very high altitude aircraft, like the Backfire bomber, down to lower altitudes in the atmosphere. There, while the aircraft are protected by layers of atmosphere from X-ray lasers, they are more vulnerable to battlefield lasers and lasers fired from aircraft.

The U.S. Army is developing the Mobile Test Unit, a 100-kilowatt laser mounted on a mobile Marine Corps vehicle, which is tracked like a tank. (See Plate 5, following page 56.) In 1976, this system, in tests at Redstone Arsenal in Alabama, destroyed drone aircraft and helicopters.

In more advanced and difficult technology programs, both the Navy and the Army are developing particle beam weapons for short-range and medium-range use. The Navy's program is an electron beam accelerator; the Army's is a neutral particle beam accelerator, called a quadripole frequency accelerator. Both of these systems are based on a Soviet accelerator design known as the Dudnikov accelerator, which was described in the 1970s in Soviet medical literature.

One article in the *Proceedings of the Naval Institute* recently described "potentially revolutionary" laser applications possible by the middle of the 1980s: "communications, anti-air warfare, antisubmarine warfare, anti-torpedo defense . . . laser radar, missile guidance, fire control pointing and tracking systems, meteorology, and environmental modification such as burning through or away fog."

The author, William J. Beane of the Navy's Strategic Systems Office, says that currently even the most advanced shipboard air defense systems

> may not be a match for a massed attack by Backfire bombers and cruise missiles. . . . A first generation shipboard laser weapon promises to be more than a match against such an attack. Why? The answer is the

> speed and high firepower of the laser. It delivers its lethal energy on a target one mile away in the time that a hypersonic missile traveling at Mach 6 would move less than an inch. . . . Technical issues such as pointing and aiming, or the size and weight of the power package, do not constrain laser defense of ships against large numbers of conventional missiles. . . . A charged particle beam weapon would have the ability in all weather conditions to engage several targets in a matter of a few milliseconds, and would be essentially incapable of saturation.

Area Defense for Europe

What is needed in Europe, in cooperation with our European allies, is to rapidly build up greater and greater "area defense" capabilities with a combination of high-energy lasers and particle beams based on the ground, and lasers operating from the air. Long-range lasers fired from space, as soon as they are developed, can provide the capability to keep aircraft from operating high above the range of these ground and aircraft-based beam weapons. But the overall objective will be to develop a grid of defended areas and constantly add to that grid—with missile fields and armed forces operations areas first and then protected major cities.

European newspapers have noted that European laboratories have much to add to an allied effort for beam weapons, and will benefit technologically from it. The University of Orsay radiation lab, for example, has reported the most advanced results known in the world for the potentially superversatile free electron laser (see Chapter 12). In many ways, in fact, President Reagan's strategic defense initiative has received more coverage—and more accurate and more detailed coverage—in European journals than in those of the United States.

Our European allies have no choice. In the MAD scenarios, West Germany's only military role in a future war is to disappear into a radioactive field of rubble in the first minutes. The German population's susceptibility to an antitechnology "peace movement" reflects this directly. By developing defensive beam weapon systems, Europe, like the United States and other nations of the world, can be defended from nuclear weapons.

Chapter 12

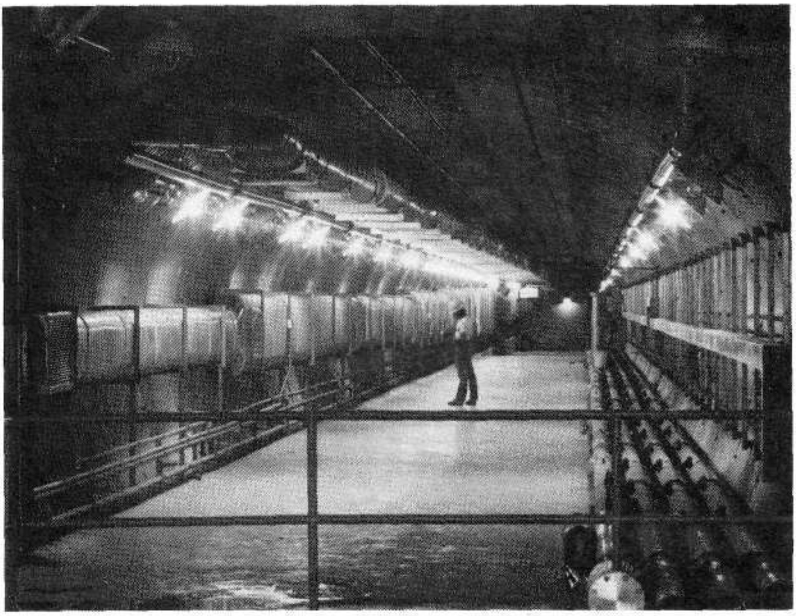
The Laser Amplifier

To shoot a missile down with a ground-based laser, requires a laser with a power level of 10 megawatts (MW), or upwards of 100 MW for more hardened targets. A conventional chemical laser that has achieved 2.2 MW already exists, and we can reach 10 MW by building a "bigger and better" version of the same thing. But by introducing a new physical principle, laser amplification, we can reach higher power levels and, more important, much higher efficiencies in producing the laser beam. The energy of high quality electron beams can be directly converted to laser radiation.

Laser fusion scientists have developed a method for amplifying a laser's power by injecting it into a stream of electrons. The beam is composed of "free electrons" not tied to particular atoms or molecules. It is produced in an accelerator that uses giant electromagnets to accelerate the beam to high velocities. When forced by a magnetic field to decelerate, or change direction, very high speed electron beams (near the speed of light they are called *re-*

lativistic electron beams) give off some of their energy as electromagnetic radiation. This may be visible light, radio waves, or other radiation, but it is not yet coherent (laser) radiation.

To amplify the input laser beam, the electron beam must be made to give off radiation at or very near the frequency of the laser. When this coupling occurs, direct conversion of electron beam energy into laser energy is achieved. The input laser beam does for the electron beam what mirrors do in conventional lasers—it imposes coherence.



Lawrence Livermore's Advanced Test Accelerator Facility provides the intense, electromagnetically self-focused electron beams used in free electron laser experiments as well as in the beam weapon program. Shown here is an inside view of the 200-meter tunnel that houses the accelerator. The electron beam travels down the tunnel (in the direction you are looking) as its energy is boosted to 50 MeV by an 85-meter linear accelerator.

Lawrence Livermore National Laboratory

This is more efficient than any other process by which laser energy is generated because the energy pump and the lasing medium are one and the same—the electron stream. This device is called a free electron laser amplifier, or just free electron laser (FEL).

The Wiggler

The pathway of the free electron beam is lined above and below with a long sequence of small permanent magnets, stretching over 120 meters, put together with alternating polarities (see Plate 22 following page 56). The first magnet in the series above the stream has its north pole on the right, the second on the left. The series below begins with a magnet whose north pole is on the left, the second on the right, and so on. This arrangement causes the electron beam to "wiggle" as it goes. The interaction of the wiggling electron beam with the oscillating electric field from the laser beam (if their frequencies and strengths are harmonically related) causes clumps of electrons to slow down. At a certain point along the wiggler, a clump of electrons suddenly gives up some of its energy. When it does, this energy lost through slowing down is emitted as electromagnetic radiation at the frequency of the input laser beam; the laser literally "harnesses" the electron beam and transforms some of its energy into laser energy, in a manner similar to the formation of a shock wave. Thus, the free electron laser *amplifies* the laser's power and efficiency.

The smaller the magnets (the quicker the alternation of polarity), the shorter the wavelength of the radiation emitted by the electron beam. Since at present magnets cannot be made small enough to achieve the desired wavelengths, scientists have exploited relativistic phenomena to get the same result.

If the electron stream is sent through the magnetic wiggler at a relativistic speed (say, 90 percent of the speed of light), the speeding electron "sees" the magnets as being much shorter than they appear to us. In this way, the magnets can become smaller than we could make them.

Since the electrons are steadily losing speed as they travel down the wiggler field, this can be compensated for by arranging the magnets with a steadily decreasing spacing.

Theoretical calculations indicate that free electron amplified lasers could be constructed to emit at wavelengths anywhere from 0.1 micron to 1,000 microns (from far infrared to soft X-ray) with efficiencies of 20 to 40 percent and eventually at the high power levels we need. Conventional high-power lasers now operate in parts of this range at maximum efficiencies of 0.1 percent to 5.0 percent.

The direct conversion of free electron beam energy to coherent radiant energy is not a new idea. It is the principle of radio and radar transmission, which involve much longer wavelengths. Efficiencies in these technologies are similarly high—from 20 to 70 percent. But the first operation of a free electron laser amplifier—carried out by John Madey and his associates at Stanford University—was reported in 1977, and Madey continues to be a pioneer in the field. Pioneering work is also being done today at the University of California's Lawrence Livermore National Laboratory and at the University of Paris at the Laboratory for Applications of Electromagnetic Radiation. Much of the U.S. effort is classified beam weapon work.

An all-out free electron laser amplifier program, according to experts, could give us short wavelength, continuous output devices with power in the 10-MW to 100-MW range within five years.

