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The Continuing Quest for Missile Defense: When Lofty Goals Confront Reality

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The Continuing Quest for Missile Defense: When Lofty Goals Confront Reality

Description

For almost three quarters of a century, the United States has spent billions of dollars and countless person-hours in the pursuit of a national missile defense system that would protect the country from intercontinental ballistic missiles (ICBM) carrying nuclear warheads. The system currently in place consists of 44 long-range antiballistic missiles stationed in Alaska and California to protect the United States from a possible nuclear weapon carrying ICBM attack from North Korea. After all this effort, this system is still imperfect, being successful only 10 out of 18 tests.

This book will provide an historical description of past efforts in national missile defenses to understand the technical difficulties involved. It will also explain how national security concerns, the evolving international environment, and the complexities of US politics have all affected the story. The book will also describe the current systems in place to protect allies and troops in the field from the threat of shorter range missiles. Finally, the book will describe the current US vision for the future of missile defenses and provide some suggestions for alternative paths.

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The Continuing Quest for Missile Defense

When lofty goals confront reality

Peter Pella

Chapter 1

National missile defense history

The idea of a national missile defense system has been around since the 1950s. It is an indication of the difficulty involved in perfecting a missile defense system that there still is not a perfected system in place today.

An anti-ballistic missile (ABM) system must be able to perform six separate functions in order to be effective. It must be able to detect an incoming missile or warhead with sufficient lead-time to allow it to perform the rest of its functions. The ABM system must be able to identify that the information being received is in fact an incoming missile. The radar system or other detection devices (optical, infrared, etc) must be able to track the flight path of the incoming target. Once a missile or other weapon is launched against the target, the system must be able to guide it to its intercept point. Of course, a successful ABM system must be able to destroy the target or render it inoperable. Finally, because even one nuclear weapon can have a devastating effect, the ABM system must be able to verify that a target is engaged successfully, and if not, attack the target once again.

Five of these functions are independent of the type of missile used to destroy the target. They rely on a complex and integrated system of satellites, land- or sea-based early-warning radars, and target tracking and missile guidance radars. The target can either be destroyed by actually hitting the incoming target, so-called hit-to-kill technology, or by detonating a small nuclear device nearby, which would either destroy or disable its capability.

Satellites

Satellites have been, and still are, an important component of missile defense architecture. They are used for early warning, target identification, and battle management. They are also the most vulnerable component of the system. Because they have to be launched into space, they must be lightweight which makes them very fragile. In addition, satellites follow very predictable orbits and can be identified easily from the ground. Although all industrial countries have refrained thus far

from developing large-scale anti-satellite (ASAT) weapons systems, this might not always be the case. The United States, China, and Russia have all tested ground-based ASAT weapons and further research is ongoing. India has expressed interest in developing a hit-to-kill ASAT weapon as well. China and Russia in 2008 and the European Union (EU) in 2010 have drafted treaty language to prohibit space-based ASAT systems but still no treaty exists. A brief discussion of satellites follows.

There are two kinds of orbits in which a satellite circles the Earth: elliptical orbits and circular orbits. Elliptical orbits fly around the Earth in the form of an ellipse, with the Earth at one focal point (see figure 1.1). Such orbits are used mostly for spy satellites that want to travel at a very low distance over certain parts of the world. It is also the type of orbit employed by the Global Positioning Satellite system (GPS). For all orbits, the period of the orbit is proportional to the altitude. For circular orbits at an altitude of about 35 000 km, the period is 24 h. The satellite circles the Earth in the same amount of time that the Earth rotates; therefore, the satellite stays in one location above the Earth. Telecommunication satellites use geosynchronous orbits for TV, data, and voice transmission.

The original GPS system was called NAVSTAR and consisted of 24 satellites in six different orbits. The NAVSTAR system originally transmitted two sets of signals, one classified and the other unclassified. The unclassified signal was designed to give anyone an accuracy of within 100 m in all three directions just by using a GPS receiver, which is now the size of a deck of cards. However, advances in technology have made it possible for everyone to use GPS with greater accuracy than 100 m. The classified signal used atomic clocks and synchronized signals to allow the military to get within 30 m 90% of the time and 10 m 50% of the time.

Figure 1.1. Types of Earth orbits. (Courtesy of The National Aeronautics and Space Administration.)

In April 1997, the military opened up a classified channel to everyone for 19 h to help search for a missing A-10 aircraft. Users of the GPS system during those times

claimed that they could pinpoint their location to within 2 m¹. The GPS system is shown in figure 1.2.

Figure 1.2. The GPS system. (Courtesy of The National Oceanic and Atmospheric Administration.)

Radar

Radar systems are crucial to any missile defense system. As mentioned previously, radar was developed for military use and was used successfully by Great Britain to counter German bomber raids over England. The term RADAR was coined in 1940 by the United States Navy as an acronym for RADio Detection And Ranging². Radar is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. A radar system consists of a transmitter and receiver and uses radio or microwave radiation. The energy emitted by the transmitter is reflected off an object and returns to the receiver and gives information about the object's location. By measuring the shift in frequency between the transmitted and reflected wave, it can also determine an object's speed.

Radar is used today for a myriad of tasks. It is used by law enforcement for traffic control and detecting speeding violations. It is used at airports for air-traffic control and on airliners for collision avoidance systems. It also allows airliners to land when weather conditions inhibit visibility. Radar has become the primary tool for meteorologists for weather forecasting. It can measure the location, path, and severity of approaching weather, such as thunderstorms, hurricanes and snowstorms and provide early warning of possible tornadoes. Finally, it is crucial to the success

¹ Schwartz S I (ed) 1998 *Atomic Audit: The Costs and Consequences of U.S. Nuclear Weapons Since 1940* (Washington, DC: Brookings Institution Press), p 218.

² Lapedes D N 1976 (ed) *McGraw-Hill Dictionary of Scientific and Technical Terms* (New York; Montreal: McGraw-Hill).

of any national or regional missile defense system. Radar provides early warning, target identification and tracking, and battle management.

