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Technological Controversy and US Ballistic Missile Defence: Star Warriors versus the Huntsville Mafiaⁱ

Abstract

Controversy over the technical feasibility of Ballistic Missile Defence (BMD) has typically been seen as correlated to judgments of that technology's desirability. Opponents of BMD tend to question its feasibility whereas supporters argue that it is technically possible, at least to a degree adequate to enhance national security. However, this categorization is a simplification; two camps of BMD supporters have emerged over the years, with distinctly different views as to which technology they believe to offer the greatest effectiveness. This paper describes the emergence of these two camps – one preferring ground-based interceptors, the other space-based systems – and argues that the lack of operational experience means that complete closure around one approach is unlikely.

Keywords

Missile Defence, Military Technology, Technological Controversy, Testing.

Introduction

Much of the debate over US ballistic missile defence (BMD) has been characterized as a battle between proponents and opponents over both the desirability and feasibility of BMD. The arguments for and against BMD have been articulated many times since they were first made in the 1960s, and the rhetoric of these positions has become entrenched.ⁱⁱ However, viewing the debate over the feasibility of BMD as either for or against is a misleading simplification. In fact, supporters of BMD are themselves divided by a dispute over the best technical means to achieve an effective defence, with one side preferring ground (or sea) based defences and the other advocating defensive systems based in space.ⁱⁱⁱ

This paper describes the history of US BMD technology as it relates to the development of these two technological approaches, and examines why such divergent views have persisted. What is distinctive about the debate over BMD is that it is not simply a matter of disagreement about the desirability of the technology. There is dispute about this, including opposition that stems from concerns about potential arms race escalation,^{iv} but a substantial part of the controversy over BMD hinges on questions of feasibility. What is particularly distinctive about BMD is the way that these doubts about technical feasibility have persisted over a period lasting more than half a century.

One view of the persistence of skepticism regarding the feasibility of BMD would be to say, as many opponents do, that it is simply too hard a technical challenge, especially in the face of a determined enemy. In this view, any technological advances that help the defence are equally likely to provide counter-measures to help overcome that defence, and the immensely destructive nature of nuclear weapons means that even a small percentage of 'leakage' would make a defence worthless.^v

However, the idea that missile defences need to be one hundred percent perfect is a construct of a particular period of time, not a requirement that has been constant throughout the whole history. At certain periods the stated goal has been population or area defence, but at others it has been the defence of missile silos or other key assets (known as point defence). What counts as an effective defence has varied over time and has never been a subject of complete agreement.^{vi}

Ballistic missile defence technology thus has always involved high levels of 'interpretative flexibility', both with regard to its objectives, as well as the means of achieving those objectives.^{vii} Although advocates of BMD believe it is possible to attain an adequate technical performance, they do not agree on the best technological means to achieve this. At the heart of the dispute is the difficulty of obtaining convincing empirical evidence about the performance of BMD technology.

There has (thankfully) been no operational experience of the use of BMD against a nuclear attack, nor indeed any experience of a nuclear conflict. Empirical evidence of the feasibility of intercontinental BMD technology thus relies entirely on testing, but this is unavoidably limited in scope.^{viii} As Phil Coyle, then Director, Operational Test and Evaluation at the Pentagon, said in 2000, 'it is impractical to conduct fully operationally realistic intercept flight testing across the wide spectrum of possible scenarios.'^{ix} Full-scale flight-testing is extremely expensive (current tests cost around \$100 million a shot), geographically limited by range safety concerns, and inevitably prone to criticisms that it is insufficiently similar to operational usage.^x

Lacking compelling empirical evidence from use or testing, knowledge about the performance of BMD technology has instead been strongly shaped by theoretical debates about the in-principle benefits of one approach versus another, and by the ability of the various protagonists to adapt to or shape the prevailing political currents. Thus, although technical disputes are at the centre of this history, BMD has been, and remains, the most political of technologies.

The history of US missile defence can be viewed as three main phases. The first, culminating in the deployment of the Safeguard system in 1975, involved ground-based missiles and radars, in which the radars were designed to guide a defensive interceptor armed with a nuclear warhead sufficiently close to the enemy warhead. The second phase, from 1983 to 1991, saw space-based systems given preference, although no system was actually deployed. Finally, the third phase, from 1991 to the present, has seen ground-based interceptors return to favour, though no longer with the use of nuclear warheads. Instead, the current system uses hit-to-kill technology in which the interceptor kill vehicle is designed to collide physically with incoming warheads.

Phase 1: The Path to Safeguard

Although interest in defence against ballistic missiles arose as soon as the first such missile, the German V2, went into operation towards the end of World War II,

serious system development did not get underway in the US until the mid-1950s. Intelligence reports in June 1955 suggested that the Soviet Union would soon have intercontinental ballistic missiles (ICBMs) able to threaten the USA and the recently-started NIKE II study on air defence, switched its emphasis from anti-aircraft defence to anti-ballistic missile (ABM) defence.^{xi}

Thereafter, during the late 1950s and 1960s ABM technology was developed with a common technical approach within a stable organizational setting. The organizational setting was established in 1958 when the Army, with its missile defence operations in Huntsville, Alabama, was given sole responsibility for ABM development, despite the protestations of the Air Force.^{xii} The first ABM system developed was the Nike Zeus three-stage missile armed with a nuclear warhead and with associated radar and control systems to direct the missile towards the target reentry vehicle. From 1960 onwards the Army pressed for a deployment decision with no success, despite enrolling support in Congress 'to loose the Zeus'.^{xiii}

While the Army was focused on building an operational system, the Advanced Research Projects Agency (ARPA) was set up in 1958 to conduct research into advanced technologies including missile defence. ARPA initiated Project Defender 'to obtain an advanced system of defense, either supplementary to or extending beyond the present Nike-Zeus terminal intercept concept.'^{xiv} Both ARPA and the Air Force carried out work on a range of approaches, including futuristic technologies such as lasers and particle beams.^{xv} Many of the approaches investigated in Project Defender, including a space-based interceptor (ballistic missile boost intercepts or BAMBI) designed to attack Soviet missiles in their initial boost phase, would be revived later in the 1980s.^{xvi} ARPA also supported research at the Lincoln Laboratory at MIT, which to this day continues to be at the forefront of developments in discrimination techniques.^{xvii} This twin track approach established the geography of missile defence for many years to come: 'Most of the people in

Washington came out of ARPA and most of the people in Huntsville came out of the Army Missile Command.^{xviii}

Secretary of Defense Robert McNamara declined to go ahead with Zeus deployment, and in 1963 instead instigated the Nike X programme which comprised a 'number of studies and exploratory developments aimed at leading from the ... outmoded NIKE-ZEUS to the next generation ABM system'.^{xix} Although conceding that Nike Zeus deployment might have some benefits – possibly reducing US casualties^{xx} in the event of a nuclear war and complicating Soviet planning – he concluded that deployment would be premature given the limitations of the technology.^{xxi}

Nike X involved two major advances over Zeus. First, Nike X comprised a layered defence, with a further development of the Zeus missile (later known as Spartan) as the first line of defence, able to intercept warheads up to an altitude of about 100 miles. A second line of defence was provided by the high acceleration Sprint missile that was designed to intercept reentry vehicles within the atmosphere, at an altitude of between 20 and 30 miles, by which time any decoys or other lightweight penetration aids would have been stripped away by drag. The second significant advance of Nike X was the use of phased array radars developed in ARPA's Project Defender. Because they scanned electronically rather than mechanically, these radars were less fragile, and could handle many more targets, more rapidly.^{xxii}

Despite these improvements, further efforts by the Army to get an ABM deployment approved in 1965 were rejected for two reasons. First, McNamara was concerned that this would be technologically premature and that early deployment would result in wasteful obsolescence. Second, comparisons of the effects of various combinations of offence and defence on American casualties in a nuclear exchange suggested that investment in defences would not be cost effective.^{xxiii} Better value, in terms of American lives saved per dollar, could be achieved by enhancing the ability of US offensive weapons to penetrate Soviet defences.^{xxiv}

McNamara continued to oppose ABM deployment, but in 1967 he was over-ruled by President Johnson who was no longer prepared to leave defence matters to McNamara's discretion. Disillusioned with the state of the war in Vietnam and attuned to the demands of domestic politics (and fearful of an 'ABM gap' being used against him in the 1968 presidential campaign), Johnson pushed McNamara to compromise.^{xxv} The arguments of ABM supporters were also enhanced by the detonation of China's first H-bomb in June 1967, and by McNamara's failure to convince the Soviet Premier Kosygin that defensive systems should be limited to prevent an arms race.^{xxvi}

The result was McNamara's famous San Francisco speech of September 1967. Chinese developments provided a rationale for McNamara to give some ground on ABM deployment – a limited system aimed at the potential Chinese threat – while resisting the major deployment geared towards the Soviet threat which he believed to be not only futile but also counterproductive. His speech commenced by pointing out that US and Soviet nuclear forces were so extensive that neither could deny the other the power to retaliate even if they did deploy an ABM. Instead, he argued, it would be more logical to engage in arms control negotiations to limit both 'offensive and defensive strategic nuclear forces'.^{xxvii} Following this logic, he dismissed the Soviet deployment of an ABM system as not posing a threat to the ability of the US to achieve 'assured destruction' against the Soviet Union, and rejected deployment of a US ABM system aimed at defending against a Soviet attack on the grounds that it would not work.