A Host of Revolutionary Uses

Lasers amplified to high power levels are bound to revolutionize our—and the world's—economy through applications to intercontinental electric power transmission; satellite, spaceship, and even jet aircraft propulsion; communications; remote sensing; and round-the-clock farming.

Power transmission. Using a network of amplified lasers and orbiting mirrors, electricity generated by power plants on the night side of the Earth could be transmitted as laser energy at 20 percent efficiency to the day side, where it would be reconverted into electricity. Power plants need not then be so strained during the day and underused at night. For developing countries, laser transmission would make possible rapid electrification of the remotest areas.

Propulsion. Jet aircraft cruising above the clouds could be directly powered by amplified laser beams. Lenses carried above the aircraft would transmit the beam into the jet's engines. That source of energy would vastly improve the efficiency of long-haul jets, whose chief cargo today is their own fuel.

Communications. Low-power lasers are already in use in parts of the United States to transmit telephone calls via optical fiber lines. With high-power lasers we could also use ground-satellite-ground transmissions for telephone communications.

Detection and remote sensing. Laser beams can be used as an extremely short wavelength radar—ladar. High-power lasers could detect the most indiscernible kinds of targets such as low-flying cruise missiles and submarines.

Agriculture. The amplified laser/orbiting mirror system could be used to supply light to crops at night. Experiments have shown that plants illuminated around the clock grow exponentially faster, and become larger and healthier.

Chapter 13

The X-ray Laser Revolution

Recent, still-classified experiments at U.S. weapons laboratories have convinced many scientists that a new laser technology—the X-ray laser—could be perfected within the next five years for use as an advanced strategic defense system even against an all-out attack. Scientists agree that the X-ray laser is the ideal "first line" of antimissile defense, firing at ICBMs while they are leaving the atmosphere above their launch sites, thousands of miles distant.

Most existing high-power lasers under development as beam weapons emit coherent radiation at infrared frequencies, below those of visible light or in the lower end of the visible spectrum. But an X-ray laser will emit concentrated, coherent radiation at frequencies much higher than visible light. This very short wavelength, high-frequency beam will deliver more concentrated energy much more rapidly to the surface of the missile. Rather than having to burn its way through the missile's skin, the X-ray laser beam will deliver a punch-like shock wave that disables the missile on the instant of contact.

Moreover, because the X-ray laser being developed for antimissile defense will be powered, or "pumped," by a thermonuclear explosive, it is extremely flexible, very light in weight relative to its power, and low in cost. It also has a high rate of "repeatability": Many X-ray laser "rods" can be separately aimed and then fired at many missiles by a single explosive pulse of power.

Scientists at Lawrence Livermore National Laboratory believe that the X-ray laser can shift the advantage in nuclear warfighting from offense to defense most definitively and rapidly. They believe that a program of no more than $200 million per year could prove its feasibility for defense in two to three years, and that not long after that it would be deployable.

Development of the X-ray laser would not only provide us with an effective ABM; an X-ray laser in our science laboratories would also mean a revolution for chemistry, biology, genetics research, fusion plasma diagnostics, and many other sciences because of the extraordinary diagnostic—"seeing"—qualities of coherent "light" at such short wavelengths. Such a laboratory X-ray laser would be driven not by a bomb, for obvious reasons, but by another laser of lower frequency. However, it is likely that even the bomb-driven X-ray laser now being actively tested could be used to take atomic-scale "pictures" of biological and chemical samples, which can be recorded electronically in the course of the explosion and retrieved. The laboratory version may be more difficult to develop, not easier, than the bomb-driven beam weapon. Yet scientists at a major European laboratory have said that a laboratory-scale X-ray laser will be in operation in two to three years.

A first generation X-ray laser will not be a "perfect" long-range antimissile weapon, of course, nor will any other system be, as we and our allies, and the Soviets and their allies, erect defenses. It might at first have a range of only 500 to 1,000 miles, a power effective only against missile boosters, and an assured kill of only two or three missiles per X-ray laser module. But it would then be quickly developed so that a third or fourth generation system could destroy the most hardened warheads from ranges of thousands of miles.

The X-ray laser, when nuclear-powered, has the inherent advantage of much greater energy density, because a million times more electron volts per atom are released in nuclear reactions than in chemical reactions. Most of the energy of a nuclear explosion comes in the form of intense X-rays, not heat or particles. The cost per missile target of the X-ray laser will be the smallest by far of any proposed system. And any offensive missile or antisatellite interceptor directed against the X-ray laser unit will cost much more than the unit itself.

For these reasons the X-ray laser can decisively shift the advantage to effective defense as it is developed and perfected.

A Revolution in Science

The development of the X-ray laser as a defense against nuclear missiles opens the way for a revolution in science and technology with the parallel development of laboratory X-ray lasers powered by visible-light or ultraviolet-frequency lasers. Advances in high-power lasers, particle beams, and fusion research over the next few years can make the X-ray laser sufficiently accessible and economical for general laboratory and factory use.

Scientists at Lawrence Livermore National Laboratory are already experimenting with the recently constructed Novette laser, a very high-power laser used for fusion experiments, to develop a laboratory-scale X-ray laser. The Novette can fire terawatts (trillions of watts power pulse) on a target to produce an intense burst of incoherent X-rays. This X-ray burst is powerful enough to energize a second target material that "stimulates" the emission of X-rays of only one precise frequency and wavelength, producing a laser beam of invisible, very high frequency X-ray "light."

Today's optical microscopes, even the very best, use ordinary light, and cannot "see" anything smaller than the wavelengths of visible light—scattered light at that. Beams of electrons give a much higher microscopic resolution, but they are highly invasive—they cannot penetrate biological tissue without killing it, nor molecular substances without changing them in definite ways. Thus what we see, while it may be quite small in scale, is not the geometry of the real process we wish to diagnose, but the geometry that remains after this process has been killed or halted, which may hide the most important features of the process.

Laser light, because it is coherent, focused, and all of one wavelength, does not scatter from an object but almost seems to "stick to it." Because of this property, lasers can provide three-dimensional pictures of objects, called holograms. As one walks around these holograms, new vantage points reveal the sides hidden at previous positions, just as would happen if one walked around the subject itself. (This of course is not true of the mere stereo projection familiar from "3-D" movies.) X-ray lasers will produce vastly magnified holograms of submicroscopic subjects, revolutionizing what is called the science of *microholography*.

Because X-rays penetrate tissues, thanks to their very short wavelengths (visible light and electrons do not penetrate tissues), X-ray microholography will permit us to "see" living processes even on the molecular and atomic scale within the cells of living organisms.

To give a sense how miniscule these X-ray wavelengths are, consider that X-ray laser wavelengths will be in the range of hundreds of angstroms, down to 1 angstrom. (An angstrom is 1 ten-billionth of a meter.) Ordinary lasers range from thousands to hundreds of thousands of angstroms in wavelength. X-ray laser wavelengths are comparable in length to the dimensions of the atom; combined with the X-ray laser's high energy-density capability to penetrate matter, this will make them tools for "seeing" the atom.

This tool can thus revolutionize chemistry, allowing chemists to "observe" the interaction of atoms and molecules as it occurs. And X-ray microholograms will give biological and medical researchers their first atomic-scale pictures of what goes on within living cells, *in vivo*. For the first time, man will be able to directly observe the structures and chemical processes responsible for life.

Genetic engineering, now an immensely promising hit-or-miss field of experimental research, can then become a science.

How It's Done

The pioneering scientific work to identify the lasing media that have the proper energy transitions for X-ray lasing was done by research groups in both the Soviet Union and the West over the past 15 years. Such laboratory X-ray lasers will use as a lasing medium a gas of a medium-weight element, rather than a heavier weight metal as in the bomb-pumped X-ray laser weapon. The gas medium allows a lower energy density than the metal.

There are two fundamental steps to the process. First, a high-energy pulse of incoherent, disorganized X-rays is generated. This can be done by turning a high-intensity infrared laser or a high-current beam of electrons on a metal foil. The process is similar to that which generates X-rays from the electron gun activating a color television's screen. The same process can be used by a laser or electron beam to drive a fusion reaction in a small pellet of fusion fuel. First the laser or electron beam hits a metal foil around the fuel, generating a burst of incoherent X-rays. Then that flux of X-rays starts the compression and heating of the fuel.

To make an X-ray laser, a second fundamental step is required. The burst of X-rays plays upon a carefully chosen gaseous medium—say, neon gas in an irradiated chamber. If the medium has been properly chosen, it is selectively energized by the X-rays to produce precisely the same "energy transition" in large numbers of its molecules. This laser will then undergo what is called *stimulated emission* of radiation—it will release a large pulse of concentrated X-ray radiation, now all of the same frequency.

The process in the laser gas is that of a rapid passage of a "shock wave" through the gas, reordering the gas to produce energy of a precise frequency, phase, and direction. This is the essence, in fact of all "directed-energy beam" technologies.