A particularly useful form of radar for missile defense systems is called phased array radar. Phased array antennas are composed of many identical antennae. This allows the radar system to be able to perform several functions and track multiple targets at the same time. They were first developed during World War II and are now used on such ABM systems as the Patriot Missile System and the ship-borne Aegis Combat System (explained later in the text). For example, the phased array radar used by Aegis is able to search, identify, and track over 100 targets while providing guidance to the Aegis missile simultaneously³. Due to the reduced cost and increased computational capabilities, phased array radars are used in almost all modern military radar systems. Even the National Oceanic and Atmospheric Administration (NOAA) uses them for more accurate weather forecasting. They have plans to implement a national network of Multi-Function Phased array radars throughout the United States within ten years, for meteorological studies and flight monitoring⁴.

Early history⁵

In the 1950s, the U.S. built an extensive array of anti-aircraft missile systems that were deployed around the periphery of the United States. The first such missile was called the Nike Ajax, which was later replaced by the Nike Hercules (shown in figure 1.3). A typical Nike Hercules Battery consisted of three areas, an administration and barracks area, the Integrated Fire Control (IFC), and the launch area. The IFC contained all the identification, tracking, and guidance area and provided the signal to launch. The launch area generally contained four launchers and six missiles. It also housed the warheads, either conventional or nuclear. The yield of the nuclear weapon could vary from the explosive power of the weapon exploded over Nagasaki or a yield of one tenth of that yield.

It is interesting to note that the general public at the time did not know that the Nike Hercules missiles, stationed in the United States, could be armed with nuclear warheads. These warheads were stored on the missile sites as mentioned above, which were generally close to major population centers, such as Los Angeles. Even though the system was inaccurate, it could still destroy incoming bombers by flying close to them and detonating the warheads high above the cities.

³ 2001 AEGIS Weapon System MK-7 *Jane's Information Group* (April 25, 2001) http://www.janes.com/defence/naval_forces/news/misc/aegis010425.shtml.

⁴ *National Severe Storms Laboratory Multi-Function Phased Array Radar (Mpar) Project* <https://www.nssl.noaa.gov/projects/mpar/>.

⁵ A more technical and extensive review can be found in the e-paper, *Missile Defense 2020 Next Steps for Defending the Homeland* by Thomas Karako, Ian Williams, and Wes Rumbaugh: A report for the Center for Strategic and International Studies, Missile Defense Project: <https://www.csis.org> (April 6, 2017).

Figure 1.3. Nike Hercules missiles and launchers. (Courtesy of the U.S. Army and Redstone Arsenal.)

By the early 1970s the U.S. Army began transferring control of these batteries to the National Guard. Most of the batteries in the United States (except for a few in Florida) were finally decommissioned in 1975. They had become obsolete and were unable to engage modern aircraft with their sophisticated electronic counter measures. The Nike Hercules missiles that were deployed in Germany, outfitted with nuclear warheads, could also be used as a medium-range surface-to-surface missile⁶.

The first attempt to build an ABM system occurred in 1957 resulting in the Nike Zeus (see figure 1.4).

Figure 1.4. Nike Zeus. (Courtesy of the U.S. Army.)

⁶ The author's first assignment as a Second Lieutenant, was at a Nike Hercules battery high in the San Gabriel Mountains overlooking Los Angeles. There were six nuclear warheads stored on site. In the early morning of February 9, 1971, in the foothills of the San Gabriel Mountains, the San Fernando earthquake (also known as the Sylmar earthquake) occurred and measured between 6.5 and 6.7 on the Richter Scale. It created a small crack in the concrete bunker that contained the nuclear weapons. The author was the duty officer that night and nervously measured the width of the crack after each of the several aftershocks that happened. He worried that the crack would widen, breaking open the concrete bunker and nuclear warheads would be rolling down the mountainside. As the ranking officer on site, he would be held responsible for the disaster.

In its first test in 1962, the missile flew close enough to its target to be destroyed by its nuclear warhead, and the test was considered a success. However, it was not deployed due to its prohibited cost, concerns with detonating a nuclear weapon in the atmosphere, and its limited operational capability⁷. The project was canceled shortly after that by President John F Kennedy in favor of the Nike-X program, which was in the design phase at that time.

Even the desirability of an ABM system was open to debate during the Kennedy and Johnson administrations. The Secretary of Defense at the time, Robert McNamara, believed that if an ABM system was not close to 100% effective against all incoming missiles, it would be destabilizing and bad for deterrence. The logic is as follows. If one had a system that was 90% effective against only 100 incoming missiles, the system would destroy 90 of the incoming missiles and 10 would get through. However, if a first strike consisted of 1000 incoming missiles, this same system would destroy 90 of the first 100 incoming missiles, but now 910 would make it through. The system would not be effective against a first strike. However, if one launched a first strike against another country, and that country's retaliatory strike consisted of only 100 missiles, the system would be much more effective. In other words, an ABM system that could only target a few incoming missiles would be a threat to another's deterrent force. And in the logic of MAD, this would be highly destabilizing.

Robert S McNamara and his advisors also worried about the so-called cost-benefit ratio. If the United States were to deploy a workable missile defense system, the Soviets might respond by building more ICBMs. To counter that move, the U.S. would have to increase its missile defense capability. Increasing offensive systems turns out to be much cheaper (just building more missiles and/or warheads) than increasing one's missile defense capabilities (with all the associated increase in tracking and guidance capability and missiles). The economics favored the offense over the defense⁸.

After the Cuban Missile Crisis, the U.S. placed greater emphasis on developing the Nike-X system. The Nike-X system was designed to use a much faster anti-ballistic missile called Sprint. The missile batteries were to be located around areas likely to be targeted by ICBMs such as cities and U.S. ICBM sites. The system included more sophisticated radar systems and better coordination between early warning, tracking, and guidance radars.

