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The Strategic Defense Initiative: A Primer and Critique

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SS-X-24 A new Soviet intercontinental ballistic missile with shorter booster burn time, 180 to 200 seconds.

technical fix A proposed solution to an international political problem based on an appeal to technology.

terminal phase The last phase of an ICBM's flight. This is the phase when the warheads from the missile reenter the atmosphere. It lasts from 30 to 60 seconds.

TNT Trinitrotoluene—a conventional high explosive. The energy released by nuclear weapons is commonly refered to in terms of the equivalent energy released by the requisite number of tons of TNT. For example, a megaton nuclear weapon releases as much energy as the explosion of one million tons of TNT.

watt A unit of power equal to one joule per second. It is a measure of the rate of energy use.

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ABOUT THE AUTHOR

John A. Jungerman is professor of physics at the University of California, Davis. There he has served as founding director of the Crocker Nuclear Laboratory and chair of the Physics Department. He began his professional career as a physicist on the Manhattan Project during World War II at Oak Ridge, Tennessee, and Los Alamos, New Mexico. He studied for the doctorate at the University of California, Berkeley under the tutelage of Emilio Segre and did a year's postdoctoral study with Hans Bethe at Cornell University. He has served as a consultant to the International Atomic Energy Agency and has pursued research at a number of institutes abroad, including the Atlantic Institute of International Affairs, Paris, where a major part of the present paper was written. In addition to scientific works, he is co-author of *Nuclear Arms: Technology and Society* (1985).

NATO The North Atlantic Treaty Organization

neutron An uncharged subatomic particle contained in the nucleus of an atom having almost the same mass as the proton.

Nitze Criteria The criteria for cost effectiveness and invulnerability to be used in evaluating a BMD system. Named after Ambassador Paul Nitze, arms control negotiator for the Reagan Administration.

NPT Non-Proliferation Treaty. A treaty established in 1968 to prevent proliferation of nuclear weapons. Now signed by 130 nations including the USSR and the U.S.

OTA Office of Technology Assessment. A U.S. government agency established by the Congress to provide independent assessments of technical developments.

nucleus The central part of an atom where almost all the mass is found.

overpressure Pressure above normal atmospheric pressure, which is about 15 pounds per square inch. Missile silos are normally "hardened" to withstand overpressures of 2,000 pounds per square inch. That is 2,000 pounds per square inch in addition to the normal atmospheric pressure of about 15 pounds per square inch.

particle beams Beams of atomic particles formed with enough intensity to damage space-based assets. Usually the atomic particles proposed are neutral hydrogen atoms that are given high kinetic energies in an accelerator.

phased-array radar An antenna controlled electronically, usually by computer, to permit extremely accurate and directional aiming or reception.

power Energy expended per unit time, or the rate of doing work. A 60-watt electric light bulb uses a power of 60 watts or 60 joules per second.

proliferation The process by which nations acquire nuclear weapons.

proton A subatomic particle, carrying one unit of positive charge, that is contained in the nucleus of an atom.

rad A unit of radiation dose. One rad is equivalent to 0.01 joules of energy absorbed per kilogram (of body weight, or weight of components in a satellite).

radar Radio detection and ranging.

radian A unit of angular measure. One radian is 57.3 degrees approximately.

Raman scattering Scattering of light by molecules with a shift in the wavelength of the light to a longer wavelength.

SALT I Strategic Arms Limitation Talks (I) Treaty signed in 1972 to limit strategic arms as a prelude to SALT II. Also included the ABM Treaty forbidding construction of BMD on more than one site. (Moscow chosen by the USSR.)

SDI Strategic Defense Initiative.

SIOP Single Integrated Operational Plan: The U.S. nuclear war plans which integrate the activities of all elements of the military.

SLBM Submarine-Launched Ballistic Missile

SS-18 A large intercontinental ballistic missile in the Soviet arsenal.

first strike An initial attack with nuclear weapons. A disarming first strike is one in which the attacker attempts to destroy all or a large portion of its adversary's strategic nuclear forces before they can be launched. A preemptive first strike is one in which a nation launches its attack first on the presumption that the adversary is about to attack.

geosynchronous (orbit) An orbit located about 36,000 kilometers from the earth. In such an orbit the speed of the satellite is the same as the speed of the earth's rotation so that the satellite remains fixed over one point of the earth.

IAEA International Atomic Energy Agency. An agency of the United Nations that is charged with monitoring compliance with the Non-Proliferation Treaty, among other tasks.

ICBM Intercontinental Ballistic Missile

infra-red radiation electromagnetic radiation whose wavelength is longer than visible radiation—literally "beyond the red" or visible spectrum.

joule A unit of energy in the metric system. A 60-watt electric light bulb consumes 60 joules of energy every second.

kilojoules One thousand joules.

kill flux The energy flux necessary to damage a missile or warhead enough to render it inoperable. Usually taken to be about 20,000 joules per square centimeter, or 20 kilojoules per square centimeter.

kinetic energy weapons Weapons that can "kill" objects in space by virtue of their energy of motion; for example, high speed projectiles.

Krasnoyarsk radar A controversial phased-array radar built by the Soviets in central Siberia that probably is a violation of the ABM Treaty.

laser A light source that produces a very parallel, and hence intense, beam of radiation of a single wavelength by a quantum mechanical process.

to lase The act of lasing. A light source is made to lase, i.e., to produce a parallel and intense beam.

MAD Mutually Assured Destruction. A nuclear policy in which each superpower has a strategic nuclear arsenal that can survive a first strike and deliver a devastating retaliatory response producing "assured destruction." The first strike is therefore not initiated.

midcourse phase The phase of a missile's flight after the boost phase. In midcourse the missile is coasting above the atmosphere.

MIRV Multiple Independently Targetable Reentry Vehicle: The several warheads of a MIRVed missile may be aimed independently of one another so as to permit precise selection of multiple targets.

megaton The energy released by the explosion of one million tons of TNT.

megarad One million rads.

microradian One millionth of a radian.

micron One millionth of a meter.

MX Missile Experimental. A MIRVed missile containing up to 10 warheads that is currently being added to the U.S. strategic arsenal.

Navstar A U.S. military satellite navigational system capable of locating a position within a few meters in three dimensions anywhere on earth.

The Strategic Defense Initiative: A Primer and Critique*

I. Introduction

A. Summary and Principal Theses

This paper argues that the Strategic Defense Initiative, or SDI, is the latest in a long series of attempts to solve a political problem, the "nuclear predicament," by technical means. It argues further that using the political process of arms control and arms reductions offers us a better chance of resolving that predicament than does technology. It explains as completely as possible in lay terms that SDI is not "technically sweet," as some earlier developments have been, but on the contrary is fraught with immense difficulties and is vulnerable to countermeasures. The paper demonstrates that even if SDI were technically feasible, it is strategically unstable without full Soviet cooperation in the testing and deployment phase. Finally, the case for negotiated arms agreements is laid out.

In order to provide a context for the discussion, a brief background is given of the history of the nuclear policy of the United States, with particular emphasis on the impact of technology on that policy, i.e., the impact of previous appeals to technological solutions.

The paper gives a brief description of the development of antiballistic missile (ABM) defenses in the 1960s, and how this culminated in the 1972 ABM treaty. This is followed by a discussion of subsequent ABM research and deployment by the U.S. and USSR as permitted by the treaty. In this paper the ABM situation is updated as to technical and strategic considerations after four years of effort by the U.S. on the SDI program.

Difficulties in forming an ABM defense with technologies that are perceived at this time will be considered in some detail. These difficulties include not only kill mechanisms but also battle management problems. Likely countermeasures and possible strategic instabilities produced by deployment by one side of even a partially successful system are also considered. Included is a discussion of the technical possibility of using a space-based ABM system for offensive purposes, such as antisatellite systems (ASAT), incendiary, or specific ground targets.

The ballistic missile defense (BMD) systems that are considered in this paper will be analyzed not only for their technical feasibility, but also in terms of the Nitze criteria[1] which state that the systems must also be survivable, "cost effective at the margin," and not themselves be tempting targets.

To assist the reader a glossary of technical and strategic terms is included at the end of the paper.

B. The Nuclear Predicament

At present the populations of the Soviet Union with its allies and the United States with its allies are held hostage to a balance of nuclear terror. This "nuclear predicament" transcends in urgency all other problems of our time. Some argue that there has been no direct superpower conflict since the advent of nuclear weapons in 1945 and that the superpowers have been circumspect in avoiding direct confrontation precisely because they exist. On the other hand, from a perspective of decades, or even centuries, one can ask if a miscalculation in time of crisis, a technical failure, or human error might not inevitably occur.

A fundamental fact of the nuclear age is that the energy released per reaction for a hydrogen or

*This paper was supported in part by the Atlantic Institute for International Affairs, Paris, France.

atomic bomb is a million to ten million times greater than the chemical reactions that produce ordinary bombs (trinitrotoluene or TNT, for example). The bomb used at Hiroshima delivered the energy equivalent of 13,000 tons of TNT and destroyed a city of 300,000 people with 100,000 persons killed immediately and a like number seriously injured. Today the combined arsenals of the United States and the Soviet Union contain the equivalent of about 12,000 million tons (megatons) of TNT, or about one million Hiroshima bombs. One can say that in the forty-some years since the dawn of the nuclear age, the U.S. and the USSR have realized in practice the factor of millions in destructive capacity inherent in nuclear arms compared with ordinary arms.

In strategic terms the enormous energy released by nuclear weapons gives the offensive a huge advantage compared to chemical weapons. If just one of the 500 kiloton bombs that are on each of the 10 warheads on the Soviet SS-18 were exploded over a city, it would be an unparalleled catastrophe. One of the 335 kiloton warheads on the Minuteman III of the United States would produce a similar disaster. It is doubtful whether the leader of a superpower would knowingly make a decision that would unleash such an event. The prospect of tens or hundreds of such explosions occurring simultaneously on the cities of a country is just unthinkable. It is therefore understandable that leaders would seek to ameliorate or eliminate the nuclear threat.

President Reagan had made it clear when he assumed the presidency that he was dissatisfied with the nuclear balance of terror. It was doubtless appealing to him to announce the Strategic Defense Initiative in his nationally televised speech of March 23, 1983,[2] in which he had the vision of making nuclear weapons "impotent and obsolete." His vision was to be accomplished chiefly through technical means using ballistic missile defense (BMD). He stated, "I call upon the scientific community who gave us nuclear weapons to turn their great talents to the cause of peace: to give us the means of rendering these nuclear weapons impotent and obsolete."[2] The response of the great majority of scientists in the United States has been pessimistic from the onset of the proposal as to the practicality of the SDI for the protection of the population from an all-out Soviet nuclear attack. The SDI has been termed "Star Wars" by some critics who view the system as principally fantasy. A study of directed-energy weapons (lasers and particle beams) concluded by a prestigious panel of the American Physical Society (APS) in 1987[3] stated that "it will take a decade or more of intensive research just to determine whether the job can be done" and "formidable technical obstacles must be overcome to produce useful weapons." On the other hand, SDI was defended by U.S. administration sources in reply to the American Physical Society report in this way:[4] "[we find] the conclusions to be subjective and unduly pessimistic" and "only a snapshot in time . . . we have made significant progress in the intervening period [since Sept. 1986 when the APS report was largely finished]."

It seems likely that the question of BMD in some form will be with us for some time. Indeed, most technically qualified persons who are critical of the SDI are persuaded that BMD research is necessary on a continuing basis in order to avoid "surprises."

C. An Abbreviated History of U.S. Nuclear Policy with Emphasis on Technological-Political Links

In the United States there is a long and complex history of the interaction of technical developments of nuclear weapons and their impact on political decisions. The appeal to technology is natural for Americans, for we are often successful in accomplishing technical goals.

For four years after World War II the United States had a monopoly in nuclear weapons. Secretary of State James Byrnes attempted to use this new force diplomatically in what came to be known as "atomic diplomacy." It may have been responsible in part for the success of the U.S. in persuading the Soviets to remove their forces from Iran.[5] However, it did not prevent the Soviet occupation of Czechoslovakia in 1948.

With the successful Soviet test of their atomic bomb in 1949, the nuclear arms race began in earnest. In the context of the Cold War, including the blockade of Berlin and the invasion of South Korea by North Korea, it was decided to develop a thermonuclear bomb. This is a clear example of the

Glossary

ABM Antiballistic missile

ASAT Antisatellite (weapon or program). A weapon or program to destroy satellites.

ATBM Antitactical ballistic missile. Such a device is designed to destroy tactical missiles (less than 100 km range) in flight.

boost phase The initial phase of an ICBM's flight, when the rocket motors are firing. Boost phase lasts from 3 to 5 minutes.

BMD Ballistic Missile Defense

CEP Circular error probable: The radius of a circle around a target within which 50 percent of the missiles will fall. If the CEP is 0.15 mile, then half the missiles will hit within a radius of 0.15 mile.

CTBT Comprehensive Test Ban Treaty. A proposed treaty to ban all nuclear testing.

counterforce (attack) An attack on primary destruction of military targets.

counterorbiting An orbit at the same elevation, but with the objects rotating about the earth in the opposite direction. Pellets that are counterorbiting would strike a space station with double the orbital speed of the station.

countervalue (attack) An attack on primarily economic targets (cities).

deterrence Dissuasion of a potential adversary from initiating an attack or conflict by threat of unacceptable retaliatory damage.

deuterium An isotope of hydrogen having a neutron as well as a proton in its atomic nucleus. Sometimes called heavy hydrogen.

directed-energy weapons A beam of electromagnetic radiation, infra-red, visible, or x-ray, or a beam of atomic particles that has enough intensity to damage space-based assets.

diffraction limit A limit imposed on the minimum size beam spot that can be obtained (hence the maximum energy flux) by electromagnetic radiation. The diffraction limit is directly proportional to the wavelength so that short wavelength radiation is capable of a higher energy flux if other conditions remain the same. The diffraction limit is also inversely proportional to the diameter of the mirror reflecting the radiation, so that large mirrors are required to produce small beam spots.

EMP Electromagnetic pulse: A short duration, high-intensity pulse of electromagnetic radiation formed when a nuclear weapon is exploded, either within the atmosphere or directly in space-based components.

endo-atmospheric Within the atmosphere.

energy The ability to do work. In the metric system it is measured in joules. Lifting one kilogram one meter requires about 10 joules of energy.

energy flux Energy striking a unit area. To "kill" a missile or warhead about 20,000 joules per square centimeter are required.

excimer A shorthand word which is a contraction of *exc*ited state of a d*imer* molecule. Dimer means a molecule made of two atoms. Excited states of molecules not normally formed are possible, such as krypton with fluorine or chlorine with xenon.

exoatmospheric External to the atmosphere.

the Soviet ABM effort should also be taken equally seriously by the Soviet Union (the Krasnoyarsk radar, for example).

We should recognize that the *absence* of significant Soviet ABM systems adds to the security of the U.S. and its allies as well as do measures to reduce the vulnerability of nuclear forces. We should recognize that the security of all nations in an era of nuclear parity among the superpowers lies in the direction of cooperation rather than confrontation—it lies in arms control and arms reductions rather than in unilateral decisions to pursue some alleged technical advantage, however alluring. It is essential that SDI research not endanger the ABM treaty or the arms control process.