Many scientists expect that gas X-ray lasers over the next five years will make the same kind of spectacular advances that optical lasers made in the 1960s. Not too many years away, the next step may be to use an X-ray laser in turn as an energy source

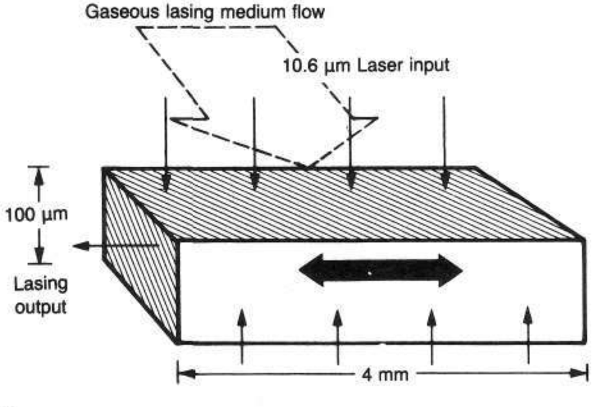


Figure 13-1
X-Ray Laser Laboratory Configuration

This configuration was used in recent laboratory experiments for X-ray laser generation with the Lawrence Livermore National Laboratory's Novette laser. The top and bottom of the box are irradiated by the two laser beams of the Novette system. Metal waffers at both top and bottom absorb these beams and generate specific lines of X-rays. This X-ray "flash lamp" output then irradiates the flowing gas within the box, and the flowing gas then generates the X-ray laser beam (at left).

for another laser—the gamma ray laser, or graser. Gamma ray frequencies, and therefore energy densities, are even greater than those of X-rays. They are at the borderline at which very high energy-density waves of electromagnetic radiation begin to "become particles," introducing the range of particle beams of directed energy. Gamma ray lasers, if they are developed, will have even shorter wavelengths of coherent "light," able to "see" on a subatomic scale—the scale of the nuclear structure of the atom and its interaction with the structure of its electrons and of other atoms.

Probing Shock Waves

The X-ray laser may expose to our view the secret of one of nature's most important phenomena—the shock wave. Scientific understanding of shock waves has not advanced since the profound work of the mathematical physicist Bernhard Riemann in the mid-19th century. A senior scientist at a national laboratory explained recently:

> We know what's going on in front of the shock and what's going on behind it. We don't know what's going on within the shock front itself. If you take the simple-minded Newtonian billiard ball model of molecules bouncing around in the shock front, you can't begin to explain the observed dynamics and effects of the shocks.

There are conclusive signs that new types of coherent matter-energy interactions are taking place within shock wave fronts, particularly those of high amplitude and frequency. The X-ray laser will permit us to observe shock wave propagation on an atomic scale and with sufficient time resolution to capture all of the important dynamics. We could learn how to tailor shock waves in very energy-dense plasma gases to achieve controlled fusion by the implosion method, and to achieve other specific physical and chemical transformations. The achievement of controlled fusion will lead rapidly to an energy revolution in which abundant electrical energy becomes as cheap as tap water.

To indicate the role shock waves can play in producing new materials, scientists cite the case of carbon when it is exposed to the shock wave of a hydrogen bomb. A new substance, never before seen, is created. The substance has the crystalline structure of carbide tools in one direction and that of diamond in another. Because of the hardness of diamond and the thermal dissipation properties of carbide, this substance could be extremely useful for micromachining metals and other materials.

Another aspect would be the the use of shock waves, produced by pulses of energy, in forming and shaping finished materials such as metals. One such process already under development is shock welding of metals to produce metal joints and welds of far, far greater strength, in which the metals have actually "inserted themselves" into each other in geometric patterns.

The overall effect could be the rapid realization of entirely new, extremely efficient and cheap industrial processes; a sort of near-term *fusion shock torch*. Such a shock torch with its high energy density will make possible the generation of entirely new families of materials. For example, it is currently projected that a stable metallic form of hydrogen can be formed only at *extremely* high pressures. Once understood, shock-wave processing could provide the unique means of generating metallic hydrogen. Current theory predicts that hydrogen metal will have stupendous physical properties compared to existing metals: Hydrogen metal could be a superconductor at room temperatures, and it could provide an extremely lightweight, strong metal capable of withstanding both high and low temperatures.

One of the most promising applications is in the production of printed circuits, a component of all modern computers and electronic devices. Applied to the technique known as laser lithography, the X-ray laser would improve production rates and miniaturization by orders of magnitude. X-ray laser lithography will permit the scale of microcircuit elements to be reduced from 1.0 micron to 0.1 micron. X-ray laser lithography can actually generate an exponential increase in the power of modern microchips.

In terms of production rates and quality assurance, the coherent and monochromatic nature of the X-ray laser radiation vastly improves microlithography as well. The general method of microlithography is to have a mask that incorporates the microcircuit design placed over a photosensitive material that is activated when a light source is shined on it. Using long wavelength and incoherent "light" sources causes penumbral blurring that makes it necessary to keep the mask in close contact with the photosensitive resist material. This means that the functional lifetime of the mask for multiple chip production is limited. Also, physical contact between the mask and resist leads to the introduction of defects in the finished printed circuit due to mask-resist sticking.

X-ray laser lithography would permit the use of a physical gap between the resist and mask, and would significantly increase the production lifetimes of masks and vastly decrease the introduction of defects. In combination, these effects will add up to a new computer revolution over the course of the next decade, producing computer chips thousands of times more powerful and less expensive than existing units.

Chapter 14

Lasers in Industry Today

The laser and plasma "tools" that have been perfected since the beginnings of plasma physics research and the invention of the laser more than 20 years ago could spread throughout the economy in one great sweep, becoming the capital goods technologies of a completely new industrial era.

This process did not begin in the 1970s only because the vast majority of industrial firms lacked access to enough investment funds at low enough interest rates to install these new machines. In fact, although military testing labs provided most of the large-scale industrial laser experience we now have, the necessity for a government push to proliferate this experience in the civilian economy has still not been grasped. If we are to build beam weapons and deploy them as rapidly as possible to defend our cities and military forces, this must change: An industrial beam technology base must be built. Industrial engineers are unanimous that the immense increases in productivity of skilled industrial workers, engineers, and farmers resulting from such a policy would be sufficient to pay off the new investment in only a few years of operation.

What was true of the U.S. space program—the Apollo program paid back $12 in increased industrial productivity and power for every dollar spent by NASA—will be true of the beam weapons program *several times over*. The research and engineering effort necessary to build a reliable beam weapon defense will push forward the frontiers of laser science and, most important, the frontiers of plasma science.

A plasma is a gas so hot that its atoms lose their electrons and it becomes an electrically charged gas. Plasmas have some very extraordinary properties, as discussed in Chapter 15. Plasma science will literally revolutionize the world economy. Electric power will become extremely cheap through fusion power. Manufacturing processes will be accomplished with vast jumps in efficiency and simplicity. Tasks now accomplished with mechanical devices will be accomplished by well-behaved plasmas! All of this means that more of the population will be highly skilled workers and professionals; fewer and fewer persons will have to remain in repetitive, mind-dulling, or physically exhausting jobs.

The beam revolution in industry will begin with the widespread use of lasers of fixed wavelengths and increasing power levels and of electron beams, in the metal-making, metal-working, and machine-tool making sectors, and with laser and plasma "advanced isotope separation" for creating chemical isotopes easily, quickly, and in large quantities. The revolution will continue, within a decade encompassing far more efficient electricity generation by magnetohydrodynamics (MHD); laser photochemistry for fingertip flexibility, control, and efficiency in chemical processes; and the increasing use of powerful superconducting magnets in transportation and industry. Its 20th century phases will culminate with commercialization of thermonuclear fusion power, and from these high energy fusion plasma developments will come the mastery of advanced, short wavelength, tunable, and powerful lasers and charged particle beams—the kind of energy-beam technologies that will transmit power across the globe without transmission lines and take man to the planets of the solar system.

This revolution can be launched now, just by proliferating existing power ranges of lasers and electron beams into high-impact industries; it is the "science driver" to lift the economy out of a decade of environmentalism and increasing depression.

Significance of the Laser

Anyone who has occasional resort to the old fashioned handsaw has doubtless reflected that the strength of the craftsman is sometimes almost matched by the resistance of the material. The Edison revolution of electrification just 100 years ago solved that kind of problem for the economy as a whole. It put much more "muscle" behind the—now rotary—blade. Not only did this electrification help to free the worker from a coarse existence as a mere source of mechanical energy; the increase in power entailed great advances in speed and accuracy. The value of each hour of worker time was now multiplied by this harnessing of electric current.

The physical process at the saw tooth, however, never changed!

Consider then what the laser revolution holds in store. As a cutting instrument the laser supersedes both the electric motor and the toothed blade, both the die and the die-press. The application of gross mechanical force is eliminated. The only moving parts are those necessary to guide the cutting.

The laser concentrates a much larger power (energy per unit time) on a much smaller surface area than any possible motorized blade or die. The beam affects the material by heating it very rapidly but very locally, since energy can be delivered much more rapidly than it can be diffused by even the best heat-conducting metals. The target spot is melted, vaporized, or burned up, depending on the material, the power of the laser, and the dwell time.

Industrial Applications

Lasers are used in industry today for calibration, cutting, machining, welding, soldering, heat treating, cladding, and surface alloying. In addition to metals, lasers have applications for plastics, textiles, paper, glass, and rubber. In seconds, a laser cuts the cloth for a dress pattern, or punches the holes in a dozen baby bottle nipples. However, despite its efficiency, versatility, and quality, there are only 4,000 lasers of all kinds in industrial use today.