Instead, McNamara announced an ABM system geared towards the Chinese, a threat that for the foreseeable future would comprise only a small number of unsophisticated ICBMs. Against this even a 'thin' ABM system might be effective, but such a system would not pose a significant threat to the much larger and more capable Soviet nuclear forces. Moreover, McNamara noted, in addition to defending against the Chinese this thin ABM could have secondary benefits. First, it could be

used to defend US Minuteman missile fields, thus adding to the ability of the US to guarantee assured destruction retaliation. Second, it could provide protection against any accidental launches of nuclear-armed ballistic missiles. What it was not, McNamara emphasised, was a first step in a wider deployment aimed at the Soviet Union. On 4 November he announced that the anti-Chinese ABM would be named Sentinel, with the Nike-X designation retained for continuing R&D on BMD technology. Later, McNamara would admit that the announcement of Sentinel was purely due to 'the political pressure, and the fact that the Congress had authorized such a system, appropriated funds for it, and was pushing unmercifully to deploy not the thin system but a thick system'.^{xxviii}

Of the fifteen areas chosen for Sentinel defence, ten were major urban centres, one was Alaska, and the other four were air force bases that housed US retaliatory forces. However, the location of many of these bases stoked opposition to ABM technology as local protesters opposed the proximity of Sentinel to cities. Critics such as the Federation of American Scientists argued that Sentinel bases would be targets, drawing down fire on nearby cities, making them 'megaton magnets', and there was also concern that the nuclear warheads on ABM interceptors might explode accidentally or, in the case of launch, prematurely.^{xxix}

Ironically, after years of pushing the administration to deploy an ABM system, Congress now saw the emergence of a coordinated opposition. Along with concern over the location of Sentinel sites, there was a pent up dissatisfaction with US defence decision-making with power having been increasingly centralized by McNamara in the Office of the Secretary of Defense, with Congress having been dominated by traditionally conservative committees that were typically unquestioning of the claims of the military, and with the Vietnam war going so badly.^{xxx}

Given this upsurge of opposition, it was not surprising that the new Nixon administration initiated a review of US strategic programmes on 20 January 1969, shortly after taking office. On 6 February 1969, the new Secretary of Defense, Melvin Laird, halted Sentinel, pending completion of this review.^{xxxii} The decision was made to change the focus of Sentinel to protect US ICBM fields rather than cities, with population defence against accidental launches, China, and even the Soviet Union suggested as future potential developments.^{xxxii}

Renamed as Safeguard, this system was to encompass up to twelve sites, with initial construction of two at Malmstrom, Montana and Grand Forks, North Dakota to protect Minuteman ICBM fields. Safeguard reduced the local opposition provoked by Sentinel by moving the ABM interceptors away from cities, but the basic technology of Safeguard – Spartan and Sprint interceptors controlled by large ground-based radars – remained the same:

... the mission change from city defense to silo defense (Sentinel to Safeguard) was made without changing the system design in the slightest. Granted that this carryover of the same system design was an expedient in a difficult political environment, it was a mistake in a technical sense. Safeguard was too large, soft and expensive to use as a defense of the Minuteman forces.^{xxxiii}

Ironically, although Safeguard procurement was largely successful with the system completed more or less on time and budget, this particular BMD technology would be very short-lived. Only one site was built, comprising radars, and both Spartan and Sprint missiles, to protect a Minuteman ICBM field at Grand Forks, North Dakota. However, the Army and DoD had serious misgivings about its effectiveness, as did Bell Labs, the prime contractor building the system. Indeed, the President had been informed as early as April 1970 about Bells' 'belief that the system, as it is being built, cannot adequately perform the missions assigned to it.'^{xxxiv} Not only was it

considered unlikely to be very effective against ICBMs carrying multiple warheads (MIRVs), but also there were doubts about whether the detonation of Safeguard's own nuclear warheads would blind the defensive radars and/or prevent the launch of the ICBMs that were being defended. Moreover, 'Spartan, which was the area interceptor, with over a megaton of nuclear warhead, could be defeated by chaff.'^{xxxv}

Congress had only initially approved Safeguard by the most marginal of votes, and the revelation that the DoD itself had little faith in its effectiveness and planned to deactivate the system within a couple of years, led to its swift demise.^{xxxvi} On 2 October 1975, just after the system had been declared operational, the House voted to deactivate Safeguard.^{xxxvii} Starting in February 1976 the Army began removing the missiles and warheads from their silos and turned off the missile site radar.^{xxxviii}

Doubts about the effectiveness of ABM systems had also by this time played a part in the negotiation of the ABM Treaty limiting the deployment of such systems by the USA and Soviet Union. Implicit in this treaty was the recognition that offensive nuclear forces would always have the upper hand, and that deployment of ABM defences would only serve to add another, unproductive, arena of competition to the arms race. The superpowers thus agreed, in effect, that 'mutual assured destruction' was an unavoidable fact of life to which there was no convincing technological alternative, and that it was thus better to enshrine this reality in an agreement limiting the development and deployment of BMD technology.^{xxxix}

Following the demise of Safeguard, work at Huntsville focused on improving concepts for the protection of missile silos and on basic R&D.^{xl} The change in approach was summed up by the Army's Ballistic Missile Defense programme manager, Major General Robert C. Marshall:

For the past 20 years the major activities of the BMD community have, for the most part, been directed toward the achievement of one primary goal – the development and deployment of a BMD system. ... Today our situation is quite different. We do not have a specific system deployment objective as a follow-on to SAFEGUARD. Instead our emphasis now is on R&D as a hedge against the uncertainties of the future.^{xli}

Although no deployment decision was taken, consideration was given to using a Site Defense system to enhance the survivability of the MX ICBM. The Army also continued to support work on directed energy weapons such as lasers and particle beams.^{xlii} Indeed the second half of the 1970s saw an upsurge in interest in such technologies, with increasing lobbying for BMD based on more exotic technologies.^{xliii} However, the most significant development at Huntsville stemmed from its work on infra-red homing guidance technology. It was recognized that infra-red detecting semiconductors had great potential for ‘seeing’ objects against the cold background of space.^{xliv} Initially, studies into the potential of this technology as an alternative to the radar-based command guidance approach, as used in Safeguard, were still predicated on the use of nuclear warheads, but with the hope that more accuracy would allow smaller warheads to be used.

However, by the early 1970s work done by Lockheed in a key study known as LORAH (long range area homing) convinced the Army that infra-red guidance could enable the interceptor to actually hit the target reentry vehicle, not just get close to it.^{xlv} The Army sought authorisation from Secretary of the Army John Walsh for a ‘hit-to-kill’ flight test programme – the Homing Overlay Experiment (HOE). Walsh’s initial reaction was skeptical. Given that Safeguard had required the use of nuclear warheads with a lethal radius of about a mile, it seemed implausible that the Army now claimed to be able to achieve a direct hit: ‘it was kind of a hard sell

because it's counter-intuitive. We were using big nuclear warheads. All of a sudden we don't have to use any warhead.'^{xlvi}

Walsh did eventually authorize HOE, and after three flight test misses, the fourth and final test was a complete success.^{xlvii} However, by then – the fourth test was on 10 June 1984 – the political climate for missile defence had changed even more drastically than the technology. Ironically, what at first seemed like a huge boost for missile defence supporters would be a set-back both for Huntsville and its hit-to-kill technology. By the time of the HOE flight tests the direction of US BMD efforts had changed completely and Huntsville would no longer be the leader of these efforts. After about a quarter century at the centre of US missile defence technology (albeit with ARPA also playing a major role until 1968), the 'Huntsville mafia' were about to find themselves marginalised.