Deterrence is an uncomfortable policy. It threatens mutual annihilation. It is, however, a realistic policy for the world as it is and will be for the near future. Deterrence *accompanied by harsh and uncompromising confrontation* in the political and military spheres is at the root of our anxieties. It is necessary for the superpowers to turn toward peaceful resolution of their differences and to find mutual interests, however difficult. Enhanced trade and cultural exchange, engaging in joint ventures for the enhancement of the human enterprise, such as a joint manned flight to Mars, should be actively pursued. It is time to pursue a stable balance based on the fact of nuclear parity between the superpowers. We need a "live and let live" attitude between the U.S. and the USSR, and for the U.S. the siren call of the "technical fix" must be abandoned.

Ultimately, we must recognize that deterrence is at best a transitional policy that is necessary as we work toward cooperative international arrangements to resolve political differences. In the nuclear age there is no other choice for the superpowers other than mutual suicide. In the very long range perhaps national armaments can be reduced, military bases on foreign soil gradually eliminated, and mutual trust and understanding developed among the world's peoples. Each nation can then be in a position to adopt a purely defensive military posture. That is, a nation would find it necessary only to defend its borders, but would not need to possess offensive weapons such as bombers and strategic ballistic missiles, which might be banned by international agreement.

For all this to happen, time, patience, and prudence are required; but the ultimate solution to the nuclear predicament lies here in the political realm rather than in the allure of technical options in the arms race, such as the SDI.

Notes

1. American Physical Society, *op. cit.,* 2.
2. S. D. Drell *et al., loc. cit.,* 98.
3. R. Z. Sagdeev and O. F. Prilutzkii, *Strategic Defense and Strategic Stability* (Moscow: Space Ressearch Institute, February 29, 1985), 11.

U.S. pursuing a technological solution to attempt to remedy the threat of the Soviet A-bomb development. The first hydrogen device was exploded by the U.S. in November 1952, followed by a similar successful test by the Soviets in August 1953. By 1955 both sides had developed deliverable thermonuclear weapons. However, the United States continued to have superiority in numbers of nuclear weapons and delivery systems throughout the 1950s and 1960s.

Herbert York, former director of research and development for the Department of Defense under Presidents Eisenhower and Kennedy, has stated[6] that the United States could have foregone the development of the hydrogen bomb, inviting the Soviets to do the same, without endangering U.S. national security. The General Advisory Committee of the U.S. Atomic Energy Commission was also of the opinion that the hydrogen bomb should not be developed. Two members of the committee (Enrico Fermi and Isidor Rabi) opposed its development as a danger to humanity as a whole and called on the president to invite all nations to make a solemn pledge to join the U.S. in renouncing hydrogen bomb research. But in the environment of the escalating Cold War the allure of the technological appeal of the hydrogen bomb as an answer to the Soviet A-bomb capability was too great. President Truman ordered a crash program for hydrogen bomb development.

With the vast superiority of nuclear forces on the U.S. side, Secretary of State John Foster Dulles was able to propose a nuclear policy of *massive retaliation* which stated, "the United States would depend upon a great capacity to retaliate instantly by means and at places of our own choosing in order to deter or counter aggression." Implicit in this doctrine is the concept of *deterrence,* in which nuclear forces are employed as a credible threat to deter another nation from taking certain actions. In 1946 Bernard Brodie had already foreseen deterrence policy as a consequence of the development of nuclear weapons.[7] He stated:

> The first and most vital step in any American security program for the age of atomic bombs is to take measures to guarantee to ourselves in case of attack the possibility of retaliation in kind . . . . Thus far the chief purpose of our military establishment has been to win wars. From now on its chief purpose must be to avert them. It can have no other useful purpose.

The doctrine of massive retaliation implied the first use of strategic nuclear weapons to deter aggression. However, the policy was short-lived because even though the U.S. had strategic superiority, the Soviet Union was by the late 1950s in a position to retaliate effectively itself.

In the late 1950s, after an extensive series of nuclear explosions conducted in the atmosphere by both the U.S. and the USSR, there was a world-wide concern about the radioactive contamination of the environment and great political pressure to prohibit further nuclear testing. The treaty to outlaw nuclear tests became known as the Comprehensive Test Ban Treaty (CTBT).

In an attempt to dissuade President Eisenhower from pursuing the CTBT Edward Teller and Ernest Lawrence advanced the idea to him in 1957 that if nuclear testing were continued a "clean" nuclear weapon could be developed (no radioactive fallout from the nuclear explosion). In this they were unsuccessful in that negotiations proceeded. In fact, Eisenhower warned in his farewell address that "in holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific technological elite."[8] Nevertheless, the nuclear weapon laboratories along with the military (Joint Chiefs of Staff) were indeed successful in forcing a compromise upon President Kennedy who accepted a Partial Test Ban Treaty that permitted underground nuclear testing rather than a CTBT. Until the present time, officials of the nuclear weapon laboratories of the U.S. (Livermore and Los Alamos National Laboratories) have often been influential in opposition to a CTBT.

The Kennedy Administration instituted a review of nuclear policy and Defense Secretary Robert McNamara introduced the policy of assured destruction, later called "mutually assured destruction" or *MAD*. This policy recognized that each superpower had the ability to annihilate the other with a devastating retaliatory nuclear strike if it were attacked. That is, each superpower was *deterred* from attacking the other because of the fear of assured destruction. It was also recognized that for a stable nuclear balance, the strategic forces of each superpower would have to be invulnerable to a nuclear attack by the other. Thus first-strike invulnerability, or the ability to deliver a devastating second retaliatory strike, lies at the foundation of the MAD nuclear policy.

McNamara was first to ask the question, "how much is enough?" to assure deterrence. It was determined that if 70 percent of the industrial capacity and one-third of the population of the Soviet Union were destroyed, it would cease to function as a viable society. This was determined to be possible with the delivery of 400 megatons of nuclear explosives on selected targets in the Soviet Union. This policy not only made specific the needs of deterrence, but also provided a means of fiscal control on the U.S. armed services.

The Kennedy Administration also produced a revision of the "single integrated operational plan," or SIOP, to provide for not only a coherent targeting policy of all the armed services and to coordinate their varied abilities, but also to provide various options from which the president could choose in the event of a nuclear exchange with the USSR.

Early in the Kennedy Administration the U.S. Navy had proposed a fleet of missile-firing submarines (SLBMs) as the ideal deterrent, because the submarines were invulnerable to attack. At that time, however, the submarine missile delivery systems were quite inaccurate so they only offered a credible threat to industries and cities (*countervalue*). The U.S. Air Force on the other hand was able to offer more precise missile delivery from land-based missiles, although they were perceived to be more vulnerable than the SLBMs. The bomber fleet of the Air Force also had the capability for more accurate delivery of nuclear weapons as well. The Air Force was thus able to propose a new policy of *counterforce* which offered the president the choice of options as to nuclear targets in terms of attacking primarily military targets. However, the "collateral damage" from such an attack to civilians might well reach millions of casualties.

The idea that there would be a balance between submarine, missile, and bomber deliveries of nuclear weapons became the foundation of U.S. nuclear policy, the *strategic triad*. It not only resolved interservice rivalries, but also provided diversity and hence more likelihood of survival of strategic nuclear forces if they suffered a preemptive first strike.

As the U.S. nuclear forces improved in sophistication and accuracy of delivery, and satellite surveillance provided comprehensive mapping of the Soviet Union, U.S. nuclear policy shifted increasingly to a posture of *flexible response* rather than the minimum deterrence of Secretary McNamara. The present nuclear policy, SIOP-6, is intended to "create the capacity to fight and prevail in a nuclear war." It was prepared by the Reagan Administration, but largely proposed as well as Presidential Directive 59 under the Carter Administration. The policy emphasizes the need to have enough resilience and flexibility of response to provide "escalation control" for any possible contingency during a nuclear exchange. According to this policy[9] a president does not have to resort to countervalue targeting in the initial phase of a nuclear exchange, but can resort to targeting selected military targets. The assumption here is that command and control by both superpowers would remain intact and that rational decisions and communication with each other would remain possible in the midst of a nuclear exchange.

Once again technological advances led by the U.S., this time in missile accuracy, which were presumed to provide the president with options and escalation control, had brought forth a change in U.S. nuclear policy. These options may in fact be a dangerous illusion as they rest on the assumption of rationality and control in the midst of a nuclear exchange.

Desmond Ball has studied the nuclear policy of the United States extensively in terms of the actual targeting policy.[10] His comments on the de facto nature of nuclear targeting and escalation control are revealing:

> The reality has been that U.S. targeting plans have *always* contained a wide variety of targets, including military targets, and that flexibility and an ability to control the escalation process have been official requirements for some two decades at least. But rather than being motivated by any need to make substantive and significant changes in these plans, the refinements prescribed in NSDM-242, PD-59, and NSDD-13 derived from a

V. Conclusions

We have seen above that from a technical point of view the original purpose of SDI, the defense of populations against ballistic missile attack, is not realizable at present. At least a decade of intensive research is needed to make an informed decision as to the practicality of directed-energy weapons[1] (lasers and particle beams). Requirements for BMD of populations via kinetic energy weapons are also formidable and such BMD is not possible at this time via these means either. *SDI for defense of populations is a fantasy at this time.*

We have also seen that *it is not practical to pursue the SDI program without Soviet cooperation, even if it were possible technically.* The threat to test and deploy a BMD system without such cooperation will result in an unrestrained arms race in defensive systems and increased strategic offensive systems to counter the defenses. It would be the latest and most tragic example of pursuit of a "technical fix" in order to attempt to solve the political problem presented by nuclear arms. Dogged insistence on the SDI program is an impediment to obtaining the cooperation of the Soviet Union that we must have to solve the nuclear predicament—for example, to reach an agreement for *reductions in strategic* nuclear arms. *The political process, exemplified by arms control and reduction agreements, is our best hope for extricating ourselves from the nuclear predicament.*

At the present time, an ongoing research program is needed as a hedge against unforseen breakthroughs, and has in fact been pursued by both the U.S. and the Soviet Union for several decades. To avoid waste such research programs should be funded steadily, but not as crash programs or as engineering programs leading to deployment. On the U.S. side this might be facilitated by forming a non-partisan advisory panel to monitor the program and to advise the public and Congress, as suggested by the Stanford group[2].

Ground-based BMD of ICBMs in terminal phase is probably technically possible. It may be desirable to do so to increase their first-strike invulnerability, and therefore to enhance deterrence. Such a development would be permitted by the ABM treaty for one missile complex. However, if ICBM defense is judged necessary, other means, such as mobile basing of single-warhead missiles may be more cost effective. It may also be judged that sufficient deterrence is already provided by the ICBMs that would survive a first strike in addition to the nuclear warheads that could be delivered by bomber and submarine forces, and therefore ICBM defenses are not necessary.

To enhance cooperation and avoid provocation leading to an acceleration of the nuclear arms race, the Soviet Union and the U.S. should keep each other fully informed as to each other's developments and intent in the ABM area, perhaps via the Standing Consultative Commission, already functioning under the SALT I treaty. Clear communication is particularly important at this time because of the accelerated U.S. ABM effort as a result of the SDI program and the steady Soviet build-up of ABM capabilities.

Although the SDI is argued as a defensive system by Reagan administration spokesmen, we have seen above that it has direct offensive capabilities. Many Soviet analysts see it as enhancing a U.S. first-strike capability. For example, Sagdeev and Prilatzkii[3] argue that:

> stability will be diminished [by deployment of a comprehensive ABM system] since any defensive system would be more effective against a ragged retaliatory strike than against a massive first strike. . . . [T]o parry the threat this side *will* develop countermeasures to the ABM defense and build up its offensive forces. . . . [A]ll initiatives to create strategic defensive systems should be regarded as intentions to achieve military superiority . . . to inflict a first nuclear strike with impunity.

Although this statement and similar ones by other Soviet commentators can be dismissed as propaganda, they may in fact be their actual perceptions and they reveal the seeds of an unconstrained arms race. Soviet fears need to be taken very seriously by the U.S. just as the U.S. counterpart fears of

Notes

1. J. J. Holst and W. Schneider, Jr., *Why ABM?* (New York: Pergamon Press, 1969), 149.
2. *Soviet Military Power, 1987,* 46.
3. S. Stevens, in *Ballistic Missile Defense,* Ashton B. Carter and David N. Schwartz, eds. (Washington, D.C.: The Brookings Institution, 1984), 212.
4. J. K. Davis and R. L. Pfaltzgraff, Jr., *Strategic Defense and Extended Deterrence,* (Cambridge MA, and Washington, DC: Institute of Foreign Policy Analysis, February 1986).
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recognition that the existing plans had little prospect of controlling escalation. In the end a better understanding of the realities of force employment policy might lead to the realization that the limited nuclear warfighting option is a chimera, and that policies which depend upon the ability to maintain escalation control of a nuclear exchange are ultimately incredible.

From a strategic standpoint it could be argued that increased missile accuracy has created first-strike vulnerability of ICBMs, thereby undermining one of the basic tenets of MAD. This situation is particularly applicable to the Soviet forces, which are approximately 75 percent ICBMs, whereas the U.S. forces are only 25 percent. Thus a case could be made for reexamination of the ABM treaty to permit reestablishment of first-strike invulnerability of ICBMs. Such invulnerability could also be enhanced by other means such as mobile ICBMs. Improvement in missile accuracy was pursued in order to give options to the president—as an attractive technological development which in principle would permit attacks on selected military targets (counterforce policy). However, it in fact has led also to perceived strategic instability and the "window of vulnerability." So in this case the relentless pursuit of technology has produced a less secure international political climate and an acceleration of the nuclear arms race.

Similarly, the development of the neutron bomb in the Livermore laboratory led to an ill-fated decision in the Carter administration for its deployment within NATO, which later had to be modified because of political opposition in Europe. In this case, even though the neutron bomb was "technically sweet," its political consequences were not sufficiently appreciated.

Again, the development of the Multiple Independent Reentry Vehicles (MIRV) by the U.S. was one of the chief reasons why the U.S. could accept an ABM treaty in exchange for limits on offensive missiles. The "technical fix" produced by the promise of multiple independent reentry vehicles or MIRVs, i.e., several warheads on a single missile, was irresistible. This technical development made it possible to saturate the Galosh ABM system that defended Moscow. Within a few years the Soviets had themselves developed a MIRVed missile system with the result that a decade later the U.S. faced at least triple the number of strategic nuclear warheads than would have been the case if the MIRV idea had been outlawed by treaty. Such a treaty would have been easily verified as MIRVed missile firings are readily observed. Henry Kissinger, who was secretary of state at the time, later stated that the MIRV idea had been a mistake,[11] although in 1972 it was technically attractive.

More recently the Livermore laboratory has proposed using an X-ray laser to be activated by a nuclear explosion to destroy Soviet missiles in boost phase using a "pop-up" system.[12] The possibility of this technical development may have been influential in persuading the Reagan administration to propose the SDI program. *The X-ray laser and other SDI proposals are thus the latest in a long history of attempted technological solutions to the nuclear predicament.* We should be mindful that this history is filled with examples of attractive technologies that have subsequently created unforeseen political or technical problems.

D. Ballistic Missile Defense in the Context of Nuclear Deterrence

Both the U.S. and USSR have been pursuing BMD research for decades. The U.S. program began in the 1950s and culminated in the Nike-Zeus system. This program was conceived to defend not only military installations but the civilian population as well.