The machine tool industry uses low-power lasers—under 1 watt—to calibrate numerically controlled machine tools. The Hewlett Packard Company reports cases of 100 percent improvement in productivity when laser calibration is used to detect otherwise unnoticeable variations in machine tools.

Carbon dioxide lasers in the multiple-watt to 100-kilowatt range are used extensively in metal working. Laser experts estimate that at least 25 percent of U.S. industry's sheet metal cutting could be replaced by laser cutting, with a fivefold to tenfold increase in productivity. For drilling and boring done by machine and machine-tool builders, a similar estimate applies: 20 to 30 percent could be done by laser, with a fivefold increase in productivity.

Laser welding is a newly emerging technology. It is faster (more inches per minute), more precise, and less intrusive than conventional welding, and uses about two thirds the energy. Unlike electron-beam welding, it does not require a vacuum. Three quarters of industrial spot welding could be done by laser, and the resulting payoff would be a threefold increase in productivity.

Laser structural welding can become widespread as soon as higher-powered, multi-kilowatt lasers become cheaper through assembly-line construction. At least half of all structural welding could be done by lasers. Laser welding produces the most dramatic improvements in productivity when applied to very thick stock, where conventional methods require many passes to produce a result less strong and reliable than laser work.

The Naval Research Laboratory is a pioneer in laser structural welding. It has developed a 100-kilowatt laser that welds steel submarine parts 1½ inches thick at more than 100 inches per minute. In another program—a pilot project in laser welding of mild steel—a 15-kilowatt laser that replaced conventional welding produces a 17-fold increase in productivity on full-penetration welds of ¾- to ⅞-inch stock. The laser, traveling at more than 25 inches per minute, requires only one pass through the steel; arc welding had required seven! On ⅛- to ⅝-inch stock, productivity increases are on the order of two to three times. The experimental system will be extended to hardening, cladding, alloying, and cutting.

Laser heat treating of large gears to strengthen them has been accomplished by the Illinois Institute of Technology Laser Center. The process replaces carbonizing of the steel, which required nearly an entire day and cost a dollar per gear. Laser treatment of the same gear takes minutes and costs 20 cents.

Lasers can also be used for surface alloying and cladding. Nuclear power plant fuel rods and other metal parts exposed to hostile environments often do not need to be made entirely of high-strength or noncorrosive alloys. A thin layer of the expensive alloy can actually be formed at the metal surface by laser, or a sheet of cladding applied and then bonded by laser. For large-scale heat treating and surface alloying, high-power lasers in the multi-kilowatt to megawatt (million watt) range are required.

Mass Producing Industrial Lasers

Up to half of U.S. capital stock in machine and machine-tool production could be replaced by lasers in the next five years. To make that possible, the U.S. industry for producing lasers would have to graduate from its present handicraft methods to mass production, and turn out 25,000 lasers every two years.

Engineers have already designed lasers in the range of 1 kilowatt power that can be mass produced on assembly lines. Mass production could reduce costs from $35 to $40 per watt of installed laser capacity, to as little as $10 per watt. At that price, the laser machine tool would become competitive with its conventional counterpart, and could be introduced into virtually every machine shop.

Mass production would use lasers to produce lasers. Each automated production unit would require a numerically controlled milling machine, a lathe, and a diamond machining station for the laser's optics, or mirrors. (Laser diamond machining can cut the cost of laser mirrors from $400 to $500 today to perhaps $100.) Automated assembly of the power supplies may be contracted out. Each production unit would cost $75 million and could turn out 500 lasers a year. Developers point out that the 100-kilowatt-range industrial laser is about the same size and complexity as an experimental automobile, and could be produced on an assembly line in about the same time.

The step beyond the widespread introduction of lasers is their integration into computer-controlled robotic systems. The combination of lasers and robotic control constitutes a "universal machine" that can cut, heat treat, surface alloy, weld, and drill holes—all in the same production cycle. Eighty percent of U.S. metal manufacturing could eventually be done in this automated manner.

The Japanese Ministry of International Trade and Industry is already the sponsor of a seven-year R&D program for laser flex-

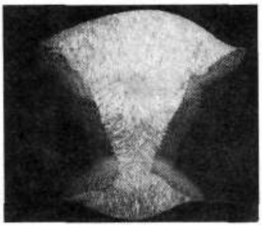
The Laser in Surgery

Many of the advantages of the laser in surgery are the same as those identified in industry. The surgeon can apply a precise amount of energy at a precise point for cutting, cell destruction, or even "welding." No mechanical instrument can match its precision and gentleness. A neurosurgeon reports that brain cells only 0.3 millimeters away from the laser incision show no disruption of cell structure. Small blood vessels along the line of incision are sealed.

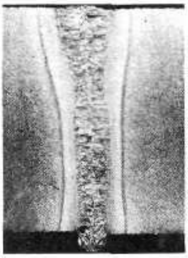
The laser can perform some vital surgical tasks not otherwise possible. The surgeon can aim an argon laser through the eye and, with numerous tiny welds, reattach a detached retina. The vitreous humor that fills the eyeball is transparent—the laser beam passes through it harmlessly. Tumors considered inoperable because of inaccessibility or interconnection with vital organs can be neatly vaporized by laser. The surgeon guides the laser with the joystick on a micromanipulator while viewing the site through a microscope.

Cancer of the finger (angiosarcoma) shown before (left) and eight years after laser treatment.
Dr. Leon Goldman, Director, Laser Treatment Center, Cincinnati, Ohio

ible machining in which 20 Japanese companies are participating. In the United States, the Illinois Institute of Technology Laser Center is developing multibeam laser flexible machining stations for use in heavy industry. General Electric and other industrial robot manufacturers are also working to join the laser to automatic control.



Conventional weld



Laser weld

Laser welding produces dramatic improvements in productivity. Shown here are cross sections of a conventional weld requiring several passes and a laser weld on a single pass. The stock is ½-inch HSLA steel (2 percent nickel/carbon alloy). The 15-kW laser traveled at 47 inches per minute. The diffuse heating in conventional arc welding distorts the stock, and may require hours of treatment to restore it to planeness.
Naval Research Laboratory

In 1982, Coherent, Inc., a manufacturer of industrial carbon dioxide lasers, demonstrated a prototype robotic laser system for welding turbine engine parts for the M-1 tank. It welded 80 to 100 inches a minute using two 575-watt lasers; while one welded, the robot loaded the other. The station ran unattended for eight hours and produced superior parts. Although limited only to welding, this laser robot will save an estimated $500 per unit!

These advances—including computer-controlled industrial robots—are not the technology of tomorrow. They are today's technology. We have already risked even our national security in postponing the investment necessary to make them standard practice, for advanced technologies in defense cannot function without corresponding, in-depth productive capabilities in the economy at large.

Chapter 15

Fusion, the Plasma Beam, and Beam Weapons

Few if any political and military leaders realize that the very best defense capabilities must emerge from the most advanced frontiers of science, just as the greatest innovations in industry and the economy must come from the frontiers of science.

Indeed, the only nation that can be defended in the long run is one that bases both its military training and its educational system on the advances of scientific culture. This is the tradition of West Point and the other great military/scientific academies launched in the 17th, 18th, and 19th centuries. Military science, like great music, literature, and physics, is studied in the "book of the heavens," and in man's growing mastery and dominion over the laws of the universe.

Plasma physics provides an outstanding example of newly discovered principles from today's frontiers of science that allow us to leap over obstacles posed by existing and emerging technologies. The frontier of plasma physics, including the special problems of the interaction of high-energy lasers and ion beams with plasmas, poses the major challenges to our development of more and more advanced beam weapons, more and more defensive "firepower" to eliminate the threat of nuclear missiles.

The spheromak or self-sustaining plasma ball—which breaks most of the rules in the physics books—may provide us with the cheapest of fusion energy systems. It may also provide a uniquely powerful, efficient directed-energy weapon for use within the Earth's atmosphere.

Since the first man-made thermonuclear fusion reaction in the 1950s, scientists have sought ways to create controlled fusion reactions as a source of energy far more powerful and efficient than controlled nuclear fission. Fusion is the process of energy release that goes on in the Sun. For fusion to take place, a small amount of fusion fuel—hydrogen—is heated and compressed to extremely high temperatures. Hydrogen is the element that undergoes fusion most easily, and yet for hydrogen fusion to occur, we must achieve temperatures above 44 million degrees Celsius, well above those in the core of the Sun! At the same time, the plasma we are heating must be compressed to very great densities.

At high temperatures, matter enters a new, fourth state—it is not solid, liquid, or gas, but becomes plasma. Plasma, which is the state of 98 percent of the matter in the universe, is a gas so hot that atomic nuclei and the electrons normally associated with them are torn apart, forming clouds of ions of positive and negative charges. The result is a form of matter dominated by electrical forces, which does not obey many of the laws of Newtonian physics. Some scientists at first thought there was something wrong with their experiments when laboratory plasmas did things that were not in their textbooks!