Phase 2: The 'Star Wars' Speech and the Strategic Defense Initiative

The origins of President Reagan's 'Star Wars' speech of March 23, 1983 are well-documented.^{xlviii} The resulting Strategic Defense Initiative (SDI) constituted a radical shift in US BMD efforts in three main ways: conceptually, technologically, and organizationally. Conceptually, Reagan's speech suggested a revolution in nuclear strategy by aiming to make nuclear weapons 'impotent and obsolete'. The President's emphasis on protecting people from nuclear attack seemed to require an impervious shield over the USA. To achieve this, the rhetoric of SDI emphasized space-basing and the advantages inherent in boost-phase interception. Not only did this add a third layer to the mid-course and terminal defences envisaged in Safeguard – thus, on paper at least, promising lower leakage^{xliv} – but also it had the benefit of intercepting missiles before their multiple warheads and decoys could be released. The idea of boost phase interception was not, of course, new; it had been studied in the earlier BAMBI concept. What was new was that SDI put boost phase interception at the heart of its claims to effectiveness, although the technology to achieve this was as yet unspecified.

Technologically, SDI initially stressed the promise of directed-energy technologies such as lasers and particle beams. However, there were disputes about which technologies should be emphasized, even within the ranks of the 'Star Warriors'. Edward Teller, along with Lowell Wood of Lawrence Livermore National Laboratory, strongly pushed Livermore's new X-ray laser concept. For example, Teller claimed that 'a single X-ray laser module the size of an executive desk which applied this technology could potentially shoot down the entire Soviet land-based missile force.'¹

Others in the High Frontier group that had lobbied Reagan to support missile defence were skeptical about the claims made for the X-ray laser. Using a device based on a nuclear warhead did not gel with Reagan's aim of making nuclear weapons 'impotent and obsolete'. Early criticism of the political problems with basing nuclear weapons in space led Teller and Wood to devise another basing mode in which the X-ray laser would be deployed in submarines and 'popped up' into space on a missile when required.^{li}

However, most of the 'Star Warriors' supported boost phase interception with systems based permanently in space. A key figure in High Frontier (he later adopted the name for his own organization) was retired Army General Daniel Graham who favoured a return to the BAMBI concept, arguing that technological advances now made it feasible. Graham resuscitated the concept, renaming it Global Ballistic Missile Defense (GBMD).^{lii} Others preferred a more 'high tech' approach, with laser battle stations in space being the most popular.

Finally, SDI marked a significant shift in the way US BMD work was organized. Nowhere was there more surprise at Reagan's speech than among the missile defence experts in Huntsville, but the Army and its contractors quickly became disillusioned with SDI: 'Yeh, it screwed things up terribly. We at first thought it was a great thing that they set up an agency at that level to do national missile defence but ... [they] had no interest in real solutions. They were interested in "new"

innovative ideas - space based defence and lasers and a bunch of other utterly ridiculous concepts that defied the laws of physics, logic and affordability.^{liii}

SDI shifted the centre of power of BMD work to Washington, DC, and increased the influence of the nuclear weapons laboratories at Los Alamos and Livermore. Indeed SDI was set up to bring new thinking to the challenge of missile defence, and to shake up what some saw as the entrenched ground-based approach of Huntsville. Secretary of Defense Weinberger decided that 'the best way to ensure the application of every available resource, as quickly as possible, to the development of this new initiative of the President, was to create a new unit within the Department, assign to it full responsibility for the research and development of the project and reallocate to it all the resource funding that was available then for defensive work.'^{liv}

Boost phase interception does in theory offer great benefits in eliminating the effects of MIRVing. However, locating defensive weapons close enough to Soviet ICBM fields was problematic. The earth's curvature meant that the early stage of a missile launch - the boost phase - would be out of the 'line-of-sight' of any surface based weapon. Guaranteed boost phase interception of Soviet ICBMs thus seemed to require space-basing, but even if the technology was available to achieve interception from space, there remained practical concerns.

The logistics of putting sufficient defensive systems into orbit was (and still is) daunting. There is only one orbit, known as the geostationary orbit, where satellites move at the same speed as the earth rotates, and so stay above the same location. However, the geostationary orbit is 35800 kilometers above the equator and thus too far from boost phase targets for any realistic weapon to be effective.^{lv} Satellites in orbits closer to the earth move across the face of the earth, and so maintaining a capability above a particular area, such as Soviet ICBM fields, would require a large number of satellites. In the early 1980s it was possible to be optimistic that the Space Shuttle might provide cheap transportation into orbit, but such optimism proved unfounded.^{lvi} Thus, apart from the availability or not of suitable weapons

technologies, the cost of putting a constellation of battle stations into orbit led many to doubt the feasibility of the space-based approach. A further concern was that battle stations based in space would themselves be vulnerable to attack.

Criticism of SDI intensified in 1984 with the publication of two detailed analyses by the Senate's Office of Technology Assessment (OTA) and the Union of Concerned Scientists (UCS). While the UCS - known amongst some missile defence insiders as the 'Union of Confused Scientists' - could be dismissed as known critics of missile defence, the OTA report carried more weight when it was published in April 1984. The OTA report concluded that current and foreseeable technologies were inadequate to meet the defensive goals of SDI, and that the prospect of a perfect or near-perfect defence was 'so remote that it should not serve as the basis of public expectations of national policy on ballistic missile defense.'^{lvii}

In fact, most administration officials were careful not to make claims about near-perfect population defence or to endorse unambiguously the President's aim to make nuclear weapons 'impotent and obsolete'.^{lviii} Nevertheless, the idea stuck in the public consciousness and would haunt future BMD development; thereafter it would always be judged against this demanding yardstick. At the time SDIO adopted a different tactic to defuse this issue. Whatever the merits of specific technical criticisms, SDIO took a philosophical approach that denied such defeatism. Thus the first Director of SDI, General Abrahamson said: 'I don't think anything in this country is technically impossible. We have a nation which indeed can produce miracles.'^{lix}

Thus continued what one Huntsville old-timer called the 'psychedelic decade'.^{lx} Many in Huntsville, as elsewhere, doubted the technical and practical underpinnings of 'Star Wars', and resented the relative neglect of their favoured ground-based interceptor approach: 'of course to us since we were ground people, naturally we would think they're biased towards space because we thought we should get more money than we got.'^{lxi} In fact, BMD policy remained vague and

contested within the administration.^{lxii} While the President appeared convinced of the possibility of building a near-perfect defence for the whole of the USA, many of his administration stated more modest goals. Even the influential Fletcher report on technological feasibility appeared to have divided views. While its unclassified executive summary was optimistic – ‘The scientific community may indeed give the United States the means of rendering the ballistic missile threat impotent and obsolete’ – the main body of the report was much more pessimistic.^{lxiii} James Fletcher himself, moreover, did not appear to endorse the optimistic tone of the executive summary, saying that: ‘There is no such thing a nuclear umbrella’.^{lxiv}

Nevertheless, the public perception, no doubt intentional, that SDI was aimed at protecting the American people from nuclear attack played well politically. The arguments of the Nuclear Freeze movement were undercut and the Reagan administration was able to soften its earlier war-mongering image. SDI demonstrated the administration’s commitment to defence and gave the opposition the difficult task of supporting vulnerability to nuclear attack. As Reagan’s National Security Advisor Robert McFarlane wrote to the President in late December 1984, ‘you have thrown the left into an absolute tizzy. They are left in the position of advocating the most bloodthirsty strategy – Mutual Assured Destruction – as a means to keep the peace.’^{lxv}

However, beyond the politics and rhetorical ambiguity of SDI there were real impacts on US BMD development, prompting concerns in the Pentagon that deployment might be rushed before it was militarily desirable or technologically feasible. Three criteria were proposed to guide a deployment decision: that a BMD system should be militarily effective; that it should be survivable; and that it should be cost-effective at the margins (that is, it should not be cheaper for the enemy to add extra forces to overcome the defence than the additional defences necessary to counter those extra forces). Paul Nitze pushed these three criteria within the administration, which thereafter became known as the ‘Nitze criteria’, with the

result that they became enshrined in law on May 30, 1985 as National Security Directive No. 172.