The system was tested for the first time in 1959. Further tests revealed that the system could not distinguish warheads from decoys. It was therefore discontinued, and the research budget for anti-ballistic missiles (ABM) was also reduced.[13]

One of the central tenets of MAD is the idea of the maintenance of a survivable second-strike capability. A second important tenet is the idea of quantification of nuclear forces needed to deter an attack on the United States. This restriction of forces in turn may stimulate progress towards arms control. In this context Secretary McNamara opposed introduction of ballistic missile defenses as being destabilizing. In his view, their introduction would start a new action-reaction cycle with the Soviets. The Sentinel project for BMD of sites in North Dakota was forced upon McNamara by Congress in the late 1960s, presumably in response to Chinese offensive capacity.[14]

Meanwhile, the Soviets had developed an operational BMD system for defense of Moscow (Galosh). According to former Secretary of State Henry Kissinger, the ABM Treaty was essentially a trade-off of the U.S. desire to limit offensive nuclear weapon deployments by the Soviets in turn for the decision to severely limit BMD defenses. Technical advantages in such defenses favored the United States in the Soviet view.[15]

E. Recent Developments in ABM Defense

The ABM Treaty was signed in 1972. With its 1974 Protocol it permitted each superpower to have one ballistic missile site. The Soviets chose to defend Moscow with their existing system. Improvements have been made steadily on this system until the present time. The system uses nuclear warheads to destroy incoming missiles. However, under the terms of the treaty the Soviets have no other ABM sites. Initially the U.S. chose to defend missiles in a North Dakota complex using the Sentinel System with 5-megaton warheads. The system was discontinued in the early 1970s as being ineffective.

The ABM treaty, now in its fifteenth year, has survived two formal reviews, with a third scheduled for 1987. It remains a cornerstone of arms control agreement between the superpowers. It was meant to be the forerunner of future arms treaties, SALT II and SALT III. The treaty is important in that both superpowers acknowledged the dangers of nuclear war and the necessity to take effective measures toward the reduction of nuclear arms.

The treaty also implicitly recognized that BMD against a major nuclear attack would not be effective and attempting to construct such a defense would exacerbate the nuclear arms race.

The proposal to develop BMD by the United States (SDI) therefore upsets a longstanding de facto agreement between the superpowers accepting the idea of MAD, in which the cities and other "soft" targets of both sides are vulnerable to attack.

Since the treaty was signed, each side has made technical improvements in computers and radar which permit better discrimination of incoming warheads. Laser and particle beams have also been improved. Radars supposedly built for non-ABM use have characteristics of power, location, and configuration which raise serious questions of ABM treaty violation. In particular, the large phased-array Krasnoyarsk radar has been formally determined by the Reagan Administration to be in violation of the treaty in that it is located well within the Soviet Union (Southern Siberia), whereas the treaty calls for such radars to be located only on national peripheries.[16] If located on a nation's periphery, they could be used for early warning of nuclear attack but could not be used for battle management of ABM forces.

It should be pointed out that the Krasnoyarsk radar is located too far from the SS-18 sites to be very effective for battle management, and could actually be part of an early warning system as the Soviets assert. It could have been built away from the Soviet periphery to avoid permafrost. It does in fact fill in a gap in the Soviet early warning system. According to a report from a visit to the site by several congressmen in 1987, the radar is far from operational. However, in any case the radar is a serious violation of the ABM treaty.

Peter Zimmerman [17] asserts that *both* the U.S. and USSR are in technical violation of the ABM Treaty by their construction of phased-array radars. These large phased-array radars were recognized during the negotiation of the ABM Treaty as key elements of an ABM system and were expressly constrained by Agreed Statement F. In upgrading the Thule and Fylingdales radars to phased-array types for modernization and economic reasons, the U.S. is also in technical violation, of the ABM Treaty. Without admitting their violation the Soviets offered to halt construction of the Krasnoyarsk radar if the U.S. and its allies stopped work at Thule and gave up construction of the new Fylingdales radar. The U.S. refused this offer.

- has not deployed the Backfire with long-range cruise missiles which would give it intercontinental capability and thus require that it be counted under SALT II limits;
- has not tested an ICBM that released more than 10 "reentry vehicles" (representing warheads), or tested an SLBM that released more than 14, in compliance with SALT II's 'fractionation' restrictions. No more than nine mock warheads have ever been released during a Soviet SLBM test. In addition, under the SALT I and SALT II accords the Soviets have removed 1,007 ICBMs, 233 SLBMs, and 13 "Yankee"-class nuclear-missile-carrying submarines.

This is an impressive history of compliance.

The Threshold Test Ban Treaty was signed in 1974. Although the treaty has never been ratified by the U.S., the superpowers have complied nevertheless with its provisions. The treaty limits nuclear explosions underground to be 150 kilotons or less. Although there have been charges of non-compliance by the Soviets, these have proven to be based on faulty information regarding calibration of seismic instruments. By limiting the scale of nuclear explosions, the treaty has had the effect of limiting some nuclear weapon development on both sides and also has saved the underground environment from more extensive radioactive contamination that would have occurred with higher yield tests.

A treaty permitting peaceful nuclear explosions (the PNE treaty) was also signed in 1976, but again was not sent to the U.S. Senate for ratification. This treaty provided for the first time for on-site inspection and measurement of the peaceful nuclear explosions by the adversarial superpower. Although the U.S. has abandoned the peaceful nuclear explosion program (project Plowshare), the Soviet program has been continued. Since the treaty has not been ratified, U.S. observers have not been able to gather information regarding Soviet nuclear explosives that would be possible under the treaty.

The Partial Test Ban Treaty and the Non-Proliferation Treaty both call for a Comprehensive Test Ban Treaty (CTBT) that would preclude further development of nuclear weapons. The CTBT remains official U.S. policy, even though the Reagan Administration has not given it high priority, possibly because such a ban, or threat of it, would interfere with the development of the x-ray laser of the SDI program. The Soviet Union, on the other hand, recently proclaimed an 18-month moratorium on nuclear tests, and invited the U.S. to do the same, in order to proceed with a CTBT. If nuclear weapons are really only useful to deter an opponent from using them, then their further development and deployment is not only illogical, but increasingly dangerous.

Given the problematic nature of SDI, it is important to recognize that in pursuing ABM defense the arms control process must not be endangered, for it remains our current best hope for avoiding nuclear war. A cornerstone of that process is the ABM Treaty of 1972, which has definite restrictions on the development and deployment of ABM defenses, but not on research.

Arms control, and the ABM Treaty in particular, represents a *political* attempt to avoid nuclear war. The approach of SALT I recognized explicitly the dangers of nuclear war and constituted a strategy for managing the nuclear peril. Arms control has broad support throughout the world as an intuitive recognition that the problem of nuclear arms must eventually be solved not in the technological sphere, but in the political realm. With all the disenchantment with the SALT process that has intervened, it remains the chief de facto limitation on the nuclear arms race. The SALT agreements and the ABM Treaty recognize our common vulnerability and the necessity to act cooperatively to avoid nuclear catastrophe.

nuclear arsenals. Since the NPT was signed there has been only one new known member of the "nuclear club," namely, India, which exploded one "peaceful" bomb in 1974. However, Israel and South Africa are strongly suspected of having nuclear weapons. This treaty assigns to the International Atomic Energy Agency (IAEA) the task of inspection of nuclear facilities to assure that they are being used for peaceful purposes. The nuclear "haves" who are signatories agree not to sell nuclear equipment to nations that are not signatories of the NPT. The system has worked reasonably well even though the IAEA has limited authority.

The ABM Treaty of 1972 has been successful at limiting the development and deployment of BMD including space-based systems. It provided that each superpower could have only one ABM site with a limit of 100 interceptors. The Soviets chose to defend Moscow. The U.S. chose to defend a missile site in North Dakota, but soon abandoned the ABM defense as being impractical. The ABM Treaty has therefore prevented another arms race in this area. The SALT I Interim Agreement also limited the number of launchers of offensive missiles (ICBMs) to those existing or under construction at the time: 1,054 on the U.S. side and 1,400 on the side of the USSR. The treaty did not limit bombers, of which the U.S. had 600 and the USSR 150 at that time. The treaty also provided for the establishment of a Standing Consultative Commission to deal with noncompliance of treaty provisions. The commission's work is not done in public and worked quite well during the 1970s to solve compliance problems with a minimum of political confrontation. According to Ambassador Robert Bucheim, who served for several years as the third U.S. commissioner,[21] "The Commission sticks to business, there is no rhetoric. A good, productive, working arrangement is formed by the commissioners through months of contact, which promotes mutual respect and efficiency." Article 17 of the proposed SALT II agreement provides for a similar commission for that treaty.

The SALT II agreements, while never ratified by the U.S. Senate, provide extensive and detailed limits on land and sea-based missiles, MIRVs, aircraft equipped with cruise missiles, and several other types of strategic weapons. The treaty sets an overall ceiling of 2,400 on ICBMs, SLBMs, and heavy bombers for each superpower. It also provides that in 1981 this overall ceiling was to be reduced to 2,250. So if the U.S. were to ratify the treaty, the USSR would be obliged to destroy 250 strategic weapons systems. Until recently both sides have complied with the SALT II limits, even though the treaty is not technically in effect. The Reagan Administration in late 1986 decided to exceed the SALT II limits, but has received considerable opposition in the Congress for doing so.

Even though SALT II has never been ratified, and in fact was withdrawn from such consideration by the Reagan Administration, since the treaty was signed in 1979 the Soviet Union has seriously altered its plans for deploying offensive nuclear weapons. According to Panofsky,[22] since SALT II the Soviet Union:

- has never exceeded the SALT I limit on ballistic missile launchers or violated its commitment not to undercut the SALT II limits on total strategic nuclear warheads and MIRVed ballistic missiles;
- has not constructed a single new fixed ICBM silo;
- has not tested a new "heavy" ICBM;
- has not increased the number of warheads on existing ICBMs;
- has not developed or tested ballistic missiles for installation on surface ships or emplacement on the ocean floor;
- has provided advance notification of tests involving multiple missile launches and extraterritorial test flights;
- has produced 30 or fewer Backfire bombers per year, and has removed refueling probes from Backfire bombers to reduce their potential utility as "strategic" intercontinental bombers;

Since the ABM Treaty was signed, the USSR has steadily upgraded the Moscow defense system, providing nuclear-tipped interceptors in 1980. They have also introduced a system that operates within the atmosphere, which permits sorting out real warheads from decoys. New phased-array radars have been constructed to provide the battle management function for the Moscow system. The system is limited to 100 interceptors by the ABM Treaty. Overall, the system could be useful against accidental attack, but could readily be overwhelmed by a concerted attack. The U.S. has improved penetration aids and has more than doubled the number of its strategic warheads since the ABM Treaty was signed in 1972.

At the time the ABM Treaty was signed, missiles in hardened silos were almost invulnerable to nuclear attack. At present, however, with the advent of improved missile accuracy, ICBM forces have become vulnerable (see below for more details). Submarine-launched ballistic missiles (SLBM) are at this time practically invulnerable, because of the difficulty of locating a deeply immersed submarine.

Therefore, the triad of strategic nuclear arms now has one vulnerable leg (the ICBM leg). To those who are concerned that each leg of the triad be invulnerable, the risk of losing a major part of the ICBMs in a first strike has become known as the "window of vulnerability." In the view of others, because of the destructive power of a single submarine or bomber and because of the invulnerability of submarines and the ability of bomber forces to become quickly airborne on warning, MAD is still intact.

Notes

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selves to the full range of strategic forces, including defenses. They have maintained and are now improving their ABM system around Moscow; their air defense network is extensive; Soviet civil defense preparations are vastly greater than our own; and they are pressing ahead with advanced ballistic missile defense technologies.

We discuss the Soviet BMD effort above. However, this development, while threatening to some, has generally not been in violation of existing arms control treaties (the Krasnoyarsk radar being a possible exception as discussed above).

The fears of other Soviet military developments as expressed by Toomay imply a perception of continued Soviet aggressive tendencies. They do not take into account historical differences between the U.S. and USSR which can account for the Soviet passion for defense. The situation of nuclear parity is in fact new and according to Soviet statements it is their intent to maintain such parity using whatever resources that are necessary. The fears expressed by Toomay could be better addressed by taking the risk of cooperation with the Soviets rather than by further appeals to technology and a new spiral in the arms race.

It is one of the theses of this paper that on balance arms control and if possible negotiated nuclear arms reductions are our best hope of extricating ourselves from the nuclear predicament. *The question may well be asked: if Soviet cooperation is essential for the success of SDI, why can't such cooperation be much more readily obtained for reductions in nuclear arms?*

The goal of SDI after all is the laudable one of "rendering nuclear weapons impotent and obsolete." We have seen that this proposed "technical fix" is illusory technically and dangerous strategically. A much more direct and simple way to rid ourselves of the threat of nuclear weapons is to negotiate them away. This will not be an easy process, for it involves to some degree changes in the mythologies that the superpowers believe about each other.

Cooperation between the superpowers in the era since World War II has not been extensive. In pursuit of technological advantage, in an illusory quest for nuclear advantage, or from fear of the adversary's nuclear arsenal, they have paid little attention to Einstein's warning "that everything has changed but our way of thinking and so we drift towards unparalleled catastrophe."

With nuclear parity between the superpowers and the appalling destructive potential in their present nuclear arsenals (capable of killing one-half of the world's population and severely damaging the ecosphere), the time is indeed propitious for cooperation.

For whatever reason or combination of reasons—a new, young, and dynamic leadership in the Soviet Union, the U.S. build-up provided by "peace through strength" the past six years, Soviet domestic economic pressures, or political pressure on President Reagan for a substantial arms control agreement—considerable progress is being made at present on arms control agreements between the U.S. and USSR. The signing of the INF (Intermediate Nuclear Force) Treaty in December 1987 for the first time finalized an agreement for *reduction* of nuclear weapons. In fact the INF Treaty eliminates a whole class of such weapons (those in a range from 500 km to 5500 km). Negotiations for substantial reductions in *strategic* nuclear weapons are seriously underway. These negotiations are more complex and difficult, but if successful would reduce the actual nuclear threat to the homelands of the U.S. and the USSR for the first time (with the exception that the long-range Pershing missiles eliminated under the INF Agreement also threatened part of the Soviet Union).

During the past four decades, in spite of the lack of cooperation between the superpowers, there have been significant international agreements to control and eliminate the threat of nuclear weapons. After the chill of the Cuba missile crisis, the Partial Test Ban Treaty was ratified by the U.S., USSR, and the U.K. It has largely prevented ecosphere contamination from radioactive debris in the atmosphere, underwater, and in outer space. Since underground tests are more difficult and expensive, this treaty may have slowed nuclear weapon development to some extent.

The 1968 Non-Proliferation Treaty (NPT) now has over 130 nations as signatories and has contributed substantially to halting nuclear weapon development in other nations. Two decades ago there were dire predictions that by the present time there would be two dozen nations or more with

According to an OTA study,[18] Soviet cooperation in not taking offensive countermeasures may be essential for deployment of a defensive system:

> A major question is the degree to which defensive measures can outstrip offensive countermeasures in general. If one argues that the United States can maintain a 5 to 10 year technological advantage over the Soviet Union, the question reduces to : will current defensive technologies suffice to defeat countermeasures which are 5 to 10 years behind the state of the art? If the answer is not in the affirmative, or the U.S. cannot achieve and maintain this level of technical advantage, the prospect of reaching a regime wherein U.S. defenses can reach and keep superiority over Soviet offenses will be dim. *In such a case, U.S.-Soviet cooperation toward mutual deployment of BMD defenses would be essential to their successful deployment, their effectiveness, or both* (emphasis added). The Soviets would have to be persuaded that a stepwise transition to a BMD regime would be in their interest and preferable to engaging in an arms race with the United States.