China, the newest country at that time to develop nuclear weapons, emerged as a possible new threat in addition to the threat posed by Soviet ICBMs. Also, the United States worried about how the small ABM system that the Soviets had installed around Moscow might impact deterrence. Reports of this system elicited a quick response from the U.S. Congress, which urged the administration to deploy a U.S. ABM system. These issues prompted President Johnson to appoint a special panel to determine if the Nike-X program would be able to address some of these concerns.

⁷ Gansler J S 2010 *Ballistic Missile Defense: Past and Future* (Washington, DC: Center for Technology and National Security Policy) p 39.

⁸ U.S. Congress, Office of Technology Assessment 1985 *Ballistic Missile Defense Technologies* OTA-ITC-254 (Washington, DC: U.S. Government Printing Office) pp 45-6.

Robert McNamara and some former Secretaries of Defense, past and present chairmen of the Joint Chiefs of Staff, and past and present presidential science advisors, met in secret to determine whether or not to deploy the Nike-X system.

The panel decided that the U.S. could not develop a system that would work against the large Soviet threat. However, a limited ABM system might prove useful against a future Chinese threat. The U.S. decided to deploy a system, now renamed Sentinel, around 14 major U.S. cities. It would use a long-range missile, called the Spartan (shown in figure 1.5), with a large nuclear warhead (over 40 times the explosive power of the weapon exploded over Nagasaki) that would hopefully destroy incoming missiles high above the atmosphere. It would be a limited ABM system that could protect the United States from the much smaller Chinese nuclear threat or an accidental Soviet attack.

This proposal was not welcomed by those living in the cities that were to be protected, and many scientists who feared the effects of large nuclear explosions above the cities. Also, some hawkish members of the U.S. Congress were disappointed that the system was not going to be much larger to protect against a Soviet first strike⁹. On the other side of the spectrum, concern was raised about how such a system would lead to a new arms race and how it could adversely affect future arms control negotiations¹⁰. When President Richard Nixon took office in 1969, he stopped all work on the project to conduct his own study of its feasibility.

Figure 1.5. Spartan missile (along with some touring West Point Cadets). (Courtesy of White Sands Missile Range Museum.)

⁹ U.S. Army Center of Military History 2009 *History of Strategic Air and Ballistic Missile Defense: Volume II 1956-72* (U.S. Army) pp 212-3.

¹⁰ McGeorge B 1969 To Cap the Volcano *Foreign Affairs* 48 1-20

The new administration quickly decided upon a new system called the Safeguard system. In addition to the long-range Spartan missile, there would be a smaller, faster, and shorter-range missile called the Sprint, which was an updated version of the interceptor envisioned for the Nike-X system. The Sprint (see figure 1.6) would carry a low yield nuclear weapon and accelerate extremely fast. Should the Spartan miss its target, the Sprint would engage the target as the warhead re-entered the atmosphere. The U.S. Senate approved the first phase of the Safeguard system in 1969 when the then current Vice President, Spiro Agnew, cast the tie-breaking vote.

Figure 1.6. The Sprint. (Courtesy of White Sands Missile Range Museum.)

President Nixon wanted to deploy an ABM system that would cost less than the Sentinel system but defend against the Chinese and Soviet threat. There was no possibility to build such a system to defend cities. However, the U.S. was worried about the survivability of its ICBM force because of the threat posed by the Soviet's three-warhead SS-9 missile¹¹. The U.S. did not know at the time which type of warheads were carried by the SS-9 and took the worst-case view that they could independently target U.S. ICBMs. They also estimated that the Soviets would have over 400 of them by 1975¹². Therefore, the decision was made to use the Sentinel system to protect ICBM silos. The U.S. began work on its first ABM system. It was supposed to protect the 150-ICBM silo complex near the Grand Forks Air Force Base in North Dakota.

In the scientific community, debate raged as to the feasibility of an ABM system. There were four basic questions to ask. First of all, would the system work, that is, could it actually detect and shoot down an incoming missile or warhead? The second question was if it did work, would it protect the silos? The third question was if it

¹¹ There are two kinds of multiple warheads or re-entry vehicles, in military vernacular (which sounds less threatening than warheads), that missiles can carry. They are known as MRVs (for multiple re-entry vehicles that all land around one target) or MIRVs (for multiple independently-targetable re-entry vehicles that can engage different targets that can be hundreds of kilometers apart).

¹² Kaplan F 1983 *Wizards of Armageddon* (New York: Simon and Schuster) pp 350-1.

protects the silos, do we need it? Finally, the fourth question is what harm would such a system do?

The answer to the first question appeared to be no. There were just too many things that an incoming missile could do to evade the system. It could use decoy warheads, which would fool the radar and cause the wrong targets to be attacked outside the atmosphere. It could employ electronic counter measures against the radars or harden the warheads to withstand the blast from the ABM missiles. It would overwhelm the system by using lots of multiple warhead missiles. Finally, there was concern about the Electromagnetic Pulse (EMP), generated by the explosion of the Spartan's warhead, that might blind the Safeguard's radar system¹³.

The answer to the second question was also no. This had to do with what is called the cost-exchange ratio mentioned above. It would be cheaper for an adversary to add more warheads than it would cost to upgrade the ABM system. In 1964, Robert McNamara estimated that the U.S. would have to spend \$3.20 on ABM upgrades for each \$1.00 the Soviets spent on adding more offensive forces¹⁴. This estimate was for the Sentinel system, but things were no better with Safeguard.

The answers to the last two questions are more subjective in nature. The answer to the third question could be no. This has to do with the synergy between bombers and ICBMs and showed that it would not be possible to destroy both the bomber force and ICBM force at the same time¹⁵. Either the bombers would get off the ground before the weapons exploded, or the ICBMs would be launched after the bombers were hit. The added expense of the ABM system was not needed. Finally, an ABM system, even if not effective, would result in worst-case analysis and generate a new arms race.