These criteria were very demanding and seemed to eliminate the possibility of deployment of a BMD system, leaving SDI as an R&D programme, albeit one with high levels of funding. Although Congress did not agree to the full amount of funding requested for SDI, the amounts approved still meant that BMD research funding tripled within three years.^{lxvi} However, because SDI was technology-driven across a wide range of potential approaches, there was little immediate focus on development of systems. Instead, individual technological breakthroughs received much of the emphasis, particularly if they were amenable to impressive demonstrations.^{lxvii} However, the optimism that was the official line of the administration and high level SDI managers was not shared by most of the scientists and engineers working on the programme, as was discovered when Congressional staffers carried out interviews during 1985 at various defence laboratories. Their report, published in March 1986, described how most SDI scientists saw little progress towards a significant breakthrough in BMD technologies.^{lxviii} Quite the contrary was true of one technology – the X-ray laser. Despite the claims of Teller and Wood, the more tests carried out on the X-ray laser, the less impressive its performance appeared, as earlier positive results were reinterpreted as having been caused by the instrumentation rather than the laser itself.^{lxix}

However, one category of BMD technology did have the unusual property, compared to most of SDI's futuristic weapons, of actually existing and having been tested successfully. Hit-to-kill technology, in which an interceptor destroys an enemy warhead through collision, was demonstrated in the HOE test of June 1984. Although Secretary of Defense Weinberger noted the significance of the HOE intercept by saying 'it will stand as one of the cornerstones upon which the president's Strategic Defense Initiative (SDI) will be built', this did not turn out to be the case.^{lxx} Indeed, his memoirs note 'the strong desire we had not to let the

programme sink back into a familiar mode of solely ground-based, largely ineffective, defensive systems'.^{lxxi}

Following the success of the final HOE test, Huntsville sought a follow-on project to develop the infra-red homing concept into a weaponised system. In November 1985 Lockheed was awarded a contract to develop and test the ERIS (Exo-atmospheric Reentry vehicle Interceptor Subsystem) interceptor.^{lxxii} This would eventually lead to two flight tests in 1991 and 1992, with the first a success and the second a failure.^{lxxiii} However, despite the apparent promise of hit-to-kill technology, ground-based systems did not fit the boost phase intercept concept that had given Star Wars its theoretical plausibility. A hit-to-kill interceptor such as ERIS could achieve an effective midcourse interception against one enemy warhead, but the Soviet Union had many thousands of warheads. Moreover, midcourse interception faces potentially great challenges from countermeasures because all objects, whatever their weight, travel at the same speed outside the atmosphere.

Proposals in 1986 for ERIS deployment were thus rejected by Weinberger, who favoured a space-based approach.^{lxxiv} Achieving Reagan's near-perfect defence pushed SDI towards a system designed to intercept Soviet missiles in their boost phase, before multiple warheads had been released. Weinberger therefore insisted that a defensive deployment must contain a space-based element. At the same time, the ground-based hit-to-kill approach was recast with the task of intercepting thousands of warheads in mind. Whereas HOE - an experiment to demonstrate feasibility - had been very large and expensive, SDI pushed ERIS towards a smaller, simpler design. Initially the plan was to make ERIS a 'dumb' interceptor with most of the target identification and discrimination activities to be carried out by external sensors, particularly ones based in space. The kill vehicle would still have an infrared telescope to enable it to home onto the target but target identification and discrimination from decoys would be the job of the external sensors.^{lxxv}

Combined with space-based interceptors (SBI), ERIS formed part of the plan for early SDI deployment – known as Phase 1 – that Weinberger promoted in early 1987. This was intended to placate supporters of early deployment and to entrench deployment plans while there was still support – but there was substance too in the shift of SDI’s funding towards kinetic energy weapons and away from exotic technologies such as lasers.^{lxxvi}

However, talk of deployment raised widespread concern, including in the armed services. The Joint Chiefs of Staff had been supportive of Reagan’s Star Wars speech while it had undermined support for the Freeze movement and deflected criticism from the MX basing dilemma, but they were concerned about the sheer scale of funding going to SDI. The prospect of SDI deployment raised alarms about what effect this would have on the budget for other military programmes. Concerned about these budgetary implications, and unimpressed by SDI’s technical claims, Chairman of the JCS, Admiral William Crowe sought to bring SDI deployment into line with standard procurement procedures.^{lxxvii}

In July 1987 the Defense Acquisition Board (DAB) gave the Phase 1 plan a Milestone I recommendation, endorsed by Weinberger that September.^{lxxviii} The plan was for phased deployment of a BMD system with Phase 1 comprising two interceptors (ERIS and SBI), three sensor systems (two of which were space-based) and a battle management/command, control and communications system. Rather than the near-perfect population defence that Reagan’s Star Wars speech had implied the initial mission of the Phase 1 system was ‘to ensure, albeit with less than 100% effectiveness, the survival of an effective US retaliatory force capability.’^{lxxix} In fact, the planning basis for Phase 1 was for a system that could stop 30% of a Soviet attack and even that proved hard to envisage in concrete terms.^{lxxx}

Attempts to flesh out the cost of the Phase 1 system led to estimates as high as \$150 billion, but reliable cost predictions proved difficult. According to a DAB Milestone Panel in the autumn of 1987: ‘As a consequence of the current gaps in systems

design and technology, none of the current cost estimates can be relied upon'.^{lxxxix} Particularly problematic was the space based interceptor element as there were many uncertainties regarding the cost of deployment. The number of battle stations that would need to be put into orbit depended on a range of factors, including the time taken by Soviet missiles in their boost phase (which could be much shorter if a new generation of missiles was deployed). It was hoped that an Advanced Launch System would reduce the cost of space transportation by more than a factor of ten (from about \$25,000 per kilogram to less than \$1,000 per kilogram), but ALS was still in the concept definition stage in 1987 and in fact would never be built.^{lxxxii}

As it turned out, the difficulties with providing a convincing development plan for Phase 1 deployment effectively stopped any deployment while the world was transformed by the collapse of the Soviet Union and the end of the Cold War. George Bush also replaced Reagan as President at the start of 1989. Bush did not share Reagan's faith in missile defence as a cornerstone of strategic policy; indeed he was keen in his first year as President to emphasise the importance of nuclear deterrence.^{lxxxiii} However, the Bush administration carried on funding SDI at roughly the same levels as before, although it did make one significant change in emphasis. The space-based element of the Phase 1 plan had always raised concerns about affordability given the sheer amount of equipment that would need to be put into orbit, and one solution was to make the space-based interceptors smaller and lighter. Such a technology - known as Brilliant Pebbles - had first been proposed in 1986. Taken up by Edward Teller and Lowell Wood at Livermore, Brilliant Pebbles became their new obsession, taking over from the X-ray laser as that technology fell out of favour.^{lxxxiv}

Brilliant Pebbles received a boost in February 1989 when SDI director Abrahamson's end-of-tour report recommended radical change to Phase 1, based on the 'improved performance and dramatic cost reductions' that the new technology offered.^{lxxxv} He claimed that Brilliant Pebbles could be proven in two years and deployed three years

later to produce a Phase 1 system that met JCS requirements for not more than about \$25 billion.

Convinced by Abrahamson's strong endorsement, the new Secretary of Defence, Richard Cheney, gave SDIO the go-ahead to focus on Brilliant Pebbles in March 1989.^{lxxxvi} However, with the Soviet Union disintegrating, and huge cuts in Soviet warheads under negotiation in START, the rationale supporting deployment changed.^{lxxxvii} The Bush administration put forward three rationales to support continuing BMD deployment. First, terrorists might gain control of nuclear-armed ballistic missiles, particularly given the turmoil that the Soviet state was going through. Second, BMD could provide protection against rogue nations that might acquire a nuclear capability. Third, there was a risk of accidental launch of ballistic missiles, again particularly in the case of Soviet weapons.

Although the Pentagon and CIA were apparently skeptical about the validity of these rationales^{lxxxviii}, they became the planning basis for a new deployment concept known as Global Protection Against Limited Strikes (GPALS) announced by the new SDIO director, Henry Cooper, in January 1991.^{lxxxix} GPALS was to consist of three main elements: a National Missile Defense (NMD) comprising ground-based interceptors, a Global Missile Defense (GMD) consisting of space-based interceptors, and several Theater Missile Defense (TMD) systems, based on land, sea or on mobile systems.^{xc}

Rather than facing thousands of Soviet warheads, GPALS was envisaged as protecting against a small attack of up to a hundred missiles, either from an accidental launch from the former Soviet Union or a deliberate attack from a small nuclear nation or terrorists. As the name implied, GPALS was also intended to provide global coverage, extending the defence to US forces abroad and allies. Brilliant Pebbles was to provide the space-based component, and according to SDIO director Cooper, the technology was sufficiently mature for development to proceed. It was also, claimed Cooper, 'clear that Brilliant Pebbles would be the lowest cost

and the most militarily effective means of defending both the United States and our overseas troops, friends and allies.^{xcvi} However, despite SDIO's conviction that Brilliant Pebbles 'was the most cost-effective GPALS component, by far', the wider politics - particularly within Congress - militated against a deployment decision. A particular sticking point was the ABM Treaty that outlawed space-basing of BMD technology. However, although Congressional opposition to Brilliant Pebbles would remain firm, other missile defence technologies were to receive a major boost from an unexpected source: Saddam Hussein, whose Iraqi forces invaded Kuwait in August 1990.