These negotiations, as has been the goal of past arms control efforts, would have as their purpose to reach a defensive posture and at the same time achieve stability in the nuclear arms race.

If there were not a negotiated transition to a defensive posture, then the U.S. could well be in the uncomfortable position of unilaterally renouncing the ABM Treaty and/or the Outer Space Treaty. One can then foresee that negotiations on offensive arms limitations would become extremely difficult. Increased tension in U.S. relations with its allies and with Third World nations would also result. For example, the Non-Proliferation Treaty of 1968 is viewed by some non-nuclear-weapon states as requiring the superpowers to negotiate in good faith for nuclear arms reduction. The renunciation of such negotiation and of former agreements would increase the pressure for nuclear proliferation.

The importance of Soviet cooperation in assuming a defensive posture was recognized by President Reagan in his March 1983 speech, in which he offered to share BMD technology with the Soviets. Later, in a speech at Austin, Texas, on March 28, 1985, Secretary of State Schulz declared:

> As our [BMD] research proceeds and both nations thus gain a better sense of the future prospects, the Soviets should see the advantages of agreed ground rules to ensure that any phasing in of defensive systems will be orderly, predictable, and stabilizing. The alternative—an unconstrained environment—would be neither in our interest or theirs.

Progress in arms control in other areas is essential to create the political climate in which agreement with the Soviets on a transition from deterrence to a defensive posture could occur.

The Fletcher Panel, an advisory committee to President Reagan on strategic matters, concluded that in order to obtain defense dominance over the offense that is the premise of SDI, arms control cooperation with the Soviet Union would be required:[19]

> The ultimate effectiveness, complexity, and degree of technical risk in this system [SDI] will depend not only on the technology itself, but also on the extent to which the Soviet Union either agrees to mutual defense arrangements and offensive limitations, or embarks on new strategic directions in response to our own initiative.

3. POLITICAL ALTERNATIVES TO SDI

Those who are dissatisfied with the present situation of approximate nuclear parity and with the results of arms control so far view the strategic situation pessimistically. Their fears are generated by the Soviet military build-up in the 1970s. In addition, they point to the more accurate Soviet missiles which now threaten the U.S. ICBM forces, coupled with their increased activity in civil defense preparations, air defense, and BMD. For example, John C. Toomay writes:[20]

> . . . our efforts pale beside those of the Soviets, whose massive build-ups have now spanned over twenty years and have brought them parity in the number of strategic warheads and superiority in explosive power. Moreover, the Soviets have devoted them-

II. Motivation for Strategic Defense in the Reagan Administration

A. Technical Changes Since the ABM Treaty

President Reagan was clearly dissatisfied with the policy of MAD which he had inherited from his predecessors. But in addition, since the U.S. has better technical and industrial resources to pursue new developments than the Soviet Union, the tendency to engage in a new sort of technical race and possibly gain some strategic superiority thereby was in accord with a longstanding U.S. tradition as outlined in the Introduction. The temptation to pursue a technical solution to the nuclear predicament was especially strong in the face of the new situation that evolved in the 1970s of nuclear parity between the U.S. and USSR and improved missile accuracy.

From a strategic standpoint also the improved missile accuracy achieved by the United States in the 1970s was followed within a few years by the Soviet Union. In 1968 the circular error probable (CEP)* was 0.2 miles for the U.S. and 0.4 miles for the USSR. With these accuracies missile silos "hardened" to withstand overpressures of 2,000 pounds per square inch or better would have a high probability of surviving a missile attack. At present the MX missile has a CEP of about 0.058 mile and the Minuteman III about 0.13 mile. The CEP of a Soviet SS-18 is about 0.15 mile. Since for a given warhead explosive power the probability of a silo "kill" is proportional to the inverse square of the CEP (halving the CEP quadruples the kill probability), improvements in missile accuracy effected by both superpowers have resulted in an enhancement of kill probabilities of an order of magnitude or more. This in turn has eroded the survivability of ICBM missile forces. The Joint Chiefs of Staff of the U.S. estimated in 1986 that: "Today the most accurate versions of the SS-18 and SS-19 missiles are capable of destroying most time-urgent and hardened targets in an initial attack on the United States using multiple targeting."[1]

The vulnerability of second-strike forces outlined above is an important consideration for a deterrent posture and therefore provides motivation for ABM defense for missile silos. This will be discussed in more detail below.

Although ABM defense was discarded by the U.S. in favor of the ABM Treaty in the early 1970s, new technical developments were viewed by some in the 1980s as motivation for seriously considering an ABM defense. For example, improvement in laser technology, particularly the possibility of an X-ray laser activated by a nuclear bomb, provided a possibility of ABM defense in the sensitive boost phase (see section III).

B. Political and Moral Arguments for the SDI

The Reagan Administration came into office at least partly because the American public was persuaded that the military posture of the U.S. had been allowed to decline. Although this may have been the case in some areas, the number of deliverable strategic nuclear warheads available to the U.S. had in fact increased during the decade of the 1970s from approximately 3,300 in 1970 to about 9,500 in 1980.[2] The Soviets had a relatively larger increase, partly due to their introduction of MIRVs subsequent to the U.S. development, such that their deliverable warheads rose from about 2,000 to 7,000 in the same period.[3] These figures represent a new political fact—namely, that a period of nuclear parity in strategic arsenals between the superpowers had arrived by the end of the 1970s. Historically, the U.S. had always had a superiority in the number of deliverable strategic nuclear weapons. The achievement of nuclear parity had therefore an important psychological impact. Actually, even when the U.S. had a superiority of six times or better in strategic weapons during the

*CEP is defined as the radius of a circle at the target point in which statistically one-half of the missiles fall inside and one-half fall outside.

Cuba missile crisis, this did not mean in practice that there were not catastrophic risks involved or agonizing choices to be made by the Kennedy administration.[4] After that experience the Soviets vowed never to be caught again in a position of strategic imparity. By 1980 they had succeeded in their "catch up" program to the limits imposed by the SALT I Treaty.

A stated above, during the 1970s missile accuracies had also improved substantially. The Soviet strategic arsenal was therefore enhanced both in numbers and in effectiveness. The political slogan "the window of vulnerability" referred to this new vulnerability of the U.S. ICBM forces. It also could have been argued that the Soviet ICBM forces were even more vulnerable because of the greater accuracy of U.S. missiles and also because their strategic force configurations have 75 percent of their nuclear arsenal in ICBMs, whereas it is only about 25 percent for the U.S. However, this reality did not enter into the domestic political debate to any extent, the emphasis being on the vulnerability of U.S. ICBM forces. Americans perceived themselves as being newly vulnerable to Soviet attack.

Early in the Reagan Administration there was considerable open discussion of "protracted nuclear war" and "prevailing in a nuclear war." This official policy had already begun years earlier and was revised under the Carter Administration as outlined in Presidential Directive 59. The Reagan Administration prepared SIOP-6, a new revision of the single integrated operational plan of the U.S. armed forces for nuclear war in which the concept of limited nuclear war and flexibility of nuclear options was stressed.

It was the fact of nuclear parity, coupled with the public discussion of nuclear policy by the Reagan Administration, that led to a grass-roots campaign opposing this policy which became known as the "nuclear freeze movement." During the 1982 elections several states passed resolutions asking that nuclear weapons and their development be frozen by the U.S. and the Soviet Union at the current levels. The "freeze" had considerable popular appeal since it provided a simple action to reverse the perceived trend in the nuclear arms race. It was presumably a first step to reduction in nuclear arms. This political movement was contrary to the political philosophy of the Reagan Administration of achieving "peace through strength," which assumed that the Soviets would not agree to nuclear arms control unless the U.S. military posture were strengthened.

Given the aversion of all presidents, and President Reagan in particular, to the idea of MAD and also the political pressure of the nuclear freeze movement, the prospect of a complete change in nuclear policy from MAD to a defensive posture had considerable political appeal. In fact, after the SDI proposal was made in March 1983, the freeze movement was effectively undermined. The SDI offered not merely a freeze but rather to make nuclear weapons impotent and obsolete. It also proposed a presumed defensive posture that would only destroy incoming missiles, not enemy populations. The SDI was therefore on higher moral ground than MAD. In fact, the Catholic bishops of the United States during this same period had courageously opposed deterrence as "not an adequate strategy as a long-term basis for peace; it is a transitional strategy justifiable only in conjunction with resolute determination to seek arms control and disarmament."[5] It is possible that the first draft of the bishops' pastoral letter could have influenced the president in his search for an alternative to deterrence.

President Reagan in announcing the shift in policy in a television speech apparently did so with little of the consultation with political and technical experts that such a major change would normally have involved. The result has been a controversial program from its inception.

It should be remembered that as the SDI program is pursued and several billion dollars of research and development funds are expended annually, an industrial constituency is produced which provides its own self-serving motivation for continuation of the program. Although research programs in BMD had been pursued for years, the prospect of carrying such programs into development and deployment is certainly attractive to firms that would be involved. Thus, after a period of time, a certain momentum for the program is produced that is difficult to arrest even if future evaluations become more negative.

Christoph Bertram addresses the threat of SDI to transatlantic relations as follows:[16]

> The final question is this: is it worth risking the future of the Western Alliance for the sake of uncertain and doubtful technological promises? Is it worth, on such shaky foundations, instilling in Europeans the fear that they will be left to themselves in the face of Soviet military power, and in Americans the illusion that a European war would not profoundly shake their own security? Since the birth of the Alliance, the Soviet Union has understandably sought to undermine the unity of the West. So far, it has not succeeded; Western cohesion has remained strong.
>
> Ironically, those who believe that the world can be made safe against nuclear attack will themselves end up undermining this cohesion.

2. SDI AND THE ARMS CONTROL PROCESS

Deployment of SDI would require revision or repudiation of the ABM Treaty. Its deployment might also violate the 1967 Outer Space Treaty, which forbids "placing in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction."

At the Summit Conference with Chairman Gorbachev at Reykjavik in 1985, President Reagan's insistence on the SDI program stood in the way of substantial agreement in principle on the *reduction* of strategic nuclear forces. It also was a barrier subsequently to negotiations for the reduction or elimination of intermediate-range nuclear missiles in Europe and the Far East, until Gorbachev removed his previous insistence that no negotiations were possible until the goals of the SDI program were placed in conformity with the ABM treaty (allowing research only). At present the superpowers agree in principle on a *50 percent reduction* in strategic nuclear weapons. The limitations on SDI research as provided by the ABM Treaty will be a key part of the negotiations on reductions. The threat of SDI deployment could provide a fatal stumbling block to the success of the negotiations.

Continued pursuit of population defense by SDI will bar any meaningful limitation on antisatellite weapons (ASAT). Sophisticated space-based BMD systems, such as lasers and particle beams, automatically would have extensive ASAT capabilities. This is the case since satellites are more vulnerable than warheads and they also travel predictable paths. The converse is also valid: research on ASAT provides a "loophole" for BMD development in space. Such development is forbidden by the ABM Treaty, but can be undertaken as an ASAT program.

It is in the interest of the United States and the Soviet Union to adhere to the ABM Treaty, as will be discussed below, but also it is in their mutual interest to sign a treaty forbidding ASATs. In a nuclear crisis situation, intelligence gathering as provided by satellites would be an urgent need for both East and West. Fears generated by lack of knowledge could make conflict more probable through misinformation. In the Cuba missile crisis ready and reliable information was crucial for President Kennedy's decisions, and presumably it was also crucial for the Soviets.

For NATO planners an ASAT treaty would be helpful, as described by Gottfried and Lebow:[17]

> . . . if we look ahead into the next decade NATO's vulnerability to Soviet ASATs is likely to increase in proportion to its growing reliance on satellite-based systems for battle management. In coming decades, NATO may have radar satellites for theater-wide surveillance of aircraft. The U.S. Navy may also become increasingly dependent upon satellites to counter stand-off threats to its carrier groups posed by Soviet aircraft and submarines. NATO forces, down to the platoon level, are expected to use Navstar satellites to improve delivery of firepower.

The SDI program is intimately involved with arms control not only because it threatens existing and future arms control agreements, but also for its own success. If SDI were to be deployed, Soviet cooperation and the arms control process would be essential in order to avoid an open-ended escalation of the nuclear arms race. Soviet cooperation was one of the conditions that Margaret Thatcher imposed in exchange for Britain's cooperation with the SDI program (see above).

Jacquelyn Davis and Robert Pfaltzgraff argued that the perceived U.S. strategic vulnerability in ICBM forces weakens extended deterrence, making it difficult for the U.S. to implement the selective options to give effect to the U.S. nuclear guarantee, especially in view of increased Soviet BMD capacity.[10] However, the U.S. administration has been reluctant to assign SDI as a response to the "window of vulnerability" of ICBM forces. It is also the case that the U.S. still retains a significant strategic force in nuclear submarines and bombers for retaliatory purposes.

Europeans have been less than enthusiastic about the SDI program because they see it, if successful, as providing protective shields for the U.S. and the USSR, thereby increasing the probability that Europe would become the nuclear battleground between the superpowers. Since most Europeans favor progress in arms control, they see the SDI program as an impediment to such progress, since the Soviets are in strong opposition to it. For example, Louis Deschamps writes: "European strategic analysts reacted very quickly and for the most part negatively to the President's speech."[11] Both the German minister of defense, Manfred Woerner, and the German foreign minister, Hans-Dietrich Genscher, expressed concern that it would be intolerable for one of the superpowers to gain a one-sided lead in setting up such an SDI system and called on the U.S. to negotiate with the Soviet Union.[12] The French representative at the Geneva Disarmament Conference on June 12, 1984, was even more negative, stating: ". . . a situation in which each of the principal powers sought to make its territory entirely invulnerable to retaliation, yet without any certainty of succeeding, would be fraught with danger: simply announcing the intention to go forward with the development of such systems *constitutes in itself a renewal of the offensive arms race* . . ."[13] In his statement the French representative also affirmed the French commitment to deterrence, "which has played an essential role in maintaining peace in Europe," and to the ABM Treaty.

British endorsement of SDI by Margaret Thatcher's administration was contingent on reaching an accord with President Reagan at Camp David (December 1984).[14] In exchange for British support of SDI, Reagan agreed that:

1. The United States' aim is not to achieve superiority, but to maintain an East-West balance.
2. Deployment of ballistic missiles defense will have to be a matter of negotiation with the Soviet Union.
3. The SDI should enhance, not undermine, deterrence.
4. The SDI approach should be aimed at achieving greater East-West security with reduced levels of offensive systems on both sides.

Given the cautious or downright negative opinion of the SDI voiced by many members of NATO, economic incentives have been cultivated quite deliberately by the the Department of Defense to instill interest. This has taken the form of offers of SDI contracts to firms of NATO countries. Such contracts offer not only direct monetary rewards, but also give the participating nation possibilities of "spin-off" of advanced technologies. Recently, however, the Congress has passed legislation requiring that U.S. contractors be given preference in contract awards. In any case, the aggregate dollar amount of foreign contracts has been only a few hundred million dollars out of an SDI budget of almost four billion dollars annually.