To achieve controlled fusion, Soviet scientists invented the tokamak device—since copied and developed by the other countries working on fusion. The tokamak applies intense magnetic fields to a plasma in a donut-shaped container or torus. As shown in Figure 15-1, these magnetic fields run in two directions at once—the toroidal and the poloidal—and are used to compress and heat the plasma. The magnetic fields also form an invisible bottle that holds the superhot plasma away from the walls of the tokamak container, which, being made of mere metal, would cool the plasma on contact.

The Spheromak

The electromagnets required by tokamaks are large and very expensive. Although fusion energy from tokamak fusion will be cheaper, more concentrated, and more plentiful than any form we now have, the capital cost of building a tokamak power plant will be greater than existing power plants.

Some scientists, therefore, have concentrated their attention

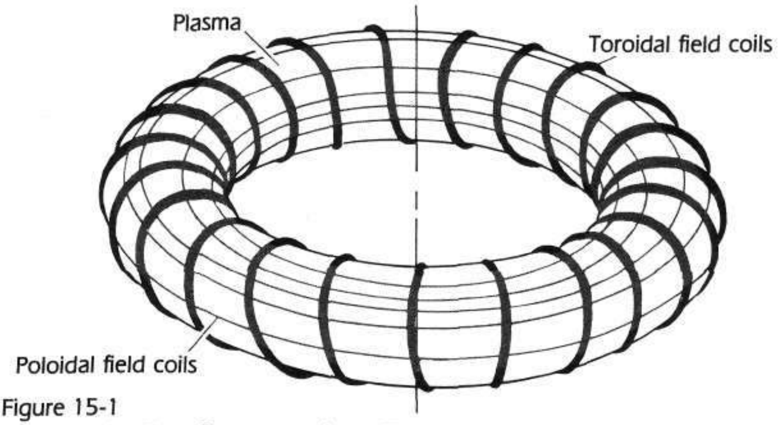


Figure 15-1
Magnetic Confinement in a Tokamak

The tokamak is a hollow, donut-shaped device through which magnetic fields twist, confining the plasma. The toroidal magnetic field is generated by electric currents flowing in turns or rings the short way around the torus. The poloidal magnetic field is generated by a current flowing the long way around the torus. The combination of both magnetic fields allows the tokamak to achieve a high level of plasma stability, which permits longer confinement times of higher temperature plasmas.

on the unpredicted and unexplained aspects of plasma behavior to find simpler fusion designs. Plasma could be formed into a small, fat donut or smoke-ring shape—so fat it looks like a ball with a hole in it. Plasmoids, as these plasma balls are called, have electrical currents running in them and, therefore, the plasmoids contain magnetic fields. These scientists asked themselves if the magnetic field of a plasmoid could be made strong enough

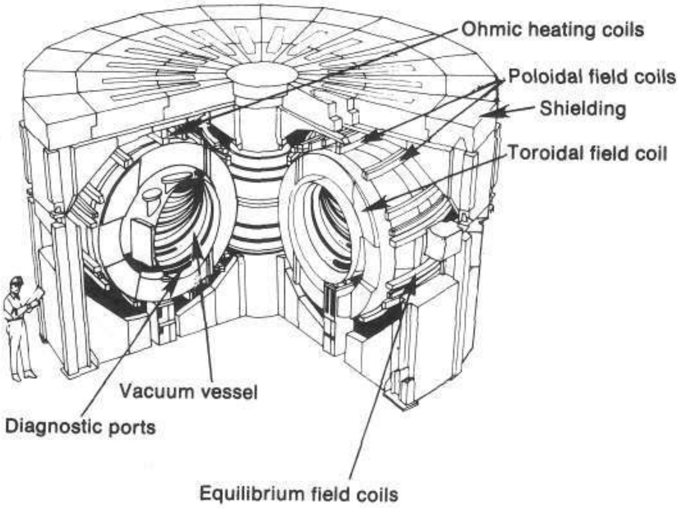


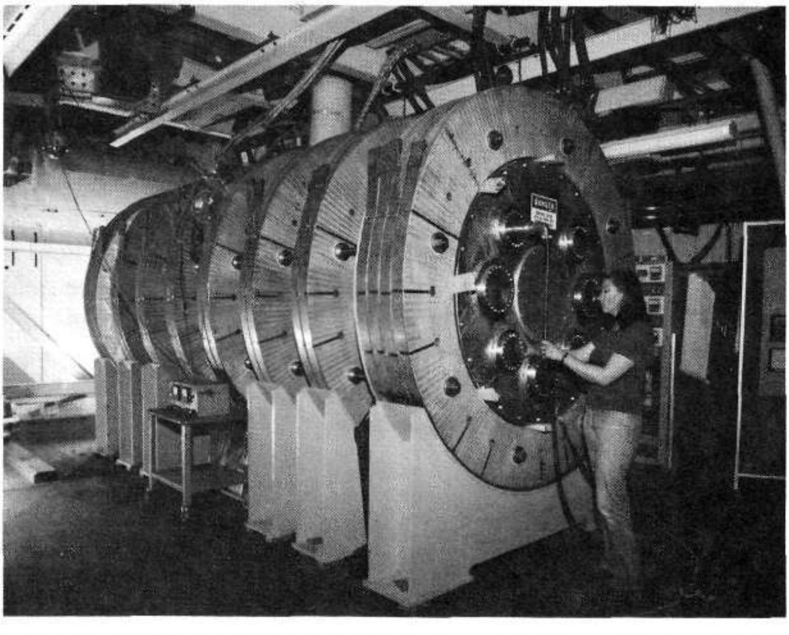
Figure 15-2
Schematic of a Tokamak Reactor

This cutaway of the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory shows the scale required for a fusion reactor. There are 20 toroidal field coils that follow around the circular shape of the torus. The poloidal field coils are made up of two separate but similarly placed coils, ohmic heating and equilibrium field coils, which produce an electrical current in the plasma. All three coil systems are made of copper and are cooled by water circulating around the windings.

The TFTR is the largest U.S. tokamak and will be the first here to demonstrate the scientific feasibility of fusion and burn reactor-grade fusion fuel.

and stable enough for the plasmoid to become its own tokamak. Could the plasmoid's own magnetic fields take the place of the powerful electromagnets?

Out of that question came the Compact Torus Experiment (CTX) at Los Alamos National Laboratory—the first spheromak. In the CTX, the plasma ring is blown out of a plasma gun in a process very similar to that which produces a smoke ring in an ordinary gas. As it leaves the mouth of the gun, the magnetic



In the Compact Torus Experiment (CTX), the plasmoid's own magnetic fields take the place of the powerful electromagnets in the tokamak. Shown here is the Los Alamos CTX spheromak as seen from the outside.
Los Alamos National Laboratory

fields generated by the gun's electrodes are wrapped around the ring, as if the ring were being blown through a spider web. These trapped magnetic fields provide internal stability and energy-containing ability for the ring.

But to sustain the plasmoid indefinitely, a cage of copper wire extends beyond the mouth of the gun to provide a stabilizing boundary (see Plate 11 following page 56). Eventually the cage will be replaced by a very low power magnetic field, a mere "guide field" that keeps the plasmoid dynamically stable.

As a recent Department of Energy review commented, this self-organized magnetic bottle "greatly simplifies the technology of Compact Toroid reactors compared with that of reactors based on other systems."

The Plasma Beam Accelerator

The plasmoid is a very mobile object. This is so because the mass of its plasma is extremely small—it is, after all, only a small amount of hot gas—while the magnetic fields that hold it together reach a very great strength. This ratio of magnetic field strength to mass is called magnetic moment, and the higher the magnetic moment of such a material, the more rapidly it can be "whipped" into a very sudden acceleration by another magnetic field outside it. Thus, a plasmoid can readily be accelerated to *very* high velocities.

Like an X-ray laser beam, an accelerated plasma, or plasma beam, has a tremendous local destructive force *not based on its mass, but on its electromagnetic structure*. A plasmoid will not hold together in space but seems to require the atmosphere to help maintain its boundary as it travels. These qualities make the plasmoid accelerator a candidate for development as an area-defense against nuclear warheads—a defense based on the ground to deal with the stage in which some warheads have penetrated preceding layers of defense and reentered the atmosphere.

A plasmoid can be accelerated by applying external magnetic fields, as in the case of particle accelerators. But instead of being forced around and around an accelerator race course, the plasmoid is whipped down a cone-shaped magnetic field toward the small end of the cone. As the plasma ball gets squeezed to smaller and smaller proportions at the tip of the cone, the magnetic field trapped within the ball is compressed and reaches a very high strength. The magnetic energy density increases as the inverse fourth power of the radius of the plasma ball or ring. Thus, each time the ring is compressed to half its size, the energy density of the ring increases by 16 times!

As it reaches the small end of the magnetic cone, a plasma ball only a fraction of an inch in diameter may store as much as 10,000 joules (10 kilojoules) of magnetic energy.

Then a new and greater acceleration takes place. The compressed plasma ball or ring comes out of the small end of the magnetic cone, and enters the small end of another magnetic cone. The plasma ball is accelerated up toward the large end of this second magnetic cone, which is much longer and narrower than the first one. The plasmoid may be accelerated to energies up to 10 million joules (10 megajoules)—the equivalent of 5 pounds of dynamite—by traveling down a cone perhaps only 100 meters in length, achieving a velocity of more than 500 miles per second. This may be only 3 percent of the speed of light, but it is a thousand times faster than the maximum velocity of missiles! A plasmoid accelerator weapon based on this type of design could spit out plasmoids at a very high rate.