Phase 3: Back to Earth

The end of the Cold War, along with growing domestic disillusionment, undercut much of the impetus of SDI, but the most significant influence on missile defence in the early 1990s was the first Gulf War. The use of Patriot missile to defend US troops and Israeli cities in that conflict provided politically compelling (albeit factually contested) evidence of how missile defence could alleviate US vulnerability.^{xcvii} Following the exaggerated claims for the X-ray laser and other futuristic technologies it was with the use of Patriot in early 1991 that missile defence began to regain political credibility, ironically despite the controversy over Patriot's actual effectiveness.^{xcviii} Patriot was an anti-aircraft missile that had been adapted for use against short-range ballistic missiles and its technology was relatively old-fashioned. However, despite later analysis which indicated a very low intercept rate, the immediate impression was that Patriot had proved successful in defending against the Iraqi Scud missiles.^{xcix}

In response Republican missile defence supporters in Congress sought to build a consensus around the perceived lessons of the Gulf War, but without recourse to politically divisive space-based technologies. They argued that two aspects of the Gulf War should be seen as supporting BMD deployment.^{cx} First, without Patriot, US forces, as well as allies, would have had no protection from Saddam's Scud

missiles. Second, the fact that Saddam had used these missiles against US forces, and also against Israel, showed that deterrence could not be relied on, an especially worrying thought if combined with Iraq's plans to develop nuclear weapons.^{xcvi}

The impression made by Patriot in Congress was such that a bipartisan Missile Defense Act was passed in 1991, but a corollary of building a consensus for deployment of ground-based BMD interceptors was that Brilliant Pebbles should be taken out of the acquisition programme. Specifically, the Act charged the Secretary of Defense with deploying 'by the earliest date allowed by the availability of appropriate technology or by fiscal year 1996 a cost effective, operationally-effective, and ABM Treaty-compliant anti-ballistic missile system,' and Brilliant Pebbles deployment was generally considered not to be compliant with the Treaty.^{xcvii} Although 'robust funding' for Brilliant Pebbles technology demonstration was promised by the Missile Defense Act, this never materialized, and work on Brilliant Pebbles was completely terminated by the Clinton Administration in 1993.^{xcviii}

Thereafter, the mainstream of BMD development returned to a more earthbound approach. Although the centre of gravity of BMD work only gradually returned to Huntsville, the technological emphasis would again be on land- or sea-based missiles.^{xcix} In particular, the ground-based interceptor technology initiated in the first Bush administration built on the work done at Huntsville in the HOE and ERIS programmes.

The Clinton administration was initially unenthusiastic about strategic BMD, instead emphasizing theatre defences.^c On 13 May 1993 Clinton's Secretary of Defense, Les Aspin, announced the 'end of the Star Wars era', changing the name of the organisation in charge of missile defence from SDIO to the Ballistic Missile Defense Organisation (BMDO). However, disastrous results in the 1994 mid-term elections led to a hostile Republican dominated Congress, and strategic missile defence again came to the fore as a political issue. The result was another major piece of Congressional legislation, the 1995 Ballistic Missile Defense Act. Like its 1991

predecessor, the 1995 Act sought deployment of a BMD system using ground-based interceptors. Unlike the earlier act, the 1995 Act specified a deployment timetable, setting 2003 as the date for an initial operational capability. Although vetoed by Clinton, the resulting compromise led to a doubling of spending on national missile defence.^{ci}

Further compromise came the following year when the Administration put forward what became known as the 'three-plus-three' plan whereby a National Missile Defense (NMD) system should be demonstrated in (roughly) three years (i.e. by 2000) with the potential then to deploy if necessary within another three years.^{cii} Politically, this plan helped Clinton fend off Republican criticism that he was soft on national defence. Technically, however, it set the BMDO a major challenge, as was confirmed by a review of missile defence programmes initiated by Lieutenant General Lester Lyles who took over as head of BMDO in 1997. This review, headed by retired Air Force Chief of Staff Larry Welch, reported in early 1998 with fairly damning conclusions over the readiness of missile defence technology. Memorably Welch argued that the tight schedule risked a 'rush to failure'.^{ciii}

Nevertheless, political pressures continued to build with the publication in 1998 of the 'Rumsfeld Commission' report on ballistic missile threats from 'rogue' states, and its apparent validation with the launch of a three-stage missile by North Korea on August 31.^{civ} Although the missile did not in itself constitute much of a threat to the US mainland, it did indicate North Korean interest in missile development, and even more significantly to some, that US intelligence agencies could not be relied on to predict potential threats.^{cv}

However, by the end of 1998 it was clear that the scepticism of the Welch panel was justified as no flight tests had yet been carried out. At high-level meetings within the administration the Secretary of Defense, Republican William Cohen, won the case for significant increases in funding for missile defence. At the same time, the

deployment timetable was deferred by two years, with 2005 now the target date, should a decision to deploy be taken.

Although the Clinton administration had become increasingly convinced of the argument for NMD, poor flight test results (the second and third attempts both failed to hit the target) led to a decision not to decide on deployment.^{cv} That would be left to the incoming administration of G. W. Bush. Once elected, the Bush administration quickly moved to increase funding for missile defence^{cvii}, and in December 2001 made the significant step of announcing US withdrawal from the ABM Treaty, to take effect six months later on June 13, 2002. The expectation amongst Star Warriors was that the administration of G. W. Bush would switch the direction of missile defence away from the land-based approach of the Clinton NMD and back towards space-based defence.^{cviii}

There was some change in emphasis, as many SDI era technologies were revived or received a boost in funding (although the space-based laser programme that had continued to receive support under the Clinton administration was scaled back).^{cix} In addition, the concept of layered defences made a comeback in the plans of the Missile Defense Agency (BMDO's successor).^{cx} However, the only deployment that proceeded had ground-based hit-to-kill technology as its centerpiece, with NMD renamed the Ground-based Midcourse Defense (GMD). On December 17, 2002 President Bush announced that the US would begin deployment with the aim of achieving initial operational status in 2004.^{cx} The plan was to have interceptor missiles based in Alaska and California with the intention of providing protection against ICBMs launched from Northeast Asia and the Middle East.

Although the flight tests had mixed results, deployment pressed ahead.^{cxii} Other elements of the Bush missile defence plan included ship-based interceptor missiles (the Aegis system) and the continued development of an airplane-based laser. However, space-based systems were not included in the plan, and if anything the climate for such technology appeared to become more unfavourable as studies by

the American Physical Society and the Congressional Budget Office cast doubt on the practicality of boost phase defences.^{cxiii} For example, the APS study concluded that 'a thousand or more interceptors would be needed for a system having the lowest possible mass and providing a realistic decision time. Even so, the total mass that would have to be orbited would require at least a five- to tenfold increase over current US space-launch rates, making such a system impractical.'^{cxiv}

Return of the Star Warriors?

The 'success' of Patriot in the Gulf conflicts, the Congressional compromise to support deployment of ground-based interceptors, and the decision of the G. W. Bush administration to push ahead with GMD deployment all seemed to mark the end of the Star Wars adventure. However, despite this apparent triumph for ground-based missile defence advocates, there remains a coterie of 'Star Warriors' insistent on the superiority of a space-based approach. Key figures include Lowell Wood of Lawrence Livermore, Greg Canavan of Los Alamos, and William Van Cleave of Missouri State University, as well as former SDI director, Henry Cooper.

These Star Warriors continue to lobby for the deployment of space-based defences, while at the same time opposing any further deployment of ground based interceptors. An extended rationale and mission statement for the space-based BMD approach is set out in a '2007 Report' on 'Missile Defense, the Space Relationship, & the Twenty-First Century'.^{cxv} What is distinctive about the Star Warriors approach is their dismissal of ground-based interceptors, which they consider to be a technologically inferior approach that is only useful, if at all, as part of a layered defence in which space-based systems play the main role. Thus the report argues that 'GMD is a limited midcourse defense that will be effective against only a few missiles with simple decoys. Because GMD cannot adequately discriminate among midcourse threats, it may be prone to failure unless it becomes part of a layered missile defense.'^{cxvi}

The Star Warriors argue that although 'ground-based missile defense (GMD) is presumed to be the most feasible because it has been under continuous development for over thirty-five years and receives far more money and attention than other options, it is also the most limited, especially when compared to the space-based systems discussed in this report.'^{cxvii} In particular, the Star Warriors lament the fact that the Bush administration 'chose to follow the Clinton administration in focusing its effort on relatively costly and largely ineffective ground-based systems rather than exploiting the most potentially effective technologies.'^{cxviii}