Although all the major European countries wished to see their companies participate in the SDI research program and the Reagan Administration sought such response to show SDI support, there was no unified approach on how this might be accomplished. Only two, Great Britain and West Germany, have signed an accord for this purpose. The French government has declined the offer to participate.

According to Hyland, the Western Alliance was to some extent in need of reassurance even before the advent of SDI:[15]

> American policy thus has two immediate objectives: first, to restore a credible strategic and European defense posture that is not only persuasive to the Soviet Union, but also reassuring to Europe, and second, to accomplish these ends while shoring up an increasingly fragile Western unity.

C. Current SDI Policy

Subsequent to the president's March 1983 speech, the Reagan Administration has deemphasized population defense, putting it in the category of a long-term goal. The 1985 Department of Defense Report to Congress[6] on the SDI stated: "In pursuing strategic defenses the U.S. goal has never been to eventually give up the policy of deterrence, but to enhance it." The report stresses that SDI is a broad research program "not based on any single or preconceived notion of what an effective defense system would look like."

According to this report, "the SDI research program will be conducted in a manner fully consistent with all U.S. Treaty obligations. The ABM Treaty prohibits the development, testing, and deployment of ABM components that are space-based, air-based, or mobile land-based." The report stated further, "as Ambassador Gerard Smith, chief U.S. negotiator of the ABM Treaty, reported to the Senate Armed Services Committee in 1972, that agreement does permit research short of field testing of a prototype ABM system or component. This is the type of research that will be conducted under the SDI program."

Subsequently, however, the ABM Treaty has been perceived by the administration as needing a new "broad interpretation" concerning field testing as pressures from the SDI program mount.[7] Ambassador Smith, however, remains firm in his opinion that such legalese is not in accord with the negotiations that led to the ABM Treaty.[8] Thus we see the beginnings of efforts to circumvent and perhaps eventually abandon the ABM Treaty, which increasingly will stand in the path of the SDI program. Those responsible for the program very naturally wish to proceed beyond the phase of laboratory research in their effort to achieve the goal of population defense set forth by the president.

Defense Secretary Caspar Weinberger defined the present rationale for SDI succinctly as : "Soviet breakthrough, Soviet breakout, and the very real possibility that American science and technology will achieve what appears to some to be an impossible dream."[9] Here, "breakthrough" refers to the continued Soviet buildup of both offensive and defensive nuclear arms creating the present situation of rough nuclear parity. "Breakout" refers to the possibility of Soviet renunciation of the ABM Treaty and subsequent rapid deployment of an effective ABM system because of their continuing and well-funded effort on BMD.

Mr. Weinberg's arguments concerning breakout do justify the prudent program of BMD research, which has been ongoing for two decades. "Breakthrough" is a matter of political judgment concerning the danger posed by the Soviet nuclear arms build up, particularly in the last decade. The current scientific and technological situation concerning SDI will be discussed in some detail below. Briefly, it does not presently give cause for optimism concerning population defense.

Notes

1. *United States Military Posture: FY 1987,* The Organization of the Joint Chiefs of Staff, 21.
2. U.S. Office of Technology Assessment (OTA), *Ballistic Missile Defense Technologies* (September 1985), 53.
3. *Ibid.*
4. George Quester, *Nuclear Diplomacy, the First Twenty-Five Years* (Dunellen, N.Y.: 1970).
5. National Conference of Catholic Bishops, *The Challenge of Peace: God's Promise and Our Response,* Office of Publishing and Promotion Services, United States Catholic Conference, Washington, D.C., May 1983.
6. *Report to Congress on the SDI,* U.S. Department of Defense, 1985.
7. Handler Chayes, "Testing and Development of Exotic Systems Under the ABM Treaty: The Great Reinterpretation Caper," *Harvard Law Review* 99 (June 1986): 1956.

8. *United States-Soviet Relations, Hearings before the Senate Committee on Foreign Relations,* 98th Congress, 1st Session, 1983, 180 (prepared statement by Hon. Gerard C. Smith):"Very briefly, my understanding of the ABM Treaty is that . . . development, testing, and deployment of sea, air, space, or mobile land-based systems was banned; if land-based systems are developed using so-called 'exotic' components—lasers, particle accelerators, etc.—they could not be deployed unless the treaty was amended."
9. C. Weinberger, "U.S. Defense Strategy," *Foreign Affairs* 64 (Spring 1986): 675.

Robert Gates, the Defense Department's deputy director for intelligence testified that "The Soviets still lack effective means to locate U.S. ballistic missile submarines at sea. . . . We do not believe there is any realistic possibility that the Soviets will be able to deploy in the 1990s a system that could pose any significant threat to U.S. ballistic missile submarines on patrol."[7]

The strategic triad still provides crisis stability because of its synergistic capabilities according to the report of the Scowcroft Commission.[8] The SLBMs, ICBMs, and strategic bombers have the function that if one side of the triad is attacked, both of the other two legs of the triad plus the remainder of the attacked side would be available for retaliation.

The Soviet forces now also possess considerable redundancy. They have SLBMs on patrol, a much larger force of ICBMs, some of which could survive a first strike. Their strategic bomber force is considerably less than that of the U.S.

Defense of some ICBMs alone leads to crisis stability in that it does not threaten the ability of the opposing side to deliver a nuclear retaliatory strike, and at the same time enhances that ability for the defense. How much crisis stability would be achieved by ICBM defense depends upon a judgment as to the effectiveness of SLBM and bomber forces as well as an assessment as to the vulnerability of ICBMs to attack with the new missile accuracies available. It is also possible that ICBM defense would also defend command and control structures that are essential for a retaliatory strike and generally for command of the nuclear exchange.

In the case of population defense, the original purpose of the SDI, crisis stability would be achieved if an extremely capable defense were available. This is a level of defense where few or no military targets or civilian targets could be destroyed in a first strike by either side. An aggressor would then have little incentive to attack. However, if nuclear weapons were smuggled into cities, crisis instability could again occur, since retaliatory capabilities would not necessarily exist.

In the transition period from no defense to extremely capable defense, serious crisis instabilities could arise. Since this period would last many years, the transition era is one of considerable risk. If one side had the ability to assure survival of *most* of its cities, then the situation arises, as described by Payne:[9]

> A third potential source of instability could arise during that phase of a transition when strategic defenses would be capable of effective area defense against an offensive threat that had been degraded by a previous first strike. Assuming that a comprehensive defense cannot spring forth fully formed, like Athena from the head of Zeus, both superpowers are likely to pass through such a transitional phase unless precautions are taken well in advance. The possibility that they might pass through such a phase (roughly) simultaneously makes this situation potentially even more dangerous. The premium for striking first, and the penalty for waiting, could be powerfully destabilizing factors—particularly during an acute crisis.

Because of the strategic instabilities generated by unilateral deployment or hostile deployment of effective area ABM defenses, *it is essential that deployment of SDI either for population defense or ICBM defense, if it should be desirable in the future, be done with the full cooperation of the Soviet Union and the United States.*

B. Political

1. SDI AND TRANSATLANTIC RELATIONS

Europeans are skeptical of the political impact of SDI. The aim of SDI seems to them to point to reducing the role of nuclear deterrence in Western security, making imbalances in conventional forces more critical for European security. They fear further that if both superpowers acquire a high degree of BMD, that is if each succeeded in making their own territory invulnerable to destruction in nuclear attack, they would be tempted to place a higher hostage value on each other's half of Europe, making nuclear or conventional war more likely in Europe.

2. ENHANCED DETERRENCE

Since the defense of populations from ballistic missile warheads will not be realized in the next decade, if ever, the emphasis of SDI is shifting increasingly toward enhanced deterrence. That means that an ABM defense of ICBM forces would render them less vulnerable to a first strike. and the surviving ICBMs could then deliver a retaliatory strike, thus enhancing deterrence. In fact, it is the view of some defense analysts that BMD would contribute to deterrence by creating uncertainty as to the efficacy of their ICBMs for the offense planners of opposing forces rather than relying only on the threat of retaliation.[4] As proposed by Davis,[5] "a compelling case can be made that traditional systems, capable of exercising preferential defense firing doctrines and making use of close-in battle space by virtue of target hardness, are ideal for military targets such as ICBM silos." That is, since ICBMs are only vulnerable to a direct hit, they can be located close together and defended by ABM as a group. In addition, the defense may choose to concentrate its forces on some ICBMs and sacrifice others to assure the survival of a significant retaliatory force. Davis sees the development of ICBM terminal defense (within ABM Treaty limitations) as a hedge against a possible Soviet breakout from the ABM Treaty, in terms of a quick deployment of BMD for a substantial number of their land-based missiles.

Successful development of BMD of ICBM bases would restore the strategic stability to something like it was in the early 1970s when missile accuracies were insufficient to threaten the opponent's land-based missiles. The development of improved missile accuracies with MIRVed warheads, which has led to instability, could have been prevented by a verifiable treaty, but this was not done. At this point, with arsenals actually containing accurate missiles on both sides, a treaty limiting accuracy is no longer verifiable.

The use of mobile missile sites is also a possible way to enhance first-strike invulnerability of ICBMs. It is not clear which method would be the most cost effective.

This constant focus on ICBM vulnerability creates a warped sense of danger in the U.S. and a false atmosphere of urgency. The fact is that the bomber and submarine legs of the U.S. strategic triad are relatively invulnerable because of launch-on-warning for the former and non-locatability for the latter. Since the ICBM forces make up about 25 percent of the U.S. strategic forces and some would survive a first-strike attack, an argument can be made that the majority of U.S. warheads would still be deliverable even in the face of a first strike, and therefore BMD defense of ICBMs is not necessary. Such an argument assumes that submarine forces would be largely at sea because of an international crisis situation. It should be recalled that the firepower of even one nuclear submarine is sufficient to destroy the USSR or the U.S. if the warheads reached their targets.

3. CRISIS STABILITY

A nuclear war could start through escalation of a U.S.-Soviet confrontation. Such confrontations have already occurred during the 1973 Middle East conflict, the Cuban Missile Crisis, and the Berlin blockade. The crisis could develop through a direct confrontation, as in the case of Berlin, but is more likely to occur because of the actions of some third country perceived to be of vital interest to both of the superpowers. In deciding whether to develop and deploy a new weapon system, an important question is whether the new system will add incentives or disincentives to employ nuclear weapons in a crisis. This concept is discussed in some detail by the 1985 OTA study.[6]

At present, without a deployed SDI or threat of such deployment, the strategic balance between the U.S. and USSR is reasonably stable despite considerable counterforce capabilities on both sides. Each side has the capability to inflict a devastating retaliatory strike. U.S.-Soviet crisis stability is enhanced by assuring that retaliatory forces are invulnerable to a first strike. Not only the retaliatory forces need be survivable, but also their associated command and control facilities, and the missiles must be able to reach their targets in substantial numbers.

Submarine forces add considerably to crisis stability since they are not at present locatable.

III. Present Assessment of SDI—Technical Considerations

A. Summary of Criteria and Some Physical Concepts

The following technical discussion depends critically on how one defines SDI. A careful distinction should be made between the original proposal of President Reagan for *defense of populations* and later proposals for *ICBM defense*, although still labeled by some as the SDI program. These two concepts are discussed in sections IIIC and IIID respectively. Section IIIE discusses the possible use of SDI hardware for offensive purposes. Finally, a system must be not only technically feasible, but also must meet economic and strategic criteria (the Nitze criteria). These criteria are addressed concurrently with the technical analysis.

There are some physical concepts that are essential to understand the technical analysis and recur frequently in different systems. For the reader's convenience they are also listed in the glossary at the end of the paper for easy reference. The concept of *energy* is important. The unit here is the *joule*. *Power* is determined by the *rate* at which that energy is delivered. Power is measured in *watts*. Thus a 60-watt electric light bulb will consume 60 joules of energy every second. That is, the watt, a unit of *power* is equal to energy consumption or delivery at the rate of one joule per second. The amount of energy delivered per unit area or *energy flux* is the criterion for assessing the capability of a laser or particle beam to destroy a missile or warhead in BMD. Approximately 20,000 joules per square centimeter are needed for such a "kill." We can label this the "kill flux."

In discussing the power requirements needed to produce a kill flux in a reasonable time (a few seconds), it is convenient to use the unit *megawatt*, or one million watts. A typical electric power station delivers several hundred megawatts.

The speed or velocity of ICBMs or ABM devices is often measured in kilometers per second. One kilometer per second is about equal to 2,300 miles per hour, or about four times the speed of usual commercial jet aircraft.

B. Nitze Criteria

Cost exchange analyses are essential in evaluating a proposed defensive system. If it costs the offense less to counter a defense than it costs the defense to deploy one, it is disadvantageous usually to proceed with the defense. The concept of "cost effectiveness at the margin" as explained above was enunciated by Paul Nitze, a senior specialist in arms control matters for the Reagan Administration, in a speech before the Philadelphia World Affairs Council in February 1985. Mr. Nitze also stated an additional criterion for an acceptable BMD system: "The technologies must produce defensive systems that are survivable; if not, the defenses would themselves be tempting targets for a first strike. This vulnerability would decrease rather than enhance stability."[1] For example, a space station could be followed by a space mine to be detonated upon radio command. To decrease vulnerability a "keep out" zone might be enforced for each space platform. Such actions, as well as the deployment of the space mines, would constitute in themselves sensitive areas of confrontation between the superpowers, and in themselves would contribute to instability.

C. Defense of Populations

We discuss first the present status and evaluation of the original proposal of President Reagan to provide a complete defensive shield against incoming ballistic missiles in order to "make nuclear weapons impotent and obsolete," as he proclaimed in his speech of March 1983. Secondly, we consider BMD of ICBM sites only.

The Strategic Defense Initiative (SDI) for population defense is usually conceived in terms of a layered defense corresponding to at least three distinct phases in the trajectory of an intercontinental ballistic missile. Since the trajectory is in part in outer space, the system has been dubbed "Star Wars" by some of its critics. The first or *boost phase* occurs during the first 3 to 5 minutes of the missile's flight while its rockets are firing. Defense at this phase is possible because the missile produces a large infra-red signal for detection by satellites. Further advantages of the boost phase are that the missile is moving relatively slowly and that it has not as yet deployed its up to ten or more individual warheads.

After the rockets stop firing, the missile enters *midcourse phase*. Here the "bus" coasts in space above the atmosphere and has a speed of 5 or 6 kilometers per second. Early in the midcourse phase, the bus deploys its warheads and possibly ten times as many decoys plus metal chaff or other deceptive devices. The task of the defense is now more difficult since the true warheads must be found among the decoys and tracked and killed possibly in an environment containing nuclear explosions or other effects that blind sensors. Since the warheads are relatively cool, their detection by infra-red signals, while possible, is much more difficult than in boost phase. An advantage is that midcourse lasts for approximately 20 minutes, so there is more time for defensive action than during either the boost or terminal phases.

The final phase is the *terminal phase* which occurs as the warheads and decoys reenter the atmosphere. The latter will quickly burn up the decoys, revealing the true warheads. However, the warheads are now descending at about 6 kilometers per second so that the entire terminal phase lasts less than one minute. For "soft" targets, such as cities, the warheads must be destroyed at elevations greater than 30 kilometers to avoid retinal damage to populations, incendiary fires, and blast damage, if the warheads are "salvage fused"—that is, set to explode if interfered with. For "hard" targets, such as missile sites, destruction of the incoming warhead can occur within one kilometer of the target, giving more time for offensive action.