The energy-equivalent of an explosion of 5 pounds of dynamite, traveling at 500 miles per second as a ball of electrical energy, is firepower no present or contemplated missile or warhead could withstand.

A Magnetic Slingshot

The ability of a plasmoid to compress energy on this scale results from the inherent tendency of a plasma to form self-organizing energy structures. Once formed, these structures proceed to further increase their energy density at greater and greater rates.

The initial plasmoid, formed in a few millionths of a second, in turn takes only a few *billionths* of a second to deposit all of its final energy on a target. The form of this energy is not well understood. When these plasmoids disintegrate, as they would on hitting a ballistic missile or another conducting target, they do not transfer their energy in a disorganized explosion. The tightly twisted magnetic field configuration begins to unravel, breaking 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 converting magnetic energy to the energy of particles in motion. 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 million electron volts have been observed as these magnetic field lines reconnect. The process is probably the same one by which the Sun's plasma propels huge solar flares millions of miles out into space.

The result is a *plasma jet*—a pencil of extremely hot, high energy matter moving at hypersonic speeds in a very precise direction. The pinpoint destructive force of a plasmoid would also make it an essentially perfect antitank or antiship weapon. No known armor could even come near to withstanding the energy of a plasmoid.

The guidance and targeting of accelerated plasmoids is so far only a matter for speculation. Because of their concentrated magnetic field strength, it is likely they will have "self-targeting" characteristics—that is, they will seek out metal targets in their path. That such structures can propagate long distances through the atmosphere is known from observations of ball lightning—a naturally occurring form of plasmoid.

The Plasma Age

As with lasers, the principles governing the behavior of plasmas hold the promise of revolutionizing the productive processes of the economy. Plasma steel making, currently being pioneered by Ashmont Metals and other companies, can do in minutes what conventional methods take an entire day to accomplish. The speaker of a high fidelity sound system today is still based on paper and cloth attached to an electromagnet. A plasma speaker already exists that completely outflanks the mechanical limitations of the finest conventional speaker.

Such examples are impressive and could be multiplied. But the essential point is that the plasma age that we must enter will be a new era insofar as we look upon science—and defense is but a branch of science—as the pursuit of new and higher principles governing the continuing creation of the universe. This is what makes science inherently efficient in the defense of nations and of civilization.

Chapter 16

The Next Space Frontiers

The U. S. beam weapon development program, as it advances, will absolutely require an expansion of the space program to build a manned space station and achieve the continuous activity of men and women in Earth orbit. Immediately, the space program will have to be propelled toward colonization of the Moon and then Mars.

Just as important, the most advanced directed energy technologies developed for the beam weapon program will make possible a truly far-reaching and high-powered space program that looks to the solar system and beyond. Energy beam and plasma technologies that will become operational over the next decades will bring human civilization from Earth out toward the stars.

Already the civilian space program managed by the National Aeronautics and Space Administration, NASA, has developed new technologies for space that will help the beam program. For example, the large Space Telescope, which NASA will launch in 1986, will have the most sophisticated pointing capability in existence, able to focus on and track stars that are billions of light years away from Earth (see Plate 6 following page 56).

The Space Shuttle's manned capabilities will be vital for defense over the next decade. With the Shuttle as a space-based engineering "test bed," crucial space technologies can be tested, modernized, perfected, and replaced with improved versions much more rapidly than with isolated orbital tests whose results must be brought back down to Earth. A manned space station will provide another leap in this test bed capability. These new powers for space-based technology development will apply equally to new industrial processes and to military advances.

Military satellites will be able to be repaired in space and their life extended by in-orbit refueling. Also, new more advanced technologies for reconnaissance and communications in space will be added to already existing satellites, because astronauts in the Shuttle will bring up new parts and put them into older satellites to update them. The Space Shuttle also allows military planners to test new technologies in space for short periods of time. New generations of infrared sensors, for example, which tell us if missiles have been launched anywhere in the world, are being tested on an experimental basis on the Shuttle. If the new sensors work, entirely new satellites can be built using the new technology.

In addition to doing quick repair and refurbishment in space and testing new technologies for a few days, new beam weapon developments will require longer-term testing. The only way to accomplish such experiments is to have men in space for as long as needed.

For this reason NASA, with input from the Department of Defense, is now designing a continuously manned space station that will be in orbit permanently and will be serviced by the Shuttle. From the space station, teams of astronauts can deploy to work on satellites, including beam weapons, that are far away from the station and much higher up in orbit than the Shuttle can reach.

The Shuttle can fly to about 300 miles above the Earth and the first space station will be at about that height. But many military and civilian space assets are in geosynchronous orbit, 23,000 miles above the Earth. NASA is designing manned and unmanned transfer vehicles to go from low-Earth orbit up to geosynchronous orbit. Thus all of the important satellites that we have in space will be accessible to astronauts, and our defense system can make use of all the capabilities of both man and machine in space. We will use the same capabilities to proceed farther to the Moon, the planets, and the stars.

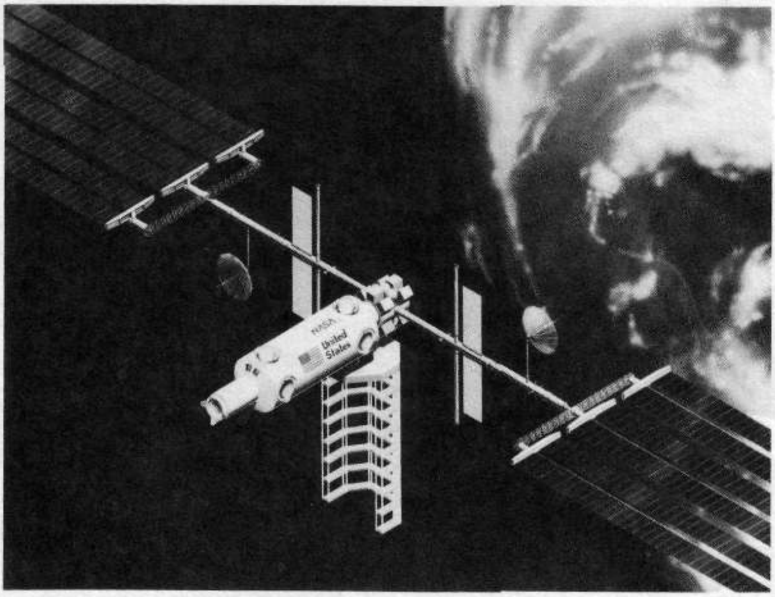
A 1990s Space Station

By 1991, the United States could have a space station in low-Earth orbit. It will be designed so that it can be enlarged as new modules are added. These new modules could be special laboratories to do experiments in biology and medicine, materials processing factories owned by industry, or even "parking facilities" for the Space Shuttle or orbital transfer vehicles.

From the space station, very large structures can be built in space. These structures would be too large to fit inside the payload bay of the Shuttle and could be assembled or even fabricated in space. Such structures might be 30-foot antennas for communications satellites, for example. As the in-space antennas get larger, the size of the receiving antenna needed down on Earth gets smaller. Very large space antennas could open up the era of the wrist watch receiver for radio transmission, phone conversations, and computers. They could also make it possible to place small and inexpensive receiving stations on Earth in remote areas of underdeveloped nations.

We will also want to construct large platforms for clusters of satellites that will share electrical connections, cooling and computer facilities, and other services. The satellites can be plugged in and out and replaced with new ones.

A space station will allow long-term experiments in important new technologies. Materials processing—creating products in the microgravity of space that cannot be produced as cheaply or at all on Earth—will go from experimental to commercial use. The creation of new medicines and pharmaceuticals to treat disease is already on the commercial horizon for space processing.



The command module docked and receiving power from the energy section of the proposed Space Operations Center, shown in a NASA artist's illustration. In the lower right is a frame-like structure for satellite services and space construction that will provide a noninterference work area for flight support operations, including orbital transfer vehicles enroute to higher orbits.
NASA

Large crystals, which gravity distorts on Earth, will be produced with greater purity in space. These are needed for semiconductors and computers. New metal alloys, made of materials that are immiscible on Earth (like oil and water) will be possible in space, where they do not separate by their specific gravity.

Return to the Moon

In addition to creating new materials and industries in space, the space station will have a broader purpose: the opening of the new frontiers of space outside of Earth orbit and the beginning of the process of spreading human civilization to the Moon and beyond.

Dr. Krafft Ehricke, the developer of the liquid hydrogen Centaur rocket, has called the Moon the "seventh continent" of the Earth. As he has documented, the resources available on the Moon could produce fuel for spaceships and metals and materials for large-scale industrial development on the Moon itself, as well as for export to Earth.

The Moon is about the same area as North and South America combined and could support as large and advanced a population of hundreds of millions. Because it is only about one fourth the size of Earth, it has a more shallow gravitational force, making transport from the Moon into space considerably easier and cheaper than from the Earth into space.