Even though work continued on deploying a Safeguard system, the U.S. and the USSR were in the process of negotiating the first Strategic Arms Limitation Treaty

¹³ An Electromagnetic Pulse (EMP) is the result of the ions produced in a high-altitude nuclear explosion. This can disrupt ground-based and satellite radio signals for several hours, severely affecting early warning and communication systems. The production of these ions creates extremely large electric and magnetic fields that propagate over large distances. It is similar to the effect of a lightning strike, except that the fields are orders of magnitude larger and are produced much quicker. This makes EMP much more damaging than the effects of lightning. The EMP produces large voltages on electrical devices. Long metal wires, power lines, metal pipes, metal fences, railroad tracks, and antennae can all act as collectors for the EMP extending the effect throughout large areas. The EMP could damage electrical power grids, radio and TV stations, and telecommunications. Particularly susceptible are low-power, high-speed integrated circuits, and computer systems.

¹⁴ Op. Cit. Kaplan 1983 (New York: Simon and Schuster) p 322.

¹⁵ The ICBM and bomber forces, taken together, provided a credible survivable force. The flight time for an ICBM from the Soviet Union to the U.S. was 30 min, and the flight time for an SLBM (Submarine-Launched Ballistic Missile) was 15 min. An attacker could follow one of two scenarios. The attacker could choose to launch both SLBMs and ICBMs at the same time. The less accurate SLBMs, not capable of destroying silos, would be targeted on the bomber portion of the Triad. Even if the attacker were successful in destroying the bombers on the ground, it would be another 15 min before the ICBMs reached their targets. By then the U.S. would have launched its ICBM force in retaliation. The attacker could also choose to launch ICBMs first and then launch the SLBMs 15 min later, so that both the ICBMs and the SLBMs reached their targets at the same time. However, the U.S. bombers would have 30 min after the attack warning before the SLBMs reached their targets and would be able to get in the air before being attacked. During the Cold War 1/3 of the bomber fleet was maintained at a 15 min alert status. Both systems could not be destroyed completely in a first strike.

(SALT I). The U.S. negotiators were also working to convince the Soviets that an ABM system could not protect cities and posed a possible threat to deterrence. The result was the Anti-Ballistic Missile Treaty.

The ABM Treaty

In the late 1960s, the United States and the Soviet Union began the first serious discussions on arms control. These discussions and eventual negotiations led toward two Strategic Arms Limitation Treaties (SALT I and SALT II). They were the first treaties that addressed the increasing numbers of U.S. and USSR nuclear weapons. Negotiations for SALT I began in November 1969 and it was concluded in 1972 during the Nixon administration. It limited the number of ICBMs, submarines, and SLBMs (Submarine-Launched Ballistic Missiles) that each country could deploy. SALT I put a cap on the number of ICBMs, submarines, and SLBMs. However, those numbers were either equal to, or slightly larger than what each country already had, so no weapons were destroyed. Its most important failure was not addressing the number of MIRV warheads a country could put on its ICBMs and SLBMs¹⁶.

SALT I had a significant impact on the future of USSR/Russian and U.S. arms control. It consisted of two parts: one, called the Interim Agreement, limited the number of weapons; and the second part was the ABM Treaty. It also obligated each country not to interfere with attempts to verify the treaty limits and provided a mechanism to discuss and resolve any discrepancies that might arise.

The full text of the ABM Treaty is reprinted in the appendix. The treaty contains three important limitations on ABM systems. First of all, in Article III of the treaty, each side was allowed two ABM sites, one around each country's capitol, and one around an ICBM silo complex. The sites could only contain 100 missiles and have a radius of 150 km or less around the sites. This was an obvious recognition of the fact the USSR had deployed a 100 missile ABM system, with a radius of 150 km around Moscow and the U.S. was building an ABM system around an ICBM base. It limited the number of radar complexes associated with an ABM site and the area of each complex.

Article V of the treaty states that '(e)ach Party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based'. Furthermore, Article VI of the treaty states that any large, early-warning radar must be located at a country's periphery and pointed outward. This was to ensure that any large radar, able to track many targets at one time, would be used for the early warning of an attack. If the radars were in the center of the country, or pointing inward from the periphery, they could be used to track

¹⁶ SALT II attempted to address the escalating number of warheads by setting limits. But once again, most of the limits were set higher than the number of warheads already in the US and USSR arsenals. SALT II was never ratified. In 1979 the Soviet Union invaded Afghanistan, and President Carter withdrew the treaty from the U.S. Senate, stopping efforts for ratification. Even though SALT II never entered into force, both the U.S. and the USSR governments pledged to uphold its limits. However, in 1986, President Reagan, believing that the USSR was in violation of other treaty obligations, negated that pledge.

targets for a nationwide ABM system designed to protect the whole area of a country and not just the two sites allowed by the ABM Treaty.

The ABM Treaty was amended in 1974 to allow for only one ABM site in each country. The Soviets would keep their system around Moscow and the U.S. was to have the one at Grand Forks, North Dakota. The site at Grand Forks was completed in 1975. The day after it became operational, the U.S. Congress refused to continue funding for the site and voted to deactivate it and the site was closed in February 1976, just 315 days after achieving its initial operational capability¹⁷. The site still exists and is maintained by the U.S. Air Force. All that remains is the large radar and a few empty supporting buildings (see figure 1.7).

Figure 1.7. Safeguard site. (Courtesy Stanley R. Mickelsen Safeguard Complex Website.)

It was clear that the vast number of Soviet MIRVs could easily defeat the system. It is ironic that the MIRV technology, first developed by the U.S. to overwhelm the Soviet ABM systems, would now make the U.S. ABM system obsolete. Also, a major problem with the U.S. ABM system was the fact that it required nuclear warheads to intercept incoming missiles.