Efficient transfer of information concerning possible targets from previous defensive layers would be very useful for effective terminal defense, which has only tens of seconds for response.

1. BOOST PHASE

This layer is essential for a nearly perfect defense, since success here would make the task of other layers much easier. The disadvantages of boost phase are that only a short time is available for targeting and kill (3 to 5 minutes), and that, since the earth is round, the rocket exhaust can only be seen from space. If the boost phase is to be attacked from battle stations in space which are in low earth orbit, then it must be recognized that these stations orbit around the earth with a period typically of about two hours and hence do not stay over the target. This gives rise to the concept of the "absentee factor," which multiplies the number of battle stations needed to assure that at least one is effective at any point and at any time over the attacker's country.

a. Kinetic Energy Weapons

We now discuss briefly some boost-phase proposals. The first are *kinetic energy weapons*. By these we mean *projectiles* that are given enough energy to destroy a missile and that can reach it within the missile's burn time, 3 to 5 minutes. They have been advocated with enthusiasm by some SDI proponents, in particular the High Frontier organization, some of whom[2] propose immediate deployment of such a boost-phase system. Here we consider a battle station in 400-kilometer earth orbit (just high enough to avoid the earth's atmosphere) which has rockets that achieve 5 kilometers per second velocity. This velocity is considerably greater than rockets that are presently available that are advocated by High Frontier. Their velocity is only about 1 kilometer per second.

In the 300 seconds, say, for a Soviet SS-18 to launch, a rocket of 5 km/sec will travel 1,500 kilometers. This range of action requires a minimum of about 20 battle stations because of the absentee factor.[3]* This analysis assumes that there are on the average 2.5 battle stations over the

*Drell et al. point out that the absentee factor can be estimated as follows: four planes, each with thirteen satellites in low earth orbit separated from one another by 3,000 km, will keep each point of the earth's surface at the latitude of Soviet territory, always within a 1,500 km operating range of at least one satellite. Since the Soviet ICBM fields are spread out, between 2 and 3 of these satellites are always on station, corresponding to an approximate absentee ratio of 5 percent on station.

IV. Present Assessment of SDI—Strategic and Political Considerations

A. Strategic

1. SOVIET ABM PROGRAMS

The Soviet BMD effort is one of long standing. According to Holst and Schneider,[1] "there is a rather strong [Soviet] tradition of substantial expenditures on active strategic defense systems. This tradition has created a strong active defense lobby within the Soviet decision-making structure." This tradition resulted in the deployment of the Galosh system for the defense of Moscow. The ABM Treaty was negotiated to permit one ABM site and the Soviets have chosen steadily to improve the Moscow defense. The system is limited by treaty to 100 interceptors and has an associated phased-array radar for battle management. The system uses nuclear-tipped missiles and during the 1980s an endo-atmospheric capability was added, giving the system a two-layered defense structure.

According to *Soviet Military Power, 1987*,[2] the "Hen House" radars located on the periphery of the Soviet Union, and permitted by the ABM Treaty, have been continuously upgraded since the signing of the treaty. In addition, according to this source, "the Soviets are deploying a series of large phased-array radars along the Soviet borders. These radars provide 'significantly improved targeting and tracking capabilities' for incoming ballistic missiles and add redundancy to the Hen House network." Although these radars are permitted by the ABM Treaty the Krasnoyarsk radar, located well within the Soviet borders, is not, as discussed above. *Soviet Military Power, 1987* claims that "the growing network of large phased-array radars is of particular concern when linked with other Soviet ABM efforts. These radars take years to construct and their existence could allow the Soviet Union to move quickly to deploy a nationwide ABM defense." This source also expresses concern over testing of air defense radars and their interceptors in an ABM mode. The U.S. has protested these tests, but the Soviets "have not fully accommodated U.S. concerns."

The advent of an endo-atmospheric, high-acceleration interceptor for use in the Moscow defense, coupled with portable radar, has been termed the ABM-X-3 system. It is suitable, in principle, for fairly rapid deployment.

A balanced perspective on the Soviet ABM efforts and the ABM-X-3 system is given by Stevens:[3]

> To those who perceive the Soviet BMD program as a vigorous undertaking only searching for the right technology and the right strategic opportunity to abandon the (ABM) treaty, this development appeared provocative indeed. To those less persuaded about the capabilities of the new system, it appeared that the Soviet Union still had a long way to go before it would really be ready to make a choice for further deployment. But from either point of view, the Soviet Union had made a significant step forward: it now had a system that appeared to have characteristics appropriate for widespread deployment.

This source further states that "it is unlikely that a truly transportable radar can do an adequate job of long-range search and acquisition against the very low radar cross section that characterizes newer U.S. ICBM reentry vehicles. . . . This recitation of the theoretically derived implications of the ABM-X-3 is simply that—theoretical." In other words, the transportable ABM-X-3 system would not be able to track and destroy the latest U.S. warheads as they enter Soviet air space.

For the Soviets to deploy a BMD system, they would have to abandon the ABM Treaty. At the present time this would negate a vigorous and successful Soviet effort for arms reductions (for example, the START negotiations for reduction of strategic missiles). On the other hand, the U.S. SDI effort, if pursued with vigor and especially if deployment is threatened, might trigger a Soviet deployment response.

8. Dietrich Schrooer, *Directed Energy Weapon Systems*, Adelphi Paper #221 (London: International Institute of Strategic Studies, 1987).
9. *APS Report,* 93.
10. *APS Report,* 78.
11. Ashton Carter, *loc. cit.*
12. *APS Report,* 384.
13. *APS Report,* 89, 93.
14. *APS Report,* 270.
15. *APS Report,* 271.
16. S .D. Drell and M. A. Ruderman, *Infrared Physics* 1 (1962): 189.
17. *Review of Scientific Instruments* 52 (1982): 503.
18. *IEEE Trans. Nucl. Sci.* NS-30 (1983): 1408.
19. R. Z. Sagdeev and S. N. Rodionov, *Space-Based Anti-Missile Systems: Capability Assessments,* (Moscow: Academy of Sciences of the U.S.S.R., Space Research Institute, March 1986): 59.
20. *APS Report,* 144.
21. *APS Report,* 350.
22. *APS Report,* 152.
23. "Hypersonic Interceptor," *Aviation Week and Space Technology* 119 (7 Nov. 1983): 44.
24. Ballistic Missile Defense Technologies (U.S. Government Printing Office, September 1985), 200.
25. *Ibid.*, 209.
26. David L. Parnas and Danny Cohen, *SDI: Two Views of Professional Responsibility, IGCC Policy Paper No. 5* (La Jolla, CA: IGCC, 1987), 1.
27. Herbert Lin, "The Development of Software for Ballistic Missile Defense," *Scientific American* 253 (December 1985): 46.
28. K. B. Payne and C. S. Gray, "Nuclear Policy and the Defensive Transition," *Foreign Affairs* 62 (Spring 1984): 820.
29. William A. Davis, Jr., *Asymmetries in the US and Soviet Strategic Defense Programs: Implications for Near Term American Deployment Options* (Cambridge, MA, and Washington, DC: Institute for Foreign Policy Analysis, 1986).
30. OTA, *op.cit.*, 201.
31. Barry M. Blechman and Victor A. Utgoff, "The Macroeconomics of Strategic Defenses," *International Security* 11 (Winter 1986-1987): 33.
32. *Space Strike Arms and International Security, Report of the Committee of Soviet Scientists for Peace Against the Nuclear Threat* (Moscow: 1985), 7.

Soviet Union at any time, because the Soviet missile fields are spread out. Since there are 1,400 Soviet ICBMs, each battle station must have 560 rockets. To provide 15 kg of guided projectile, about 160 kg of rocket fuel is needed.[4] Therefore a total weight of 160x560 kg, or 89,600 kg is needed per battle station. This is about 5 space shuttle loads. So 100 space shuttle loads are required to fuel all 20 battle stations. Since a space shuttle flight costs about 100 million dollars, the cost to place only the necessary fuel in orbit would be approximately 10,000 million dollars, or 10 billion American dollars. The cost of the entire system would greatly exceed the cost of just placing fuel in orbit. Five km/sec fast rockets would need to be developed and deployed in space. A complex battle management system to find, aim the rockets, and provide kill assessment would have to be developed and deployed as well as the space-based infra-red sensors to detect the missile exhaust. The above estimate assumes a perfect "kill" capability. A conservative system would need some redundancy in the fast rocket arsenal. The overall cost of the system would therefore be several times the cost to place fuel in orbit—at least 30 billion dollars.

Since the cost for the Soviets to produce an ICBM is about 10 million dollars, the cost to double their present ICBM forces, i.e., add another 1,400 ICBMs, would be 14 billion dollars. Clearly this kinetic energy boost-phase system fails the Nitze criterion of being cost effective at the margin. The space-based assets are also vulnerable to space mines that could follow the battle station and be detonated by radio command, or to antisatellite weapons (ASAT).

If the Soviets used their new SS-X-24 missile with a boost phase time of 200 seconds, then the range of the rocket station is reduced to 1000 km and 45 battle stations are needed, with a cost to fuel in orbit of about 22 billion dollars. For the High Frontier proposal with rocket velocities of only 1 km per second given by present technology, and hence with a range of 300 km for the SS-18 boost phase, about a thousand battle stations would be needed for adequate coverage of the SS-18 missile system, and with no effectiveness at all for the SS-X-24 missiles. In the latter case even if the 1 km/sec rockets were fired straight down at the rising SS-X-24 boosters, they could not reach them before the booster exhaust ceased, so that the infra-red sensors would be inoperative. In view of these considerations, Ashton Carter[5] concluded that "It would appear that the technical characteristics of the High Frontier scheme result in a defensive system of extremely limited capability for boost phase intercept of present Soviet ICBMs and with no capability against future MX-like Soviet boosters, even with no Soviet efforts to overcome the defense."

Even so, there has been pressure for early deployment of a kinetic-energy boost-phase system by some proponents. However, according to an article in the San Francisco Chronicle,[6] "Top weapons experts at the Lawrence Livermore National Laboratory estimate that advanced Soviet missiles cannot be stopped by the Star Wars defenses the Reagan administration wants to set up in the early to mid-1990s." In the same article Sidney Drell is quoted as saying that "This means analysts all the way across the spectrum found early deployment with kinetic kill vehicles won't work."

b. Directed-Energy Weapons—Lasers

The following boost-phase systems are in the classification of *directed-energy weapons*. A detailed report of a two-year study of directed-energy weapons by a committee of eminent scientists of the American Physical Society (APS) has recently been issued.[7] The discussion below of the boost phase is indebted to this study and is confined to various types of laser weapons.*

Particle-beam weapons** are also a possibility and are considered in the midcourse phase. For an excellent review of directed-energy weapon systems the reader is referred to a recent article by Dietrich Schrooer.[8]

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*Lasers form very parallel intense beams of electromagnetic energy to produce a "kill flux." These beams can be in the form of visible light, longer wavelengths that are invisible, such as infra-red radiation, or shorter wavelengths that are also invisible, such as ultra-violet (excimer lasers) or X-ray lasers.

**Particle beams would be formed by accelerators based in space. The accelerators would create beams of atoms, usually hydrogen atoms, that would travel at speeds approaching the velocity of light and could be focused to a spot to provide a "kill flux."

(1) Chemical Laser A particular directed-energy system is a space-based chemical laser. Such a laser derives its beam energy from a chemical reaction. In the case considered below this reaction is one of deuterium* and fluorine gases. The deuterium fluoride laser emits radiation of 3.8 micron** wavelength in the infra-red. It is a promising candidate because the atmosphere is transparent to this wavelength. If the atmosphere is not transparent to a directed energy beam, the attacker can arrange for the boost phase to occur within the atmosphere and therefore its missile would be shielded from destruction by such a beam. (Such is the case for the X-ray laser, for example.) A laser in orbit with an infra-red beam of 100 megawatts and a 5.6 meter diameter optically perfect† mirror could deliver 20 kilojoules of energy per square centimeter in one second at a range of 1,500 km. This is deemed sufficient to "kill" the missile by thermal shock or melting (kill flux). If a laser energy burst lasting one second is used, then each such burst must contain 100 million joules of energy.

If two seconds are required to find, track, aim, and kill a missile, then in the 300 seconds of boost phase for an SS-18, 150 missiles could be theoretically "killed." For 1400 missiles with one hundred million joules of energy needed for each "kill," the total energy required is 140,000 million joules. To "kill" 1400 missiles, 10 battle stations are required since each station can kill about 150 missiles, but due to the earth's rotation under the battle stations only 5 percent of the stations would be on target at any particular time so that actually 200 battle stations are needed. Using the optimistic figure of 500 joules of laser beam energy per gram of fuel, one obtains a fuel requirement of 5,600 metric tons.‡ This would cost about 28 billion dollars to put in orbit. The total cost of the system is estimated by the Pentagon to be about 500 billion dollars. However, in view of the extensive development needed, such an estimate must be regarded as dubious.

The chemical laser system has at present been extensively tested only with hydrogen fluoride, which lases at 2.7 micron where the atmosphere is opaque. Using such a laser would double the number of battle stations. This is because the time available for kill would be the time the missile is above the atmosphere, which is only about one-half the total time of rocket burn for the present SS-18 missiles. Even the hydrogen fluoride laser has only been tested in the laboratory at one megawatt. A substantial increase of power level is needed as well as conversion to a deuterium fluoride system in order to conform to the proposed BMD system discussed above. Although possible in principle, this would require intensive research and development effort. Scaling to higher power levels will require extensive technological innovation.

Regarding chemical lasers the APS study concluded: "We estimate that chemical laser output powers at acceptable beam quality need to be increased by at least two orders of magnitude (factor 100) for HF/DF lasers for use as an effective kill weapon in the boost phase."[9]

The development of an optically perfect mirror over five meters in diameter to be deployed in space is also a major technical undertaking. In fact, fabrication for terrestrial use of the 200-inch diameter mirror (5.1 meters) at the astronomy laboratory at Mt. Palomar in California was a formidable technical achievement. The large diameter mirror is necessary in order to minimize diffraction effects which enlarge the focal spot of the beam. If the mirror is smaller in diameter, or has imperfections, the beam spot will be less intense, requiring more time for missile "kill" and reducing the efficiency of the system.

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*Deuterium is an *isotope* of hydrogen having a neutron as well as a proton in its atomic nucleus. It is also sometimes called "heavy" hydrogen. Ordinary hydrogen has simply one proton in its nucleus.

**One micron is one millionth of a meter. Visible light falls in the range from 0.4 (violet) to 0.7 microns (red).

†For a mirror to be optically perfect the imperfections in its surface must be less than the wavelength of radiation the mirror is reflecting. In this case the mirror 5.6 meters in diameter must be of perfect form to 3.8 microns or 3.8 millionths of a meter.

‡The fuel requirement is calculated as follows: 140,000 million joules/500 joules per gram of fuel → 280 million grams required. Due to the absentee factor this must be multiplied by 20, giving a system requirement of 5,600 million grams. Since one metric ton is 1000 kilograms (2,200 pounds) or one million grams, the result is 5,600 metric tons. Since a shuttle load is 20 metric tons and costs $100,000,000, the cost to place the fuel in orbit is the cost for 5,600/20 or 280 shuttle loads, or 28 billion dollars.

so-called SDI may be regarded as a major U.S. attempt to break the nuclear stalemate (nuclear parity)."