Over the next decade, with a U.S. space station and orbital transfer vehicle (OTV) under way, the road to the Moon will be "paved." When a satellite or vehicle has reached geosynchronous orbit, it has already used 90 percent of the energy necessary to get to the Moon! A manned OTV, which is parked at the space station, will receive colonizers that the Shuttle has delivered to the station, and take them to the lunar surface.

Ehricke has outlined a five-stage lunar development program, where each stage depends upon the development of more advanced sources of energy for industrialization and colonization (Figure 16-1). In the first stage, "prospectors" would be sent to the Moon to map the body more completely for raw materials. Like the Apollo program, this stage would require the use of small-scale portable nuclear power sources to provide energy continuously through the two weeks of the lunar "night."

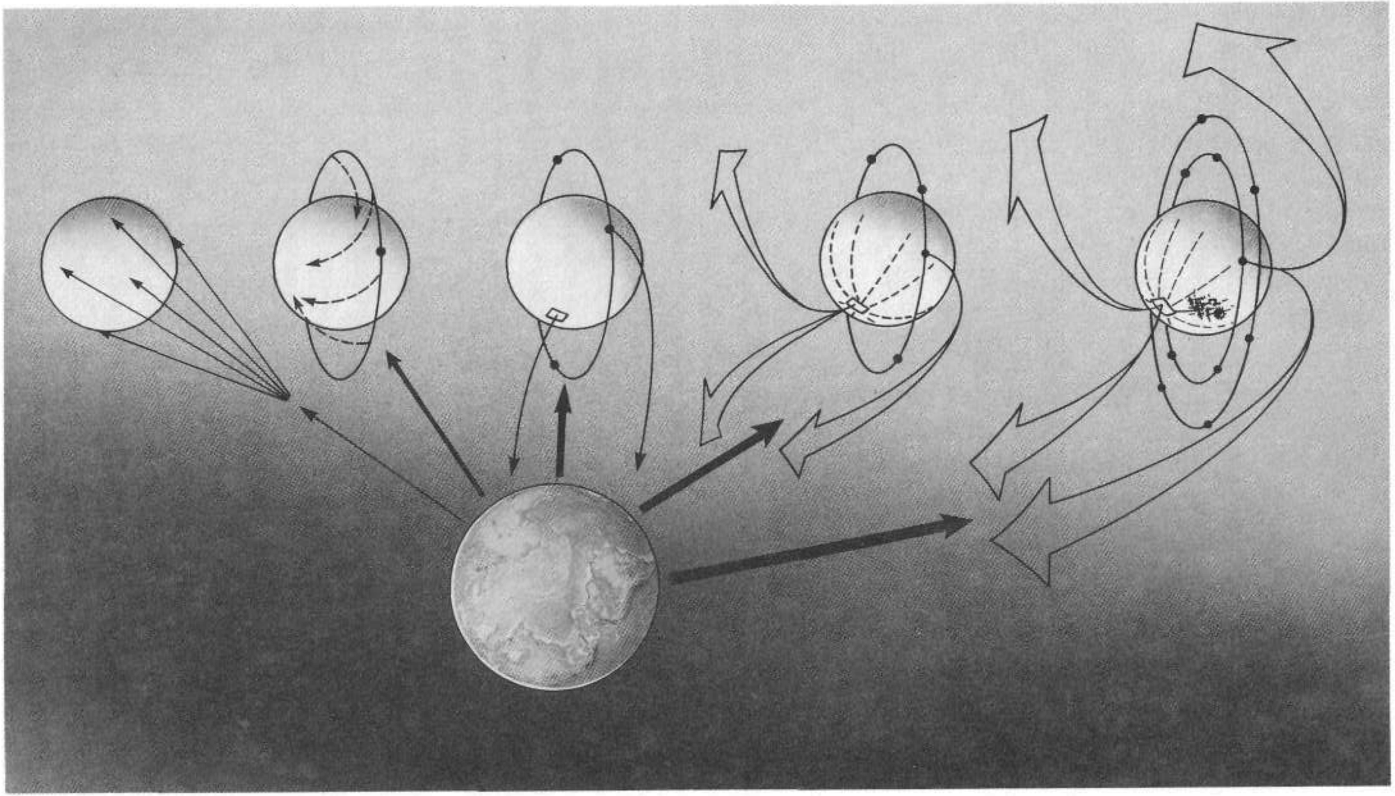
The second stage would see the operation of a space station orbiting the Moon, which would provide the staging ground for crews of colonizers and provide continuous communication with Earth. This stage would require on-board nuclear and solar electric generation.

In the third stage, a central lunar processing complex would be powered by a nuclear plant on the Moon and would begin the processing of lunar materials for commercial exploitation. Crews will spend a few weeks at a time on the lunar surface setting up the large-scale factories for industrial development.

Stage four will see the expansion of the industrial base to areas outside the processing complex, to exploit rich mineral deposits. Transportation of loads of raw materials to different parts of the Moon will be a much less energy-consuming process than on Earth. Catapults using ballistic trajectories can be used, because of the slight gravity of the Moon and the fact that there is no atmospheric drag.

By stage five, a viable economic foundation will have been laid, with lunar industry exporting to Earth. Fusion-powered cities will be built, with an advance community centered around a corps of scientists and engineers living permanently on the Moon. A lunar city, or Selenopolis as Ehricke has named it, will provide a full biosphere for its inhabitants with plants and animals for agricultural production.

Lunar materials processing itself will use advancing levels of nuclear and fusion technology. Reduction of lunar materials in furnaces would be most efficient with the heat from high-temperature nuclear reactors. Such reactors are now nearing com-



mercial operation and could reduce lunar materials at a temperature of about 900 degrees.

Underground fission and fusion "microexplosions" are the important next steps, as discussed both by Ehricke and Dr. Friedwardt Winterberg, a fusion scientist. Contained in a cavern under the lunar surface, these microexplosions could produce concentrated energy that would release gases trapped in lunar rocks and refine the materials. Winterberg has developed a scheme of mining the Moon to its very core, by using nuclear energy to tunnel down to the probable reserves of heavy metals near the center.

Martian Colonization

Although the Moon will be the first extraterrestrial home for mankind, the development of Mars will pose some of the greatest challenges to science and technology. Because of the greater distance to Mars, new technologies based on directed energy lasers and plasmas will be required.

There are more than 50 million miles between the Earth and Mars, and the faster we can get from here to there, the better. Chemical rockets based on liquid hydrogen and oxygen fuel can get us to the Moon in a couple of days, but if used for Mars, the trip could take many months, or even a year.

Rocket performance, regardless of the fuel, is measured by *specific impulse*. This is a measure of how long a push (in seconds)

Figure 16-1
Five Levels of Lunar Development

The extensive lunar industrialization plan proposed by Krafft A. Ehricke. In stages one and two of lunar development, the Moon is the recipient of Earth-launched capital equipment and associated infrastructure. By stage three, this investment is generating a wide range of products for the Earth market; and in stages four and five, the Moon begins servicing the geolunar and translunar space markets, far more economically than could Earth. In stage five, Earth and Moon are roughly in trade balance. The arrows in the diagram represent this process schematically.

can be given to a certain weight of payload by a unit weight of fuel. The specific impulse depends upon the exhaust velocity of the fuel. The hotter the gas that the rocket expels, the greater the exhaust velocity. In rocketry as in materials processing, the higher the temperature, the better.

Today's conventional chemical rockets have a specific impulse of less than 450 seconds. Nuclear rockets, using fission energy, would likely raise that to about 1,000 seconds. Using thermonuclear fusion, however, would bring this measure of rocket performance up to about 100,000 seconds. This increase in specific impulse translates directly into greater speed for rocket systems, which could decrease our Mars trip time from years to weeks. The fusion temperature of hundreds of millions of degrees is the key to this greater efficiency.

It is likely, according to Winterberg, that fusion rocket systems could carry a payload of thousands or even millions of tons. This is important for trips to Mars, because unlike trips to the Moon, the trip time will require that the astronauts who are sent there stay for a while.

For trips still farther from Earth, fusion propulsion systems will be the only alternative. Even for unmanned missions, we will not be able to wait the decades required with chemically propelled spacecraft to find out what the rest of the universe looks like.

Beam Technologies in Space

Communicating with astronauts on the Moon is quite simple—it takes about *3 seconds* for a message to be received and an answer returned. Because of the greater distance of Mars, that message will take about *18 minutes* one way. Scientists will have to develop autonomous systems for Mars, so our citizens on the planet can operate without waiting nearly an hour to exchange information with mission control on Earth.

Laser communications in space, rather than radio waves, will be key for future manned missions and also the unmanned satellites we send to the farthest reaches of our universe. Coherent laser light can pack two orders of magnitude more information into a transmission than a radio signal can. When communication between civilizations far apart has to return vast amounts of information efficiently, lasers will be able to do it.

Another important use of lasers in space will be for the transmission of energy from one space asset to another. When we have in space a large space station, many orbiting scientific telescopes and laboratories, and satellites for communications, remote sensing, and the military, then it will be more efficient to place a large, central power-generating station in orbit and distribute that electricity to each satellite, instead of outfitting each one with an independent power source.