Moreover, the Star Warriors see the failure to deploy their preferred space-based technology as the result of a 'small but vocal minority' producing a situation where 'political considerations have by and large dictated technical behavior, with the goal of developing the most technologically-sound and cost-effective defenses subordinated to other interests.'^{cxix} Much of the case put by the Star Warriors relies on the familiar argument that boost-phase interception is key, because the target is conspicuous, vulnerable, and has not yet released its warheads and decoys. However, alongside this theoretical argument there is some empirically-grounded evidence used to support the case for the feasibility of space-based defences. This does not derive from testing of Brilliant Pebbles technology per se. Some tests were carried out between 1990 and 1992, but these were largely unsuccessful.^{cxx} Instead, the main empirical experience drawn on is a space probe programme known as Clementine. Clementine was devised in the dying days of Brilliant Pebbles, when its supporters within SDI, aware that funding for Brilliant Pebbles was about to be cut, sought a way to carry out a demonstration of some of its key technologies. Jointly supported by the BMDO and NASA, the Clementine probe was launched on 25 January 1994, and successfully orbited and imaged the moon. The second part of Clementine's mission, to carry out a fly-by of an asteroid and then continue into deep space, was not a success, however, due to a computer malfunction.^{cxxi}

Nevertheless, Clementine has been accorded mythical status amongst Star Warriors because of its role as a test-bed for Brilliant Pebbles technology. In May 2001 Cooper claimed that 'the Clementine deep-space probe successfully space-qualified nearly the entire suite of first-generation Brilliant Pebbles hardware (scavenged from the then-defunct Pebbles program, scuttled by the Clinton administration) and software.' According to Cooper: 'The undeniable scientific fact is that the Pebbles technology was mature in 1991 -- as the Clementine mission to the moon so clearly demonstrated in 1994.'^{cxix}

Nevertheless, despite these arguments, ground-based interceptors are currently the system of choice for US national missile defence. The Star Warriors continue to press their case, arguing not just that space-based defences are better, but also that the ground-based interceptors are ineffective. In doing so, of course, they also thus undermine support for the current GMD system. Despite the (temporary?) closure around the choice of ground-based interceptors, the technological divide remains as large as ever.

Discussion: Technical Controversy and the Politics of Missile Defence

For most of its history, now over half a century, ballistic missile defence technology has been deeply controversial. Critics have questioned whether it is technically feasible, whether it is strategically wise, and whether it is economically justifiable.^{cxix} The issue of technical feasibility, in particular, has come to be central to the arguments of BMD opponents. However, it is clear that the technical disputes run deeper than this because supporters of missile defence also strongly contest claims made about the performance of certain missile defence technologies, with two main opposing camps divided by their preferences for ground or space based systems.

Such disputes are hard to resolve on purely technical grounds because empirical evidence of technological performance is less than compelling. Actual use of missile defence has been very rare; the only examples being the short-range Patriot against

Iraqi Scud missiles in the two Gulf conflicts. Tellingly, even that operational experience produced evidence that was far from clear-cut. Initial claims of high Patriot success rates in the first war were contested, and it is now generally accepted that in that conflict the Patriot was responsible for shooting down few, if any, Scuds.^{cxxiv} In the case of defence against nuclear-armed ballistic missiles, there is not only no experience of such use, but also no experience of nuclear war at all.

Most empirical evidence instead comes from testing, but here again there are limits to what can be achieved. Evidence gained from testing can always be questioned on the grounds that the tests are insufficiently similar to operational use.^{cxxv} Such arguments have been well articulated by critics of BMD. Amongst the issues raised in relation to GMD testing are that most tests have been on the same intercept trajectories, with the sun in the same position, and that the time and direction of attack, as well as the nature of the incoming warheads and any decoys, have all been known in advance.^{cxxvi}

Disputes over BMD technology thus rely heavily on theoretical arguments. Although the origins of Reagan's Star War speech and the resulting SDI had much to do with domestic politics, the pivotal conceptual element was the argument for using boost-phase interception to overcome the challenge of multiple warheads and decoys. This is compelling in principle because the difficulties of midcourse discrimination are considerable, and this is generally considered a significant potential weakness of the GMD system that is currently deployed.^{cxxvii} However, advocates of midcourse defence maintain discrimination would be possible with a well-designed system against likely decoys.^{cxxviii}

The practicality of space-based systems, on the other hand, hinges on the cost of putting them into orbit, but cost estimates depend on the weight of the interceptors and number required, and this calculation in turn is based on assumptions about the duration of enemy missiles' boost phase and the speed of the interceptors. This calculus is further complicated by the potential countermeasures that could be used

by enemies seeking to overcome a boost phase defence. Thus, the claim that boost phase interception eliminates the problem of midcourse discrimination can be countered by the argument that opponents could deploy missiles with such short boost phases as to make interception practically impossible. Even with a boost phase lasting four minutes (typical for liquid-fueled ICBMs compared to three minutes for solid-fueled ones), the time left for interception is very short once detection, tracking and decision-making are taken into account.^{cxxxix} In addition, the APS study noted other countermeasures that could defeat boost-phase defences -- whether terrestrially or space based -- 'such as maneuvering and deployment of thrusting decoys during upper stage boost, and even multiple upper stages (all of which were employed in one form or another as early as 40 years ago.)'^{cxxx}

The scenarios for missile defence use are thus highly speculative and dependent on a wide range of assumptions. Theoretical discourse, not empirical experience, is the main means for determining the technology that is developed and deployed. Test performance obviously matters, but concept credibility is also important. In this regard the Star Warriors have a problem if their credibility has been undermined by the association that some of them have with the ill-fated X-ray laser. Because the X-ray laser was over-sold so aggressively and under-delivered so spectacularly, its supporters may not now be seen as reliable in regard to their claims for what technology can be developed.^{cxxxi}

The battle lines between the Star Warriors and the Huntsville mafia remain as divided as ever. As far as deployment is concerned, the supporters of ground-based systems are now in the ascendancy, although the current deployment is limited and some advocates of GMD are unhappy with the way the programme has been managed, and particularly with the limited nature of flight testing and the lack of improvement through 'spiral development'.^{cxxxii} However, supporters of space-based systems remain convinced of the superiority of their approach, and it seems unlikely that any conclusive test could be devised to settle this dispute. If both types

of system were to be deployed (very unlikely), and if there were to be a substantial ballistic missile attack on the US (extremely unlikely), then it might be possible to gauge the relative effectiveness of the two technologies (although given the chaos of the 'fog of war' this is also questionable). Otherwise, and almost certainly, the argument will remain largely theoretical and unresolved. Success for BMD technology will thus remain dependent on theoretical plausibility, credibility and the shifting currents of US domestic politics.

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- i The term 'Huntsville Mafia' is used to depict a like-minded grouping with strong loyalty, and not, of course, to imply any criminality. The term 'Star Warriors' seems to have been first popularized by William Broad's Star Warriors (Simon & Schuster, 1985) book about the 'O' Group at Lawrence Livermore National Laboratory.
- ii An early and influential critique was Jerome B. Wiesner and Herbert F. York. 'National Security and the Nuclear Test Ban', Scientific American (October 1964), pp. 27-35.
- iii This is, of course, a simplification. For example, advocates of airborne boost phase defence do not fit into this schema. See Dean Wilkening, 'Airborne Boost-Phase Ballistic Missile Defense', Science and Global Security, Vol. 12 (2004), pp. 1-67.
- iv See, for example, Lisbeth Gronlund, George N. Lewis and David C. Wright. 'The Continuing Debate on National Missile Defenses', Physics Today online (December 2000), <http://www.physicstoday.org/vol-53/iss-12/p36.html> accessed 1/2/08. Both Russia and China have repeatedly argued that US deployment of missile defences could lead to an arms race. See, for example, Thom Shanker, 'US Tries to Ease Concerns in Russia on Antimissile Plan', New York Times (22 February, 2008); Erik Eckholm, 'US Missile Shield Will Set Off a New Arms Race, China Warns', New York Times (25 November, 1999). In August 2000 a classified report to Congress apparently warned that US BMD deployment 'could prompt China to expand its nuclear arsenal tenfold and lead Russia to place multiple warheads on ballistic missiles that now carry only one'. David E. Rosenbaum, 'The Democrats: The Military; Plan for Missile Defense Survives, but in Competing Versions', New York Times (15 August, 2000).
- v On countermeasures, see Andrew M. Sessler, John M. Cornwall, Bob Dietz, Steve Fetter, Sherman Frankel, Richard L. Garwin, Kurt Gottfried, Lisbeth Gronlund, George N. Lewis, Theodore A. Postol and David C. Wright. Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned US National Missile Defense System, Union of Concerned Scientists and MIT Security Studies Program, Cambridge, Mass. (2000).
- vi These are the 'proximate' goals of BMD. The 'ultimate' goals are another matter, which I will not go into in this paper. However, one strand of strategic thinking during the Cold War saw BMD as an important element of the credibility of deterrence, particularly in the context of reducing the 'self-deterrence' of a nuclear stalemate between the superpowers. See Charles L. Glaser, 'Do We Want the Missile Defenses We Can Build?', International Security, Vol. 10, No. 1 (Summer 1985), pp. 25-57; Bill Keller, 'Missile Defense: The Untold Story', New York Times (29 December, 2001).
- vii On interpretive flexibility, see Trevor J. Pinch and Wiebe E. Bijker. 'The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other', Social Studies of Science (1984), pp. 399-441.
- viii There is some experience of the use of the short-range Patriot system against non-nuclear missile attack in the Gulf, although its effectiveness, especially in the first Gulf conflict, has been highly contested. For a summary, see H. M. Collins and Trevor J. Pinch. The Golem at Large: What You Should Know about Technology (Cambridge University Press, 1996), chapter 1.