The microwave laser, the excimer laser, free-electron laser, X-ray laser, particle-beam weapons, and kinetic-energy weapons would have the ability to destroy satellites at ranges of at least that planned for ABM defense, 1,500 km or more. Therefore, although their presumed purpose is for BMD they can be easily used as antisatellite weapons (ASAT). These targets are "softer" and are predictable as to location. Attacks against satellites would seriously damage communication for battle management purposes and could be expected to occur in the early stages of a nuclear exchange. ASAT at orbits of a few hundred kilometers would accompany any deployment of the above space weapons. ASAT capabilities against satellites in geosynchronous orbit at 36,000 km could also be anticipated, if strategy required it.

The laser beams that can penetrate the atmosphere, the frequency-shifted excimer laser, the deuterium fluoride microwave laser, and the free-electron laser could be formidable weapons for attack on ground targets if in fact the capabilities discussed above were realized, i.e., delivery of a flux of 20 kilojoules per square centimeter at 1,500 kilometer range.

At a range of 300 kilometers from space to earth, if the beam were directed downward, the flux is 25 times greater or 500 kilojoules per square centimeter. With the specifications discussed above for these weapons, this flux is delivered in one second.

A flux of 80 joules per square centimeter, if delivered in one second, is sufficient to ignite clothing, newspapers, wood, oil, dry leaves, and to produce third-degree burns on human beings. The lasers therefore have the capability to start such a fire or inflict serious burns on humans at the rate of 6,000 strikes per second.* If desired, the weapons could cause immense conflagrations in cities and terrorize populations or troops, since they could fire without warning.

Since 20 kilojoules per square centimeter is sufficient to destroy a missile or other similar asset, a burst of 20/500 seconds, or 1/25 second duration would be sufficient to do so on the ground.

The above estimates indicate clearly that space-based weapons envisioned by the SDI indeed would have impressive offensive capabilities against targets on the ground.

Notes

1. Paul Nitze, Speech to the Philadelphia World Affairs Council, February 20, 1985.
2. *High Frontier, A New National Strategy,* High Frontier, 1010 Vermont Ave., N.W., Suite 1000, Washington D.C. 20005.
3. Sidney D. Drell, Philip J. Farley, and David Holloway, *The Reagan Strategic Defensive Initiative: A Technical, Political, and Arms Control Assessment* (Stanford, CA: Stanford University Press, 1984), 47.
4. Ashton B. Carter, *Directed Energy Missile Defense in Space* (U.S. Office of Technology Assessment, Washington, D.C., 1984).
5. Ashton Carter, *loc. cit.,* 35.
6. "Livermore Experts Hit Star Wars," *San Francisco Chronicle,* August 13, 1987.
7. *APS Report,* 60.

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*Here it is assumed that the lasers are pulsed in time. If they are capable of delivering 500 kilojoules per second per square centimeter, or 500,000 joules per second per square centimeter, and only 80 joules per second per square centimeter are required to start a fire, then the laser need be on only 80/500,000 of a second to deliver 80 joules per square centimeter, or 160 millionths of a second. The laser could deliver such a burst about 6,000 times in one second. If the beam were moved between bursts, then thousands of fires could be potentially started each second or nearly one hundred thousand per minute of laser firing.

defense is a distant or perhaps chimerical goal. For example, Payne and Gray state: "near-term BMD technology could provide the means for important lower tiers of conventional defense designed to defend U.S. ICBMs, strategic bomber bases, and selected critical commmand, control, and communication facilities."[28] Using the SDI label for such discussions makes for considerable confusion for the public.

The case for a BMD defense of ICBM sites is argued in detail by Davis.[29] He has been associated with BMD research and deployment for several decades. He argues for a system composed of conventional late mid-course and terminal defense elements, with all the interceptors based on the ground. The system would be prototype-developed within the constraints of the ABM Treaty. Its purpose would be to defend against tactical ballistic missiles (ATBM) and as such would be suitable for deployment in NATO. It would be a counterpart to the Soviet SA-X-12 ATBM system and would possess similar capability against strategic ballistic missiles. The system would consist of a high-acceleration non-nuclear interceptor and a mobile phased-array radar. According to Davis:

> The terminal phase discussed above could be used for ICBM defense. Warnings of imminent attack with tracking information from satellites would be an important part of this system. Discrimination of decoys from actual warheads would be obtained as they enter the atmosphere in the last minute of their trajectory. A survivable communications system connecting the tracking information from ground-based radar to the interceptors is essential. Perhaps redundant pop-up radars could be used so that preceding nuclear explosions of the attack would not have destroyed or blinded the entire system.

The homing devices on the interceptors (for example, infrared detectors) must be protected from the strong signal coming from its own nose as well as the "red-out" produced by nuclear explosions.

According to an OTA study,

> in reacting to a defensive system that uses only terminal defenses the Soviets could apply countermeasures which are well within the realm of today's technology. They could proliferate reentry vehicles with relative ease. The marginal cost-exchange ratio between offensive reentry vehicles and defensive interceptors might or might not favor the interceptor.[30]

Blechman and Utgoff[31] analyze a system for defense of ICBMs, bombers, and submarine bases using low and high atmospheric interceptors with an assumed 90 percent kill probability and only one radar per site. They estimate a cost of about 160 billion dollars for the system under these assumptions.

Other technical measures might be preferable for restoration of ICBM invulnerability, such as mobile-based single-warhead missiles to replace the present arsenal of MIRVed missiles. With present missile accuracies the latter are attractive targets at the present time. It is beyond the scope of this paper to compare this alternative with ABM defense of ICBMs. Neither shall we explore the political questions of accepting the vulnerability of one leg of the strategic triad or examining whether Soviet response might trigger a new round in the nuclear arms race.

E. Offensive Use of SDI

Although the SDI is proclaimed by the U.S. as a defensive system, its components could also be used in conjunction with a first strike to destroy satellites and other space assets as well as some targets on the ground. Strategically, an SDI in place also could be used to suppress a ragged retaliatory strike from an opponent who had suffered a first strike. Hence it can be viewed as enhancing a first-strike capability. Hence it is not unreasonable that it is regarded as a threat by the Soviets. The publication of an analysis of SDI by an eminent committee of Soviet scientists and military personnel entitled "Space-Strike Arms and International Security"[32] attests to this threat. They state: "The plans to create a large-scale anti-missile system with space-based elements under the program of the

The deuterium fluoride chemical laser fails the Nitze criteria both as to vulnerability and to cost. The sophisticated laser battle station could be readily rendered inoperative by a space mine, nuclear explosion in space, or by pellets put in counter orbit, which would strike the battle station with double the orbital velocity or about 15 km/sec. Even a small pellet, say 1 gram, would carry an enormous kinetic energy (for 1 gm, about 100 million joules) and would be highly destructive if it hit the battle station.

Since the cost of producing 1,400 missiles is about 14 billion dollars and the cost of the space-based chemical laser is 500 billion dollars, the cost-exchange ratio is also unfavorable for the defense and fails this Nitze criterion by a factor of over thirty.

(2) Excimer Laser Another proposal for a boost-phase system is to employ excimer lasers. The word "excimer" is derived from *ex*cited states of d*imer* molecules. The later are molecules formed from two atoms. These lasers work with excited chlorine-xenon or krypton-fluoride molecules and provide coherent radiation in the ultra-violet region at a shorter wave length of about 0.3 microns. Excimer lasers are attractive in that the atmosphere is partially transparent to their radiation, permitting attack on the boost phase from its inception. By shifting the wave length of the excimer light to 0.5 microns by scattering it in a hydrogen Raman cell, the resulting light is in the blue part of the visible spectrum so that the atmosphere is transparent to it, if there are no clouds or other interfering matter. In the analysis below it will be assumed that the atmosphere is perfectly transparent to the laser light.

Since the diffraction limit* of spot size on the target is proportional to the wavelength, the mirrors can be smaller than for the chemical laser discussed above. It has been proposed to install these lasers on the ground at high elevations to avoid a decrease in beam intensity due to clouds and atmospheric matter. Since cloudy conditions can occur on mountain sites as well, some redundancy of sites would be necessary. Ground installation is attractive since space deployment is more vulnerable to attack and also because these lasers have large power requirements (see below). The ground-based lasers would send their beams to a 3.0 meter-diameter mirror located in geosynchronous orbit at 36,000 kilometers. This mirror would stay fixed over the Soviet Union. The geosynchronous mirror then would send the beam to a "fighting mirror" 5 meters in diameter located in an orbit 1000 km above the earth. The fighting mirror then targets the ICBM booster using the infra-red signal from the rocket exhaust.

A pilot laser accompanying the mirror in geosynchronous orbit would provide signals allowing in principle for the high-power laser beam from the earth to be compensated at the ground to minimize density fluctuations in the atmosphere (active optics). Active optics is accomplished by deforming the ground mirror in response to the pilot laser signal. This technique remains to be proven for high-power beams which may themselves perturb the atmosphere.

The power output of the excimer lasers required for the above system is proposed at 10 megawatts, which is an extension from present experience of at least four orders of magnitude (factor 10,000) in power level, since excimer lasers in the laboratory now operate at about one kilowatt.[10] A ten-megawatt beam-power level might be accomplished by combining hundreds of excimer lasers. The technical requirements for the mirrors of the excimer system are more stringent than for the infra-red system in that imperfections in the mirror shape must be generally less than the wavelength, which is now 0.5 microns, or one-half of a millionth of a meter, rather than 3.8 microns, and they must be capable of withstanding the power densities required (about 150 joules per square centimeter). Construction of such mirrors on the ground presents a formidable technical challenge, and their subsequent deployment in a possibly hostile environment in space would be even more difficult.

*The diffraction limit is due to the wave nature of light. The minimum spot size (and hence maximum "kill flux") is given approximately by the wavelength divided by the diameter of the mirror and multiplied by the distance at which the minimum-sized spot is focused.

The total power required of the excimer lasers is estimated below: It is assumed that the geosynchronous and fighting mirrors are optically perfect and that the active optics also works perfectly as well. A maximum range of 3,000 km will be assumed. Using a 5-meter diameter fighting mirror, the beam spot is then 25 centimeters in diameter at 3,000 km. If it is assumed that a "kill" is to occur in 1 second and 20 kilojoules per square centimeter is required on the missile to do this, then the excimer beam must deliver 10 megajoules in one second, or have a power output in that burst on target of 10 megawatts.

Ashton Carter assumed excimer lasers with wavelength shifters are about 5 percent efficient,[11] whereas the American Physical Society study appears more optimistic. Below we shall assume 100 percent efficiency of input power into laser beam energy to give a lower limit of power requirements. Since there are 1400 Soviet ICBMs, the system energy required for their destruction in this ideal case is: 10 megajoules x 1400 ICBMs or 14,000 megajoules. If this energy is delivered in the 180 seconds of interception time for an SS-X-24, then the total ideal power requirement is about 80 megawatts. This capacity must be available at any time in a standby mode and must be increased to account for possible cloud cover at some sites and laser and mirror inefficiencies as well as to permit reaiming for different targets. Allowing for redundancy of 50 percent, mirror imperfections of 50 percent, and an over-all laser efficiency of 10 percent (not yet achieved), and optimistic reaiming time as described below, the power required for the excimer laser installations would be 80 times greater or 1,600 megawatts. This is the power output of approximately two commercial nuclear reactors. It would have to be on standby, available within seconds, since attack time only lasts about three minutes in boost phase for, say, an SS-X-24 missile.

If one assumes that the synchronous-fighting mirror complex can be reaimed after only one second, then 90 bursts can be fired in the 180 seconds available during the three-minute boost phase. To target 1,400 boosters, sixteen 10-megawatt lasers, 16 geosynchronous mirrors, and 96 "fighting mirrors" would be needed to deliver the bursts in the time available. The number of the latter mirrors is increased above by a factor of 6 to account for the absentee factor.If the Soviets should choose faster-burn boosters, say with one-half the burn time of the above example, then the number of lasers, geosynchronous mirrors, and fighting mirrors needed is doubled.

The complex that would contain the excimer lasers is difficult to harden and is therefore a vulnerable and attractive target for offensive ICBMs. According to the APS study: "Attack by moderate yield (hundreds of kiloton) weapons from present submarine-launched ballistic missiles would very effectively prevent the lasers from performing their strategic defense function".[12] The optically perfect battle mirrors are also difficult to protect from space mines, counter-velocity orbital sand and pellets, or x-rays from nuclear explosions in space, although the vulnerability of the overall system would be less than for a chemical laser since the laser itself is located in friendly territory on the ground. Since the system would be inoperative if any of its critical components fail, the whole system is vulnerable to countermeasures since the space-based part of the system is particularly difficult to defend.

Cost estimates of the complete system are difficult to give at this time because of the extensive development that is necessary for many of its components. However, it is not unreasonable to assume that it would be comparable to the chemical laser system, although perhaps somewhat less expensive since the lasers need not be orbited. However, at this time it seems very unlikely that the costs would be a factor 30 less than the chemical laser, and therefore the excimer laser also fails the Nitze cost-exchange ratio criterion.

(3) Free-Electron Laser Another possibility for directed-energy weapons is the development of free-electron lasers which promise to produce high-power levels of infra-red radiation using stimulated emission of such radiation from the energy of an electron beam. According to the American Physical Society Report,[13] the free-electron laser "appears capable of demonstrating one megawatt of one micron radiation in the future," but "they will require validation of several physical concepts." Overall efficiency of these lasers is now only a few percent, but efficiencies of 20 percent are anticipated.

electromagnetic background and other countermeasures. For population defense it is essential that the boost-phase defense be effective; otherwise, the battle management is readily overwhelmed.

In any case it has been estimated that approximately ten million lines* of computer code alone need to be written for the battle management system. Since the code can not be realistically tested except in actual battle, it must function perfectly or with imperfections that do not greatly hinder its utility the first time it is actually used. For this reason, as well as others, there is room for considerable doubt as to the feasibility of the battle management system for population defense.

David Parnas resigned from the SDI Panel on Computing in Support of Battle Management because he had concluded that the battle management program as presently conceived by the SDI program is unattainable. Dr. Parnas has an impressive background in computer science both at the academic level and also in U.S. defense applications. After his resignation he subsequently wrote a paper explaining in some detail his pessimistic assessment of the feasibility of SDI software.[26] His principal reasons for this conclusion were that both the threat that SDI components would face and the SDI components themselves were uncertain in characteristics and behavior, that it would be impossible adequately to test the software, which would not be amenable to human intervention or debugging. He also has serious doubts that the software could successfully control a fluid and growing number of subsystems embedded in the constituent defensive weapons.

Again, Herbert Lin concludes that[27] "no software-engineering technology can be anticipated that will support the goal of a comprehensive (population defense) ballistic missile defense."

In summary, *population defense by the SDI is only a fantasy at this time. If defense of populations by SDI is seen as the latest in a "technological fix" to a political problem (see Introduction), then in contrast to earlier attempts at such "fixes" by the U.S., SDI defense of populations is not only not "technically sweet," but it will take years to determine whether it is even possible.* Furthermore, present technologies for the defense of populations fail the Nitze criteria of cost effectiveness and vulnerability to a first strike. Therefore, the BMD of populations in the future remains extremely dubious.