The central, megawatt-sized nuclear power plant would "pump" a laser and produce concentrated energy. This could be beamed to other facilities, where the light would be converted directly into electrical energy and used on board. Each step in colonization, from lunar and Martian orbiting stations to communities on the ground, could make use of this kind of laser transmission system.

The future of space exploration is limitless. The technologies that are needed for the defense of the nation against nuclear war are dependent upon the development of next-generation space technologies. The beam weapon program makes urgent the development of these capabilities, which will give mankind the ability to begin the real push outward from Earth to the edges of space. Eventually, with the tremendous energy density made possible by fusion plasmas, and the concentrated direction of that energy in beam technologies using the entire radiation spectrum, we will "Earthform" Mars, Jupiter's moon Titan, and then other bodies, giving them biospheres in which man can live as he does on Earth.

Chapter 17

The Coming of the Plasma Age

As important as beam weapons are for military application, their military impact will be dwarfed by their civilian economic impact. Much like the NASA Apollo project to send a man to the Moon, the development of beam weapons will revolutionize every aspect of our lives.

The technologies brought into common use because of beam weapons will usher in the "plasma age"—an industrial revolution that will see entire industrial complexes without moving parts and the application of the entire electromagnetic spectrum to industry, agriculture, and medicine.

Studies of the Apollo project by Chase Econometrics, as well as studies using the Fusion Energy Foundation's econometric model, show that the impact of such a program is, strictly speaking, not measurable by adding up all of the new products and new methods of production that a new technology introduces. The qualitative impact of a fundamentally new technology on the economy is like that of a well-ordered shock wave. We can measure this impact in three basic ways:

(1) The increase in the manpower skills required for, and generated by, the development and use of new technologies. 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 professionals such as computer analysts skilled in image enhancement, automation, and remote sensing. Perhaps even more profound, the space program inspired a generation of students to demand the most of themselves so that they could participate in the excitement of conquering the next frontier.

(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 of 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 was slowed by the curtailment of the space program and by lack of investment in the early 1970s. The communications industry; remote sensing of the Earth, substrata, and oceans; industrial processing in a zero-gravity environment; and the Space Shuttle-space station project are examples of the impact of the space program that transcend the spinoffs in any one area.

The same qualitative impact, magnified many times, will result from the development of beam weapons. 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. Succeeding decades 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 most energy dense form of matter known—plasma—and the most powerful forms of energy known—coherent radiation beams and particle beams—for all the work that civilized man does.

Mastery of plasmas would put at our command the following:

- An energy source—nuclear fusion—that has an unlimited fuel supply taken from seawater and is cheap, clean, and inherently safe.
- 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.
- 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-like aspects of these industrial technologies come from the special qualities of plasmas, the same qualities on which beam weapons are based. Plasma technologies use energy densities millions of times greater than those now industrially available. Instead of having a working fluid at 500 degrees, as used in today's energy sources, fusion takes place at temperatures of 100 million degrees (on the Kelvin scale). Instead of applying .01 electron volt per atom, as in today's 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 entail.

A study done by the Fusion Energy Foundation estimated that an additional 20,000 engineers would have to be trained by the end of this decade to begin to develop a beam weapon and the related plasma technologies. This force of engineers (about twice the number of American engineers that now graduate) would have to be supplemented by a quadrupling of the number of nuclear, plasma, and high-temperature physicists graduating over the next decade.

The spinoffs in product terms are easier to quantify:

(1) Laser technologies. High-power lasers are already used in the medical, metal working, textile, construction, and communications industries. However, the effort to produce reliable and compact high power, high quality laser energy for beam weapons would vastly speed up these applications. There is an especially close and interactive relation between beam weapon technology and the technique for inducing nuclear fusion using lasers (laser or inertial confinement fusion). Both require the mastery of high-energy, short-pulse lasers. The solution to the problem in one area would immediately push forward the other.

(2) Particle beam technologies. Particle beams have also had important applications in medicine and energy production. The solution to 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 such as 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, thus, intimately related to the problem of controlling particle beams and plasma beams using magnetic fields.

(4) Pulsed power production. The production of high intensity electric pulses, needed for beam weapons, is also 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 such materials will have at least as great an impact on the general economy as NASA's development of exotic materials.

(6) Advanced automation techniques. The tracking and control technologies required for the successful operation of a beam weapon will be used across industry, for optical tracking of production processes, infrared monitoring of energy use, control of fast processes, and automated control. The advances in automation spurred on by the space program are now being applied in Japan with the widespread introduction of robots; another leap in automation will follow from the perfection of automation and control technologies in beam weapon propagation, aiming, and firing.

Although all of 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. Technologies that exist today but cannot be used for lack of energy will come into their own. 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 economically.

Similarly, 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. This technology will revolutionize mining and refining more than did the introduction of electricity.

The Science Driver of the Economy

During World War II, the American economy was lifted from depression into unprecedented productivity growth through the use of new industrial technologies, new metals, materials, and assembly-line processes that had been known previously *but not used,* and the use of much more electricity for higher quality production. Today the national necessity—really an international necessity—to end the unstable balance of thermonuclear terror by developing defense against nuclear weapons can be the "science and technology driver" for an economic recovery without war. And the energy, particle, and plasma beam technologies we develop to meet this necessity can unleash a process of economic development that will uproot the deepest causes of war.

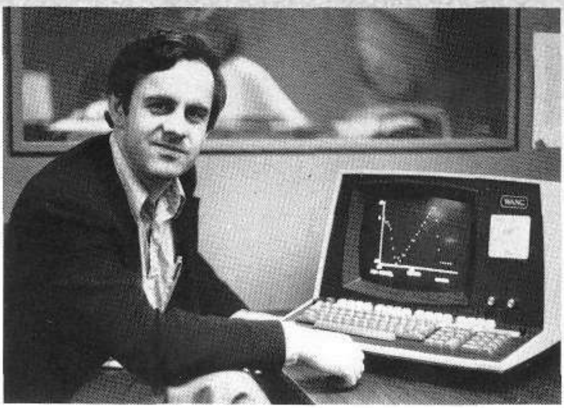
This spurt in economic activity does not, at first, depend on the discovery of new technological developments, but on the perfection and proliferation of state-of-the-art technologies that only await capital investment. The immediate spinoffs to industry of a successful crash program for development of beam weapons include magnetohydrodynamics for energy conversion, superconducting power transmission, magnetic levitation of trains for land transportation, laser and particle beam metal working, and robotics.

The second decade of a beam weapon development program would generate more advanced technologies: the fusion-fission hybrid, nuclear steel making, integrated nuclear agricultural-industrial complexes (nuplexes), high-energy laser and beam applications to drilling and materials processing, and plasma torch technologies.

The economics of the 21st century, provided we reach the 21st century, will be dominated by the commercial application of nuclear fusion energy and by the use of coherent radiation beams and particles for more and more industrial and agricultural work. *We can even foresee the time when each skilled worker will work* with tools that can transmute the basic composition of matter.

Real National Security

At first sight it seems ironic that the solution to man's problems of economic development might come out of a military development program. But such a role for the armed forces and their engineering corps used to be a tradition in advanced nations. Real national security rests on economic growth, technological development, and human advancement that simultaneously provide a strong military and make war unlikely.



Uwe Parpart Henke, research director for the Fusion Energy Foundation, was the first U.S. scientist to go on national television to support President Reagan's March 23, 1983 speech calling for the United States to develop a defensive weapon system that would make nuclear weapons "impotent and obsolete." Parpart Henke appeared on CBS Morning News, March 29.

The Fusion Energy Foundation (FEF) has been promoting the development of beam defense since 1977. In this book, the FEF scientific staff tells you why.

Here's what the press has said about the FEF:

Defense Daily, April 14,1983

"Within 10 to 12 years, the U.S. could build a short wavelength space-based laser system that could defend the nation against a full-scale Soviet ballistic missile attack, an official of the Fusion Energy Foundation said. . . . The FEF is a nonprofit foundation formed in 1974 to promote development of thermonuclear fusion energy and it has become a leading advocate of laser and beam weapons."

Aerospace Daily, April 18, 1983

"A system of ground-based, 10-megawatt lasers, whose beams could be reflected from orbiting mirrors, would be able to destroy Soviet missiles in their boost or lift-off phase, could be built by the United States within five to seven years, and is the only system that could provide an effective missile defense for Western Europe, a New York think-tank reported."

Air Force Times, Dec. 6, 1982

"Dr. Steven Bardwell, FEF's director of plasma physics research, described at a Capitol Hill briefing the technology now available that would make 'nuclear war obsolete.' FEF, a nonprofit educational organization, has proposed legislation that would launch the beam weapon program and related efforts. It said the program would do more for world peace than a nuclear weapons freeze."

Honolulu Star-Bulletin & Advertiser, Jan. 2, 1983

"In 1983, according to Paul Gallagher, FEF executive director, the Soviets are expected to install high-energy laser weapons with a range of more than 6 miles on their new Kirov-class nuclear-powered missile cruisers."

Associated Press, March 28, 1983

"The United States could have within 10 to 12 years a space-based system of laser weapons that would afford the entire country a 'foolproof' defense against missile attack, according to the research director of a foundation which has explored the concept since 1977."

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