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- ix Statement by The Honorable Philip E. Coyle Director, Operational Test and Evaluation, Before the House Committee on Government Reform Subcommittee on National Security, September 8, 2000.
- x For an analysis of the 'similarity' issue in the related area of missile accuracy, see Donald MacKenzie, 'From Kwajalein to Armageddon? Testing and the Social Construction of Missile Accuracy', in D. Gooding, T. Pinch and S. Schaffer (eds), The Uses of Experiment: Studies in the Natural Sciences (Cambridge University Press, 1989), pp. 409-435.
- xi Donald R Baucom, The Origins of SDI, 1944-1983 (University Press of Kansas, 1992), p. 7.
- xii Ernest J. Yanarella, The Missile Defense Controversy (University Press of Kentucky, 1977), chapter 2; Baucom, 11. See also Herbert F. York, Race to Oblivion, (Simon and Schuster, 1970), p. 214.
- xiii Congressman Daniel Flood, quoted in Yanarella, 62. See also James Walker, Lewis Bernstein and Sharon Lang, Seize the High Ground: The Army in Space and Missile Defense (Historical Office, US Army, Space and Missile Defense Command, 2003), pp. 42-43.
- xiv First director of ARPA, quoted in Yanarella, p. 40.
- xv These are documented in Barber Associates, The Advanced Research Projects Agency, 1958-1974 (Washington, December 1975).
- xvi Broad, William J. "'Star Wars' Traced to Eisenhower Era', New York Times (28 October, 1986).
- xvii Interview with Bill Davis; William Z. Lemnios and Alan A. Grometstein, 'Overview of the Lincoln Laboratory Ballistic Missile Defense Program', Lincoln Laboratory Journal, Vol. 13, No. 1 (2002), 9-32; Philip A. Ingwesen and William Z. Lemnios, 'Radars for Ballistic Missile Defense Research', Lincoln Laboratory Journal, Vol. 12, No. 2 (2000), pp. 245-266.
- xviii Interview with Dave Montague.
- xix Baucom, (note 11) p. 19.
- xx Although according to McNamara civil defence measures would be a much more cost-effective way to reduce US casualties. See Yanarella, (note 12) 86-87. In particular, McNamara argued that civil defence would be important because of the radioactive fall-out caused by the defence's own nuclear warheads, never mind those of the Soviets.
- xxi Quoted in Yanarella, (note 12) 85. Harold Brown, DDR&E later testified that: 'The United States decided not to deploy the Nike-Zeus because its effectiveness was inadequate against US penetration aids programmed for entry into the US inventory before a Nike-Zeus system could be deployed, and we assume the same would be true of Soviet penetration aid capability.' Quoted in Ibid, p. 88.
- xxii Ibid, p. 90.
- xxiii This 'damage limiting study' was carried out during 1963-64 by General Glenn Kent, and released as 'A Summary Study of the Strategic Offensive and Defensive forces of the U.S. and the USSR' on September 8, 1964. See Glenn Kent, 'Looking Back: Four Decades of Analysis', Operations Research, vol. 50, No. 1 (Jan-Feb 2002), 122-124. Its basic conclusion was that 'if the United States strives to stay at the outcome where 70% of the population survives against a reactive Soviet threat, the United States must spend at least two billion dollars to limit damage for every one billion dollars the Soviets add to create damage.' Achieving a higher US survival rate of 90% gave a much more unfavourable ratio of six to one.
- xxiv See Fred Kaplan, The Wizards of Armageddon (Simon and Schuster, 1983). 320-324; Benson D. Adams Ballistic Missile Defense (American Elsevier Publishing Company, 1971), pp. 108-10.
- xxv A Republican booklet produced in February 1967 was entitled 'The Missile Defense Question: Is LBJ Right?'. Cited in Yanarella, (note 12) p. 125.
- xxvi John Newhouse, War and Peace in the Nuclear Age (Knopf, 1989), p. 205.
- xxvii Quoted in Baucom, (note 11) p. 36.
- xxviii Quoted in Ibid, p. 37.

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- xxix Yanarella, (note 12), 146-147. Anne Hessing Cahn. 'American Scientists and the ABM: A Case Study in Controversy', in Albert K. Teich, Scientists and Public Affairs (MIT Press, 1974), pp. 41-120 at 66-68 describes local opposition in the Chicago area.
- xxx Yanarella, (note 12), pp. 149-154.
- xxxi Adams, (note 24), pp. 187-91.
- xxxii Baucom, (note 11), p. 40.
- xxxiii Bill Davis, 'BMD Technology Advances', Paper presented at the 40th Anniversary Celebration of the US Army Space & Missile Defense, May 21, 1997. My thanks to Bill Davis for providing with a copy of this paper.
- xxxiv Memorandum for the President from Henry Kissinger, Subject: Contractor Doubts about Safeguard, April 15, 1970. National Archives, Nixon Presidential Materials Project, National Security Council Files, Box 841, ABM System Vol. IV.
- xxxv Interview with Dave Montague.
- xxxvi The vote on 6 August 1969 was tied 50:50 in the Senate, with Vice President Spiro Agnew's casting vote proving decisive. Baucom, (note 11), p. 50.
- xxxvii Walker et al, (note 13), 71, gives 28 September as the date the Safeguard complex reached full operational capability, whereas Baucom, (note 11), 96, implies a date of 1 October.
- xxxviii Baucom, (note 11), p. 97.
- xxxix Initially each side was limited to deployment of two 'point defence' ABM systems - one to protect the national command area, the other to protect an ICBM field - but this was later reduced to one each. The Soviet Union retained its Moscow Galosh ABM, while the US had Safeguard, briefly.
- xl Walker et al, (note 13), p. 86.
- xli Senate, Hearings on FY77 Authorizations, Part 12, Research and Development, p. 6682, quoted in Baucom, (note 11), p. 98.
- xlii Interview with Bill Davis; Erik K Pratt, Selling Strategic Defense: Interests Ideologies and the Arms Race (Lynne Rienner Publishers, 1990), pp. 59-60.
- xliii Ibid; Baucom, Origins of SDI.
- xliv Davis, (note 33).
- xlv Interview with Dave Montague.
- xlvi Interview with Bill Davis, 29/11/06.
- xlvii Further information on HOE, and on the flight test failures, can be found in G. Spinardi, forthcoming.
- xlviii See for example, Frances Fitzgerald, Way Out There in the Blue: Reagan, Star Wars and the End of the Cold War (Touchstone, 2000); William J. Broad, Teller's War: The Top-Secret Story Behind the Star Wars Deception (Simon & Schuster, 1992); Baucom,(note 11); and Pratt (note 42).
- xlix In testimony before the Senate Foreign Relations Committee in April 1984, the first SDIO director Abrahamson referred to the Fletcher report using a five-layer concept to achieve 99.9% effective defence. See Fitzgerald, (note 48), 250. However, the Fletcher Report did not say that 99.9% was achievable.
- ¹ Broad, (note 48) p. 167.
- ^{li} Ibid, p. 108.
- ^{lii} Ibid, p. 101.
- ^{liii} Interview with Dave Montague.
- ^{liv} Casper Weinberger, Fighting for Peace: Seven Critical Years at the Pentagon (Michael Joseph, London; 1990), p. 217.