The Soviets continued to operate their system around Moscow. It was comprised of two missiles, similar in concept to the Safeguard system, both carrying nuclear warheads. However, after the fall of the Soviet Union, the Russians have been either unable or unwilling to maintain the system, and it has deteriorated significantly.

In presenting the SALT I and ABM treaties to the congress, President Nixon stated.

...the treaty and the related executive agreement which will limit, for the first time, both offensive and defensive strategic nuclear weapons in the arsenals of the United States and the Soviet Union. ...From the standpoint of the United States, when we consider what the strategic balance would have looked like later in the

¹⁷ Finney J W 1975 Safeguard ABM System to Shut Down; \$5 Billion Spent in 6 Years since Debate' *New York Times* (November 25, 1975) <http://www.nytimes.com/1975/11/25/archives/safeguard-abm-system-to-shut-down-5-billion-spent-in-6-years-since.html>.

*seventies, if there had been no arms limitation, it is clear that the agreements forestall a major spiraling of the arms race—one which would have worked to our disadvantage, since we have no current building programs for the categories of weapons which have been frozen, and since no new building program could have produced any new weapons in those categories during the period of the freeze....I can assure you, the Members of the Congress, and the American people tonight that the present and planned strategic forces of the United States are without question sufficient for the maintenance of our security and the protection of our vital interests*¹⁸.

For most of its history, the ABM treaty provided assurances that each side's deterrence capability would not be threatened by an ABM system. In fact, the rest of the world came to the belief that the ABM treaty was an important arms control measure. However, it also reinforced the policy of MAD. Nuclear war between the United States and the Soviet Union could only be prevented by essentially holding each other's populations hostage, since there seemed to be no way to protect a country from total annihilation should war break out. Most national security planners seemed to adopt an uneasy comfort with MAD, however, civilians' fear and anxiety would fluctuate with the rise and fall of global tensions.

In 1988 the Reagan administration accused the Soviets of a serious violation of the ABM treaty. The USSR had begun construction of a large phased array radar system near Krasnoyarsk. The radar was located in the middle of Siberia and clearly was not on the periphery of the country as required by the ABM treaty. According to the Reagan administration, this was another example of Soviet cheating, and provided another reason for President Reagan to order the deployment of forces that violated the SALT II treaty as described previously. Why the Soviets built the radar site at that location was never made clear. In all probability, building a radar station on the periphery would have been too expensive. In any case, after the fall of the Soviet Union, when the radar station was examined, it was found to be of very poor construction and less than half completed.

SDI

In 1983, in a televised speech to the nation, President Ronald Reagan proposed that the U.S. explore the possibility of a new missile defense system. He said the following.

Tonight, consistent with our obligations of the ABM treaty and recognizing the need for closer consultation with our allies, I'm taking an important first step. I am directing a comprehensive and intensive effort to define a long-term research

¹⁸ Richard Nixon: *Address to a Joint Session of the Congress on Return From Austria, the Soviet Union, Iran, and Poland* (June 1, 1972). Peters G and Woolley J T *The American Presidency Project* <http://www.presidency.ucsb.edu/ws/?pid=3450>.

*and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles. This could pave the way for arms control measures to eliminate the weapons themselves. We seek neither military superiority nor political advantage. Our only purpose—one all people share—is to search for ways to reduce the danger of nuclear war*¹⁹.

The proposal seemed quite modest at the time, but the impact of his proposal is still being felt today. Why would he want to revisit this issue, when the ABM had appeared to be an effective treaty?

First of all, President Reagan was uncomfortable with the concept of mutual deterrence. Secondly, he was influenced by Edward Teller, self-proclaimed 'Father of the Hydrogen Bomb' and the High-Frontier Group. This private organization, directed by Daniel Graham, who was a former head of the Defense Intelligence Agency, was lobbying for a massive research effort into using exotic technologies in a missile defense system.

Certainly, the technological landscape had changed greatly since the 1970s. Computers were smaller and faster, the space program had matured greatly, there were a whole array of new sensors available, and there had been much research on particle beams and high-energy lasers. The research program was called the Strategic Defense Initiative (SDI) but the popular press dubbed it 'Star Wars' after the George Lucas movies. Before examining some of the technologies, let us look at what must be accomplished. The following relies heavily on an unclassified briefing given by the Strategic Defense Initiative Office (SDIO) in July 1986 and a 2000 study by the Institute for Foreign Policy Analysis entitled *National Missile Defense: Policy Issues and Technological Capabilities*.

There are several possible targets to be engaged. First is the missile itself, or in the vernacular of missile defense technicians, the booster. Secondly is the bus, or post-boost vehicle, which can carry multiple warheads and other devices used to foil an ABM system, called penetration aids, or pen aids for short. Finally, there are the individual nuclear warheads or re-entry vehicles (RVs). Figure 1.8 shows the flight path for the missile and its warheads. There are three major parts to its path called the boost and post-boost phase, the midcourse phase, and the re-entry phase. The U.S. has examined systems to attack targets in all three phases.

The rocket engine burns for about 2–5 min (called the boost phase) and then begins to fall back to Earth. The ICBM is generally 300 to 800 km down range and at an altitude of between 200 and 600 km at this point. It releases the bus, which begins to coast along its path until it leaves the atmosphere (the post-boost phase, which lasts from two to 10 min). During these times, if the booster or bus is destroyed, everything else it is carrying is also destroyed. The rocket engine signature is very dramatic, and there is an enormous amount of heat flowing from the back of the rocket, making it easy to observe.

¹⁹ http://www.townhall.com/hall_of_fame/reagan/speech/sdi.html.

Figure 1.8. ICBM trajectory. (Courtesy of the Missile Defense Agency.)

This heat is emitted as infrared radiation. Even as the bus moves through the upper atmosphere, air friction makes the bus's temperature greater than the ambient air, and again makes it easy to detect with infrared sensors. However, if detection is to be performed by satellites, the rocket must make it through the cloud cover before it is easily detected. This could take anywhere from 10 s to a minute.