D. ICBM Defense

In contrast to defense of populations that President Reagan originally proposed, the defense of assets hardened against nuclear attack, such as ICBM silos, is a much more tractable problem. Such a defense would not be a departure from the present nuclear weapons policy of deterrence nor would it "make nuclear weapons impotent and obsolete," but would rather enhance deterrence by increasing the second-strike capability of ICBM forces.

The technical advances in accuracy of strategic missiles as well as the increased number of the adversary's warheads through MIRVing have made the ICBM component of the strategic triad increasingly vulnerable to missile attack. These developments, which seemed promising in the early 1970s, have in fact *lessened* the security of the superpowers.

Thus, the other technical changes discussed in the preceding section on terminal defense make the ABM defense of ICBMs seem attractive. Such a defense would act to restore to some extent the invulnerability of ICBMs to a preemptive first strike and would return the strategic situation in this respect for this leg of the triad to what it was in the early 1970s.

However, an ICBM defense, concerned with enhancing deterrence, is philosophically contrary to the concept of the SDI as proposed by President Reagan. The SDI in its original form had as its principal objective to rid ourselves of deterrence in favor of a defensive posture. Nevertheless, some SDI proponents now argue the case for enhanced deterrence via missile silo defense since population

*a "line" refers to a series of computer instructions occupying one line of computer printout. It may contain up to about 80 characters.

with. For example, a 50-megaton warhead exploded at a height of 30 kilometers in clear weather could create fires in an area of 2,500 square kilometers. A further disadvantage is that incoming warheads are traveling at about 8 kilometers per second upon entering the atmosphere, and about 3 kilometers per second upon impact. These high speeds and marked deceleration due to air drag make tracking difficult.

To provide a terminal defense, early-warning satellites are needed to give notice of attack launch, and either air-based infrared sensors or land-based radar for tracking incoming warheads are also necessary. These devices need to be able to operate in an environment which may contain nuclear explosions, which give a large electromagnetic background. A battle-management system is needed which can assign interceptors to targets within a fraction of a second per target. The system must be able to distinguish warheads from decoys in a few seconds.

Several thousand fast-acceleration interceptor rockets (or possibly electromagnetic rail guns*) with infra-red homing capability would also be needed. Ordinary explosives might be employed to destroy the warheads if the interceptors can get close enough to the incoming warheads, otherwise small nuclear warheads could be used. However, the intense radiation from the latter could possibly confuse defensive sensors. *Aviation Week* and *Space Technology*[23] reported a hypersonic interceptor which would rise rapidly (5 to 6 kilometers per second) with an intercept range of about 200 kilometers. The warhead would deliver a shower of pellets that would be highly destructive if even one were struck by the incoming reentry vehicle.

Land-based non-nuclear interception of a single Minuteman missile was achieved in 1984 at an altitude of over 160 kilometers as it approached reentry at Kwajalein Island in the Pacific Ocean. The interceptor was another Minuteman missile with an on-board computer and long-wave infrared sensor for detecting the missile in space. This test was exoatmospheric and would not have distinguished decoys from an actual warhead.

According to the OTA,[24] many of the technologies needed for terminal defense either exist or could be developed in the near future. However, according to this same source,[25] for terminal defense to be effective for population defense so as to provide "for a nearly leakproof defense (to defend populations) . . . a high level of boost-phase intercept effectiveness must be obtained [as well as] excellent discrimination capability between decoys and warheads in the midcourse [and] space-based assets must defend themselves or be defended by other assets against concerted attack." *That is, terminal defense alone cannot defend populations and the failure of the Nitze criteria as well as the technical difficulties of boost-phase and midcourse phase discussed above must be overcome before the terminal phase can be effective.*

4. BATTLE MANAGEMENT

Although kill mechanisms are often given much attention, the problems associated with battle management are indeed formidable. For the layered defense to operate successfully it is essential that information concerning locating, tracking, aiming, and kill, and if necessary repetition of this sequence, be accomplished for thousands of missiles in boost phase within the three to five minutes that it lasts, and that this information be passed to the midcourse-phase defense in an accurate and useful manner.

During midcourse there may be as many as hundreds of thousands of objects to track as the buses deploy their warheads and decoys. The system must be able to function accurately in spite of possible pre-attack detonation of nuclear warheads and the resulting "red-out"** of intense

*An electromagnetic rail gun uses huge currents to provide powerful electomagnetic forces to accelerate projectiles to speeds of tens of kilometers per second.

**"red-out" refers to the intense infra-red radiation that a nuclear explosion produces that will blind infra-red sensors tracking the boost-phase rocket plume and later possibly warheads and decoys.

Recalling the estimate made above for a 3.8 micron wavelength beam from the DF laser weapons system, the free-electron laser beam will have a spot size 1/3.8, or roughly one-quarter (with the same mirror system). The beam power requirement to produce the same power density for missile kill is therefore reduced from 100 megawatts to about 7 megawatts for a weapon system with a 1500 km range. At this time much research remains to be done to establish the feasibility of the free-electron laser idea. However, its vulnerability would be similar to that of the excimer laser, since the lasers would probably be ground-based. (The atmosphere is transparent to one micron wavelength radiation so that space basing of the lasers is not necessary.)

(4) X-Ray Laser The final boost-phase defensive system that we shall discuss is that of the x-ray* laser. The lasant material is in the form of thin rods of the order of meters in extent and tens of microns in diameter. This material is made to lase in copious amounts by the enormous flux of x-rays produced by a nuclear bomb. The beam divergence is determined by the ratio of the diameter of the rods to their length, and is considerably greater than for the laser systems discussed above. The increased beam divergence arises because it is not possible to reflect x-rays on perpendicular incidence on internal mirrors as in an ordinary laser. However, in a nuclear weapon the flux of electromagnetic radiation is enormous and is most intense near the frequency required for the x-ray laser. Therefore, in spite of the large beam spot produced by its divergent beam, it is still possible in principle to produce a killing flux of x-rays.**

To avoid the vulnerability associated with a space-based system it has been proposed to use a deployment wherein the x-ray laser is "popped up" from a submarine with a fast-burning rocket when an attack occurs. Since x-rays are absorbed by the atmosphere and since the earth is round, the laser must rise to at least 350 km within the boost time of the ICBMs in order to attack them, assuming they can be launched from submarines near the Soviet Union. It has been proposed to use individually aimed multiple laser rods so that several x-ray laser beams could be produced, thereby destroying several ICBMs (if they are launched simultaneously). Accurately aiming several individual laser rods during the high acceleration ascent and time constraint presents a formidable technical task. For pop-up use the nuclear warhead, say at a distance of 3,600 km from the target instead of 36,000 km in geosynchronous orbit, need be only 3.7 kilotons TNT equivalent of explosive energy instead of 370 kilotons.†

Besides thermal damage or radiation damage to electronic components, missiles may be destroyed by shock waves and momentum transfer from the use of pulsed laser beams. However for all but the x-ray laser more laser beam power is required than for thermal damage.‡

The x-ray laser is subject to several countermeasures: Since x-rays are absorbed by the atmosphere, use of a fast-burn booster that burns only within the atmosphere would deny the x-ray laser system the necessary targeting information. That is, the booster rocket exhaust would have ceased before the missile emerged above the atmosphere where it could be attacked by the x-ray laser.

It is also possible to produce "atmospheric heave" by exploding a nuclear weapon in the atmosphere near the launching site prior to launch. The atmosphere can effectively be raised locally

*X-rays are electromagnetic radiation of very short wavelength. They are produced copiously in a nuclear explosion.

**For example, for an x-ray laser located in geosynchronous orbit at 36,000 km which is activated (or "pumped") by an 370-kiloton nuclear bomb at 3 percent efficiency, the flux is 20 kilojoules per square centimeter over an area of 540 meters in diameter at the rocket booster. (It is assumed here that the lasing rods are 30 microns in diameter and 2 meters in extent.)

†This reduction is a result of the beam divergence so that if the distance to the target is 1/10, the energy release required is only 1/100.

‡For the frequencies produced by the excimer, free-electron, or chemical lasers the required flux is "about 50 kilojoules per square centimeter delivered on target for coupling coefficients valid for most materials."[14] This is more than double the 20 kilojoules per square centimeter needed for thermal kill. However, for the higher frequencies of the x-ray laser "only 5 kilojoules per square centimeter is required."[15] Therefore, in the x-ray laser calculation above, a 90-kiloton nuclear explosion would suffice for x-ray shock kill of a booster from geosynchronous orbit, rather than 370 kilotons for thermal kill.

by this method to shield an ordinary booster from x-ray attack, since x-rays are absorbed by the atmosphere.[16]

In the case of U.S. defense, since the submarines that would launch the pop-up x-ray lasers would be necessarily located as close to the Soviet Union as possible, they would be subject to detection and nuclear attack if indeed a first strike were contemplated by the USSR.

One of the conditions necessary for this BMD to be effective is that it must be almost completely automated, as there is a maximum of only three minutes available from receipt of satellite information validating an ICBM launch to the time of x-ray laser attack. There is no time available for presidential authorization. The nuclear explosions resulting from the x-ray lasers could well be misinterpreted by the Soviets as part of a first-strike nuclear attack (for example, to produce an electromagnetic pulse to destroy communication systems prior to a missile launch) and hence would be a cause of instability, especially during an international crisis.

2. MIDCOURSE—PARTICLE BEAMS

In midcourse the bus of the ICBM has deployed the warheads and perhaps 10 times or 100 times as many accompanying decoys (chaff, aluminized mylar balloons in which warheads are hidden, false warheads that attempt to mock radar or infra-red signals of real warheads, etc.). All of the BMD methods discussed in boost phase could also be applied to this phase.

Although there is now an increased time, roughly 20 minutes, to mount the defense, the task of finding the targets and their identification is much more difficult. Although in principle low-intensity infra-red signals from warheads and decoys could be detected against the cold background of space, the signal is much reduced and sensitive to countermeasures, such as nuclear explosions in space, which might accompany an attack. Since warheads are protected with shields for reentry into the atmosphere, laser kills might be more difficult than attacking a rocket in boost phase.

Midcourse is especially attractive for the possible use of particle beams for either target identification or destruction. In either case it has been proposed to use neutral beams of hydrogen atoms. We discuss first the possibility of target identification.

In principle, if these beams had energies of several hundred million electron-volts, they could penetrate the skin of decoys and into the warheads to send back gamma-ray signals that are characteristic of the materials of which they are made. The intensity of the returned signal would also be approximately proportional to the amount of material present, which would also assist in determining the actual warheads.

A neutral beam is necessary in order to avoid the bending of a charged-beam by the earth's magnetic field. Since the gamma-ray signal is proportional to the inverse fourth power of the distance from the source if detector and source are located together, the system is very sensitive to the target-to-detector/source distance. For example, if this distance is doubled, the intensity of the returned gamma-ray signal is one-sixteenth of its original value. By locating detectors in positions that are different from the source, communication links are more complex, but then the received signal is only reduced by the inverse square of the target-detector distance. If a range of 1,000 km is deemed necessary, then neutral particle beams of at least one hundredth of an ampere would be required. This means in turn a power of several hundred kilowatts in the particle beam. If the overall efficiency of a particle accelerator is given the optimistic value of 50 percent, the overall power requirement is about one-half megawatt. This power might be produced by a nuclear reactor located in orbit.

It should be emphasized that neutral particle beams formed of hydrogen atoms are readily stripped of their electrons by the atmosphere, and are therefore only effective in space.

Using neutral particle beams for "kill" of warheads in space, once identified, has also been proposed. One of the advantages of such beams, if they could be produced, is that the beams would have a velocity of about ⅔ that of light, so that they reach their targets in a matter of milliseconds and could in principle be switched readily for multiple targeting. These beams produce damage by irradiation of components and also by thermal effects.

To produce a beam of neutral hydrogen atoms the most likely route is to accelerate a beam of negatively charged hydrogen ions. Several amperes of such beams have been obtained recently at low energies[17] for the thermonuclear fusion program for nuclear power, but have not been used as an accelerator source. The Los Alamos Scientific Laboratory has produced negative hydrogen ions of 50 million electron volts energy at a current of 0.1 ampere in a linear accelerator.[18] In order to penetrate adequately warhead components, at least two hundred million electron volts of energy is needed.

A principal effect of particle beams is the damage to semiconductor and other sensitive components. With silicon components of the warhead, radiation doses in the order of megarads are needed for radiation "kill." If the dose is increased to tens of megarads, then radiation-resistant materials such as gallium arsenide will be rendered inoperable. The energy deposited is then sufficient to produce melting in some materials also, such as the plutonium components of a nuclear bomb. One megarad represents the deposit of 10 joules of energy per kilogram of material. At several hundred million electron volts energy the range of the beam is of the order of several centimeters of material. With the beam characteristics of the Los Alamos linear accelerator, taking into account the spread in the beam incurred in stripping the hydrogen ion of its electron to form a neutral beam, and assuming a radiation dose of 20 megarads, about three amperes of beam is needed for a kill range of 500 km and 9 amperes for a kill range of 1,000 km, according to Soviet scientists.[19]

A similar estimate was made by the American Physical Society study.[20] The study assumed that only 10 megarads were needed for a "kill" and assumed a more optimistic value for the beam divergence (one microradian). In this case a beam of one-tenth of an ampere on target for one second at several hundred million volts is deemed sufficient for a "kill." The Soviet estimate is perhaps more realistic in view of the large extrapolation upwards in power level from present knowledge.

It should be emphasized that an accelerator of 200 million electron volts energy and with a beam intensity of 9 amperes will have 1.8 megawatts of power in the particle beam. If the accelerator efficiency is taken as 50 percent, and it is powered by a nuclear reactor, the reactor would need to deliver something of the order of 4 megawatts. The beam-power levels involved here are a factor one thousand larger than any comparable accelerator of this energy that has been constructed on the ground.

There is at present in the U.S. a program (SP-100) to develop a one-tenth megawatt space-based nuclear reactor. Conceptual studies for higher power levels have been initiated.[21] It is estimated that an accelerator for neutral particle beams of a 1000 km range would weigh about 100 tons if some advances in radiofrequency technology are achieved. One hundred such accelerators would be needed for full coverage of midcourse.[22] For a constellation of 100 battle stations, 500 U.S. space-shuttle loads would be required just to place the weight of the accelerators in orbit. This number could readily be doubled if the power source, assembly, and activating tasks are also included.

An accelerator based in space would be vulnerable to hostile action as is the case of the chemical laser. Its sophisticated technology could be rendered inoperative by counterorbiting pellets, nuclear explosions a hundred kilometers away, or space mines. The cost of mid-course defense is at least as great as for chemical lasers, or in excess of 500 billion dollars. The cost of 1,000 shuttle loads alone is 100 billion dollars. Particle-beam weapons that are presently conceived therefore also fail the Nitze criteria of vulnerability and cost effectiveness since the cost for 1,400 new Soviet ICBMs is about 14 billion dollars.

3. TERMINAL DEFENSE

Terminal defense has several advantages: The systems are on the ground in friendly territory, decoys are burned up in the atmosphere so that the system can concentrate on actual warheads, the systems are less vulnerable to attack than space-based systems, and they are much less expensive. Disadvantages include the possibility of fall-out, electromagnetic pulse, thermal radiation, and blast damage effects from exploding warheads that are "salvage fused," that is, set to explode if interfered