Detecting a launch in the boost and post-boost phase is only one part of the problem. The targets must also be tracked. For most ICBM launches, the rocket goes straight up for about 15 s before it begins to follow its parabolic path. It is difficult to determine how far down range the missile is traveling unless it is tracked. This means that a missile defense system would not know if the missile were aimed at a target 4000 km or 10 000 km down range until near the booster burnout point. Also, some ICBMs such as the Russian SS-18 and SS-27 can change directions during the boost phase. Finally, the ICBM does not travel at a constant rate of acceleration during the boost phase. As rocket fuel is consumed, and empty stages are jettisoned, the acceleration of the rocket changes. Any attempt to engage an ICBM during its boost phase must be able to anticipate this jerky pattern.

After the post-boost phase, the bus begins to release the RVs, which coast through space. The bus may also release decoys at this time. There could be hundreds of decoys. They are very light but can be made to have the same size and radar signature as real RVs. The RVs and decoys could be fabricated with special coatings or enclosed in cooled 'balloons' to help reduce their infrared signature. In outer space, they are all at the same temperature and, without the effects of air friction, they all move in the exact same manner.

In addition to decoys, there are many other objects that can be used to foil an ABM system. There is usually debris left from the deployment of the RVs and from the rocket stage separations. An adversary could also explode the final rocket stage

to increase the launch debris. Chaff (numerous thin metal strips) could be released to help foil radars and make finding the RVs and decoys much harder. There could be active electronic jamming devices that broadcast a signal to confuse radar systems. Finally, it has been postulated that some warheads could be programmed to detonate if they were struck while en-route to their target. The EMP produced by this high-altitude explosion could blind or even destroy those items being used to track and identify the incoming RVs, particularly those stationed in outer space.

The midcourse phase can last from 20 to 30 min. At this point the RVs enter the atmosphere again and fall toward the target. The decoys are now severely affected by air friction and are easily distinguishable from the RVs. However, after the RVs re-enter the atmosphere, there are only a few minutes left before they must be engaged.

The SDI program was initially sold as providing a shield to protect the whole of the United States, making nuclear weapons obsolete. However, the truth was that it was designed, at least initially, to counter only the threat from ICBMs. An SLBM's flight path is very short, and it does not even enter the upper atmosphere. In 1985 the SDIO released its vision for SDI. It was a seven-layer system with thousands of space-based systems. This Phase I Architecture was approved in 1987 and consisted of: a space-based interceptor (SBI), a ground-based interceptor, a ground-based sensor, two space-based sensors, and a battle management system (see figure 1.9)²⁰. The cost was estimated by Senator William Proxmire to be \$1 trillion (10^{12})²¹.

Figure 1.9. Diagram of Phase I. (Courtesy of SDIO.)

²⁰ See the Missile Defense Agency at <https://www.mda.mil>.

²¹ *Congressional Record* (vol 132, part 6) (April 22, 1986) p 8253.

The initial systems envisioned for SDI used an assortment of weapons systems from rail guns, high-energy lasers, and directed particle beams. Over the next four years SDI researchers examined each of these systems but came to the conclusion that they were just not ready for use in an effective system. The weapons systems were also large, requiring an enormous increase in the capability of the U.S. space program to frequently launch heavy payloads. Finally, these large satellites would prove to be easy targets for a Soviet Anti-Satellite (ASAT) weapon. A brief discussion follows on each of the systems.

A new gadget, called a rail gun, also called a kinetic kill vehicle, received serious consideration. A rail gun (see figure 1.10) would use strong pulsed electric and magnetic fields to propel large metal projectiles at hypersonic speed, disabling a target. Because of the large electrical power needed to accelerate projectiles, plans were to develop an operational system for naval vessels to use against incoming missiles. Current research is focused on designing self-guided projectiles and miniaturizing power supplies to be able to deploy them in space.

Figure 1.10. Artist sketch of a rail gun. (Courtesy of SDIO.)

Nuclear and high-energy physicists have long used particle accelerators to study the properties of matter and the nuclear and strong force. The new application of this technology was to use intense beams of high-energy particles to melt holes in the metal skin of the missile or warhead. The beams might also be effective in damaging the electronics inside used to arm and guide the missiles or warheads. The particles from these directed-energy weapons would be traveling close to the speed of light and allow for a rapid-fire defensive system (see figure 1.11).

Charged particle beams, using ions, protons, or electrons are not usable in outer space. The like charges repel each other, forcing the beam to diverge, and the charges are deflected by the magnetic field of the Earth. However, neutral beam accelerators, producing high-energy beams of hydrogen atoms can be employed. Neutral beam accelerators start with ions that are accelerated using

strong electric fields as with charged particle accelerators. After the ions are accelerated they are sent through a 'stripper' which adds or removes electrons, as needed, to make the ions neutral atoms. The technology is promising but current systems are too large to deploy in space and have not overcome problems with steering and focusing.

Figure 1.11. Artist sketch of an air-based particle beam in action. (Courtesy of Los Alamos National Laboratory.)

Charged particle beams can be used on land-based systems. The intense beam of charged particles burns a channel through the atmosphere by super-heating it. This channel keeps the beam focused. However, they only have a useful range of 1 km. Considering that an RV is traveling at about 10 km s^{-1} before it hits its target, engagement times would be on the order of tenths of seconds. Such systems would be suitable for the defense of military targets such as ICBM silos, but too risky for the defense of cities.

The term 'laser' stands for light amplification by stimulated emission of radiation. A laser produces a very intense narrowly focused beam of electromagnetic radiation. Lasers in the infrared, visible, ultraviolet, and x-ray parts of the electromagnetic spectrum have been used in industry, medicine, and science research. High-powered lasers are also used in inertial confinement fusion. The SDI program examined the possibility of using lasers, particularly space-based lasers, to engage ICBMs in the boost phases and RVs in the midcourse phase. Chemical-fueled lasers, such as CO_2 , HF, and Iodine lasers, whose output is in the infrared, showed some promise (see figure 1.12). However, the size of such an airborne laser, and the amount of fuel needed for each system, make deployment of an effective system unachievable at the present. In addition, the technology needed to build large, lightweight mirrors to launch into space to be used to reflect the powerful laser beams onto a target has yet to be developed.

Figure 1.12. Artist sketch of a space-based chemical laser. (Courtesy US Air Force.)

Ground-based lasers were also studied (see figure 1.13). They consisted of the above-mentioned chemical lasers and new types of lasers called excimers, and free electron lasers that produced energy in the ultraviolet part of the spectrum. They are still in the experimental stage; but a large CO₂ laser was able to shoot down an aircraft in a test in 1973 against a target drone and a more recent test in 2008²². These systems would be most useful during the re-entry phase. Using ground-based lasers against targets in the midcourse phase still has some significant difficulties. As a high-power laser beam penetrates the atmosphere it tends to spread apart, called de-focusing. In order to compensate for this, the beam must be spread across a large, curved space-based mirror, that focuses the power on the target and prevents the mirror from overheating. The mirrors must be large and precisely fabricated yet be able to quickly aim at the appropriate targets while being light enough to be deployed in space (see figure 1.14).

Figure 1.13. Artist sketch of the operation of a land-based laser. (Courtesy of SDIO.)

²² Aviation Week website http://www.aviationweek.com/aw/search/basicsearch_articles.jsp?arct=26&wdct=0&wect=0&blogct=29&tartIndex=1&sortType=date&OASKeyword=laser_shootdown.

Figure 1.14. Photo of a possible mirror design. (Courtesy of SDIO.)

An interesting concept that was highly touted by Edward Teller was called the x-ray laser (see figure 1.15).

Figure 1.15. Sketch of an x-ray laser.

Figure 1.16. Operation of an x-ray laser. (Courtesy of Lawrence Livermore National Laboratory.)

It was basically a small nuclear weapon inside a container that had many metal cylinders protruding outward. When the nuclear weapon was detonated, the metal cylinders would vaporize, and x-rays would then be emitted in a collimated beam along the direction of the cylinders. These intense x-ray beams could then destroy RVs in the midcourse phase (see figure 1.16). Some proposed housing them in space, although that would be against a treaty prohibiting nuclear weapons in space or suggested that the lasers could be mounted on rockets and fired into space when an attack was occurring. Research on the x-ray laser ended when the U.S. decided to stop testing nuclear weapons. It was also clear that the x-ray laser project was oversold from the beginning.

Recent history

The original SDI proposal was clearly overambitious, but research efforts continued. Ground-based missile system research shifted from using nuclear warheads to a hit-to-kill philosophy where the target would be disabled or destroyed by actual contact with a non-explosive warhead. Even before President Reagan's speech in 1983, the advances in sensor and computer technology progress made this type of ABM system seem possible²³. The U.S. Army developed the Homing Overlay Experiment (HOE) in 1977. The HOE used a modified Minuteman booster to deploy a 'kill vehicle' against an incoming warhead. This kill vehicle then expanded

²³ U.S. Army SMD/ARSTRAT Historical Office 2007 The Homing Overlay Experiment: The First "Hit-to-Kill" Kinetic Energy Interceptor Missile *Eagle* 14 (6) (June/July 2007) 11.

to a net of metallic spokes about 13 feet in diameter. The HOE weighed around 1200 kg (see figure 1.17)²⁴.

Figure 1.17. HOE kill vehicle (Wikimedia).

In 1984, the SDIO funded the research and development of two hit-to-kill ground-based systems, the Exo-atmospheric Re-entry-vehicle Interceptor Subsystem, or ERIS (see figures 1.18 and 1.19), which would destroy warheads in midcourse, and the High Endo-atmospheric Defense Interceptor (HEDI), which destroyed enemy missiles in the upper atmosphere. These had similar missions to the Spartan and Sprint missiles but did not use nuclear warheads.

One alternative proposal to SDI from Congress was the Accidental Launch Protection System (ALPS), introduced by Senator Sam Nunn in 1988. It was intended to use more near-term promising technologies until other more exotic SDI systems could be developed. In order to fulfill U.S. obligations under the ABM Treaty, the United States would station 70 ERIS and 30 HEDI interceptors at the Grand Forks ICBM complex. It could provide protection against a few Soviet ICBMs that might have been launched by accident. This capacity might have provided protection against only one or two MIRV-equipped Soviet ICBMs, however, and would have been of little use against an SLBM launch. In 1990, the Senate voted down an amendment to fund ALPS from SDI funds²⁵. The HEDI and ERIS programs were eventually canceled in 1991 and 1992 after mixed test results and the brief euphoria from the collapse of the Soviet Union²⁶.

²⁴ National Research Council 2012 *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington, DC: The National Academies Press)

²⁵ Daalder I H 1991 *Strategic Defence's (sic) in the 1990s: Criteria for Deployment* (London: International Institute for Strategic Studies) pp 24–31.

²⁶ Global Security *High Endo-atmospheric Defense Interceptor (HEDI) and Exo-atmospheric Re-entry-vehicle Interceptor Subsystem (ERIS)* <https://www.globalsecurity.org/space/systems/hedi.htm>.

Figure 1.18. ERIS. (Courtesy of the U.S. Air Force.)

Figure 1.19. Kill vehicle for ERIS. (Courtesy of the U.S. Army.)

Research also continued on space-based systems encouraged by the rapid advance in computer chip and sensory technology. In 1987, Lowell Wood and Edward Teller of the Lawrence Livermore National Laboratory proposed a large number of small satellites that could detect and destroy Soviet warheads in midcourse by disabling them with high-speed projectiles²⁷. It was estimated that as many as 7000 satellites would be needed to cover the Soviet Union at any given

²⁷ Coffey P 2014 *American Arsenal: A Century of Weapon Technology and Strategy* (New York: Oxford University Press).

time²⁸. It was modified in 1989 to a system of thousands of small satellites called Brilliant Pebbles and a land-based interceptor for terminal defense. These interceptors would not carry nuclear weapons but would destroy their targets with a 'hit-to-kill' capability.

Each Brilliant Pebble satellite (see figure 1.20) would have its own system of sensors to detect a missile launch, onboard computers to track the targets and for battle management, and an array of small, supersonic missiles to engage and destroy RVs in the boost through midcourse phases of flight.

Figure 1.20. Brilliant Pebbles concept. (Courtesy of Lawrence Livermore National Laboratory.)

Figure 1.21. Sketch of deployment of Brilliant Pebbles. (Courtesy of MDA.)

²⁸ Stevens C and White C 1990 Brilliant Pebbles are not that Smart *EIR Sci. Technol.* 17.

Since the Brilliant Pebbles satellites could be mass-produced, and there was one less system of sensors needed, the cost of deploying the system would be reduced. Also, the large directed-energy weapons systems that were easy targets for a Soviet ASAT weapon would be replaced by thousands of smaller, and harder to target, satellites (see figure 1.21).

Many significant concerns were expressed about Brilliant Pebbles. First and foremost was the cost. In early 1988 initial cost estimates for the whole system was about \$10 billion and about \$100 000 for each satellite²⁹. By the end of that year, the estimate had jumped to between \$500 000 and \$1.5 million per satellite³⁰. This did not include the cost of placing the satellites in orbit. It was thought the space shuttle would be able to place several Brilliant Pebbles in orbit per launch. An additional concern was the fact that a Brilliant Pebbles satellite could function autonomously. It was feared that any glitch in the massive lines of computer code needed might lead to the accidental engagement of a non-threatening satellite. There simply was no way for hundreds of thousands of lines of computer code to be tested before deployment. Finally, many feared that thousands of additional satellites would create a serious traffic jam with all the other vital nonmilitary satellites already present. Even so, funding for SDI continued at about \$4 billion a year from 1987 through 1990³¹.

In 1991, at the end of the Cold War, President George H W Bush ordered a new emphasis for the SDI effort known as the Global Protection Against Limited Strikes (GPALS)³². It was also supposed to provide protection for all 50 states and not just the continental United States from a 'limited strike' of up to 200 ICBMs or SLBMs³³. The new GPALS concept was fully described in a May 1991 report published by the SDIO. It consisted of four parts; a ground-based missile system to protect the United States, a ground- and sea-based system to defend overseas United States forces and allies, Brilliant Pebbles in space (seen as both a system for providing early detection of launches, as well as being able to attack any missile with a range greater than 600 km)³⁴, and a command and control system tying them all together. A system of additional satellites called Brilliant Eyes, a low-orbit detection platform, would also be able to aid Brilliant Pebbles and the ground-based missiles. (See figure 1.22, with definitions of acronyms³⁵.)

²⁹ Op. Cit. Coffey.

³⁰ Smith R J 1989 Year of Lobbying Turned "Brilliant Pebbles" into Top SDI Plan *Washington Post*.

³¹ Schwartz S I (ed) 1998 *Atomic Audit, The Costs and Consequences of U.S. Nuclear Weapons Since 1940* (Washington, DC: Brookings Institution Press) p 291.

³² Bush G H W *State of the Union Address* (speech, Washington DC, January 29, 1991).

³³ Cooper and Hadley 2017 'GPALS: Briefing,' 14. From *Missile Defense 2020 Next Steps for Defending the Homeland* by Thomas Karako, Ian Williams, and Wes Rumbaugh: A report for the Center for Strategic and International Studies, Missile Defense Project: <https://www.csis.org> (April 6, 2017).

³⁴ Baucom D 2004 The rise and fall of Brilliant Pebbles *J. Soc. Polit. Econom. Studies* 29 171.

³⁵ E²I = Endo/Exo-atmospheric Interceptor; GBI = Ground-Based Interceptor; GBRT = Ground-Based Radar Termonal; GSTS = Ground Surveillance and Tracking System.

Figure 1.22. GPALS architecture. (Courtesy of SDIO.)

The SDIO sent their proposal to the U.S. Congress for funding which passed the Missile Defense Act of 1991. This legislation stated that a limited defense system should be in place by 1996 that was in compliance with the ABM treaty. This system then could have no more than 100 ground-based interceptors near the Grand Forks Air Force Base. Although Brilliant Pebbles would not be part of this system, the legislation provided funding to continue research and development and encouraged renegotiating changes to the ABM Treaty for the deployment of future systems³⁶. The Missile Defense Act of 1991 increased funding for TMD systems, which will be explained further below.

The Brilliant Pebbles weapons system was tested on three different occasions, in August 1990, April 1991, and October 1992. They all failed^{37,38,39}. During the initial months of the presidency of newly-elected Bill Clinton, interest in the Brilliant Pebble concept waned. In early 1993, Secretary of Defense Aspin reduced the budget for Brilliant Pebbles from \$100 million to \$75 million and designated it as a possible future ABM system component. In 1993, it was renamed the Advanced Interceptor Technology Program⁴⁰. Also in 1993, the SDIO was

³⁶ Op. Cit. Baucom, p 171.

³⁷ Global Security *Brilliant Pebbles* <https://www.globalsecurity.org/space/systems/bp.htm>.

³⁸ 1993 Strategic Defense Initiative: Some Claims Overstated for Early Flight Tests *Technical report* GAO p 36.

³⁹ Op. Cit. Baucom, p 181.

⁴⁰ Op. Cit. Baucom, p 184.

renamed the Ballistic Missile Defense Organization (BMDO), increasing the emphasis on TMD systems. The Brilliant Pebble's program was finally eliminated at the end of 1993 and the BMDO focused solely on a single ground-based interceptor for national missile defense⁴¹.

⁴¹ Op. Cit. Global Security, Brilliant Pebbles.