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- lv Directed energy weapons such as lasers operate at the speed of light and so could not be ruled out in theory, but in practice focusing the laser beams would require infeasibly large mirrors. In any case sufficiently powerful lasers have not yet been developed.
- lvi Brian Woods, 'Artifacts, Revolutionaries and Bureaucrats: the Sociotechnical Shaping of NASA's Space Shuttle (University of Edinburgh, PhD Thesis, 1998).
- lvii Ashton B. Carter, 'Directed Energy Missile Defense in Space', Background Paper, April 1984, Prepared under contract to the Office of Technology Assessment. Available at <http://www.princeton.edu/~ota/disk3/1984/8410/8410.PDF>.
- lviii Fitzgerald, (note 48) pp. 251-54.
- lix Quoted in Fitzgerald, (note 48) p. 248.
- lx Interview with Bill Davis.
- lxi Interview with DB, 29/11/06.
- lxii Fitzgerald, (note 48) p. 263.
- lxiii See Ibid, p. 253.
- lxiv Quoted in Ibid, p. 253.
- lxv Quoted in Ibid, p. 261.
- lxvi Ibid, p. 372.
- lxvii William J. Broad, 'Science Showmanship: A Deep "Star Wars" Riff', New York Times (December 16, 1985).
- lxviii Fitzgerald, (note 48) p. 374.
- lix Broad, (note 48), 205-207. The X-ray laser would finally be cancelled by the Bush administration in 1992. See, Michael R. Gordon, "'Star Wars" X-Ray Laser Weapon Dies as Its Final Test Is Cancelled', New York Times (21 July, 1992).
- lxx Quoted in Michael W. Munn, 'The Homing Overlay Experiment: A Major Step in Ballistic Missile Defense', Lockheed Horizons, Issue 45, p. 43.
- lxxi Weinberger, (note 54) p. 221.
- lxxii ERIS was intended to be an upper-tier system, complemented by the lower-tier HEDI (High Endoatmospheric Defense Interceptor).
- lxxiii The second test was actually postponed from 1991 because of a problem during countdown.
- lxxiv Fitzgerald, (note 48) pp. 379-380.
- lxxv Interviews; General Accounting Office. 'Strategic Defense Initiative: Some Claims Overstated for Early Flight Tests of Interceptors', GAO/NSIAD-92-282, September 1992.
- lxxvi William J. Broad, "'Star Wars" Push Dimming Prospect for Exotic Arms', New York Times (9 March 1987); Fitzgerald, (note 48) pp. 388-389 and pp. 402-403. Funding on directed energy weapons peaked in 1988. See James A. Abrahamson, and Henry F. Cooper. 'What Did We Get For Our \$30-Billion Investment in SDI/BMD?', September 1993 (National Institute for Public Policy, 1999), p. 14.
- lxxvii Fitzgerald, (note 48) p. 405.
- lxxviii Steven A. Hildreth, 'The Strategic Defense Initiative: Issues for Phase 1 Deployment' (Congressional Research Service, March 7, 1988), p. 2.
- lxxix Ibid, 4.
- lxxx Fitzgerald, (note 48) p. 405.
- lxxxi Quoted in Ibid, p. 406.
- lxxxii <http://www.globalsecurity.org/space/systems/als.htm>, accessed 13/9/07. Email from Dave Montague, 22/2/08.

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- lxxxiii Fitzgerald, (note 48) pp. 470-71.
- lxxxiv Broad, (note 48) chapter seven.
- lxxxv Fitzgerald, (note 48) p. 481.
- lxxxvi Ibid, p. 482.
- lxxxvii William J. Broad, 'New Course for "Star Wars", From Full to Limited Defense', New York Times (31 January, 1991).
- lxxxviii Fitzgerald, (note 48) p. 484.
- lxxxix Ibid, 484.
- xc Walker et al, (note 13) pp. 172-174.
- lxi Letter from Ambassador Henry F. Cooper to Senator John Warner, July 31, 2000, reprinted in Independent Working Group. '2007 Report' on 'Missile Defense, the Space Relationship, & the Twenty-First Century', sponsored by the American Foreign Policy Council (2006), p. C12. Available at www.ifpa.org/publications/IWGReport.htm.
- lxii K. Scott McMahon, Pursuit of the Shield: The US Quest for Limited Ballistic Missile Defense (University Press of America, 1997).
- lxiii Early reports echoed official claims of success. See, for example, William J. Broad, 'The Patriot's Success: Because of "Star Wars" or in Spite of it?', New York Times (10 February, 1991).
- lxiv The initial claimed success rate was 96 percent, or 41 intercepts out of 42 attempts. See William Safire, 'The Great Scud-Patriot Mystery', New York Times, March 7, 1991.
- lxv It may have helped that some Senators experienced a Scud attack first hand in Tel Aviv. See Abrahamson and Cooper, (note 76) p. 4.
- lxvi McMahon, (note 92) pp. 106-07; Fitzgerald, (note 48) p. 485.
- lxvii Although the Reagan administration had devoted much legal effort to arguing for a reinterpretation of the ABM Treaty.
- lxviii Cooper in (note 91) p. C13.
- lxix As part of the BRAC (base realignment and closure) programme, it was decided in 2005 to move the Missile Defense Agency back to Huntsville.
- lxx The Bush administration had allocated roughly 20 percent of SDIO's budget to theatre defence and 80 percent to strategic defence, whereas the Clinton administration reversed these allocations. Fitzgerald, (note 48) p. 491.
- lxxi Bradley Graham, Hit to Kill: The New Battle Over Shielding America from Missile Attack (Public Affairs, 2001), p. 26.
- lxxii Ibid, p. 27.
- lxxiii 'Report of the Panel on Reducing Risk in Ballistic Missile Defense Flight Test Programs', (27 February, 1998). This is available on the MDA's website, at www.mda.mil/mdalink/pdf/welchrpt.pdf
- lxxiv Michael R. Gordon and Steven Lee Myers. 'The Nuclear Shield: Looking for Cover; Politics Mixes With Strategy In Plan for Antimissile System', New York Times (23 June, 2000). Known as the Rumsfeld Commission after its chair, Donald Rumsfeld, its full title was 'The Commission to Assess the Ballistic Missile Threat to the United States'.
- lxxv Graham (note 101) p. 61.
- lxxvi Eric Schmitt, 'Clinton's Missile Decision: The Overview; President Decides to Put Off Work on Missile Shield', New York Times (2 September, 2000).
- lxxvii In the final year of the Clinton administration, FY01 funding was \$4.8 billion; under Bush it was \$7.8 billion for FY02, \$7.4 billion for FY03, and \$9.1 billion for FY04). See Lisbeth Gronlund, David C. Wright, George N. Lewis and Philip E. Coyle III, Technical Realities: An Analysis of the 2004 Deployment of a US National Missile Defense System (Union of Concerned Scientists, May 2004), p. 6.

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- ^{cviii} Irwin Goodwin, 'Bush targets space-based missile defence system', Nature, Vol 409 (11 January 2001), p. 122. Bush had earlier, in May 2000, supported a return to 'Star Wars' type defences. See William J. Broad, 'The Nuclear Shield: Repelling an Attack; A Missile Defense With Limits: The ABCs of the Clinton Plan', New York Times (30 June, 2000).
- ^{cix} James Glanz, 'Other Systems Might Provide a US Missile Shield', New York Times (4 September, 2000). James Glanz, 'Cast of Star Wars Makes a Comeback in Bush Plan', New York Times (22 July, 2001).
- ^{cx} See, for example, the Special Briefing on Missile Defense given by MDA Director Lt. Gen Kadish on June 22, 2002. <http://www.defenselink.mil/transcripts/transcript.aspx?transcriptid=3519>, accessed 15/2/08.
- ^{cxii} Gronlund et al (note 108) p. 1.
- ^{cxiii} See Graham Spinardi, 'Ballistic Missile Defence and the Politics of Testing: The Case of the US Ground-based Midcourse Defence', Science & Public Policy, Vol. 35, No. 8, (December 2008), 703-715.
- ^{cxiiii} American Physical Society. 'Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense', July 2003; Congressional Budget Office, 'Alternatives for Boost-Phase Missile Defense (July 2004). Gregory Canavan, 'Estimates of Performance and Cost for Boost Phase Intercept', Paper presented to The George Marshall Institute, Washington, DC (24 September, 2004). Available for download at the Intitute's website: <http://www.marshall.org/> agrees in rough terms with the calculations of the APS and CBO reports (though more with the former than the latter), but argues that they overstate the cost of space-based interceptors because they fail to address the potential for a satellite deployment that provides concentrated coverage of a limited geographical area. However, Canavan's claim is disputed by Oelrich and Steve Fetter, 'Not So Fast: Comments on "Estimates of Performance and Cost for Boost Phase Ivan Intercept"' presented to the Marshall Institute's Washington Roundtable on Science and Public Policy by Greg Canavan on 24 September 2004. Available at <http://www.publicpolicy.umd.edu/Fetter/publications.htm>.
- ^{cxv} American Physical Society (note 113) Executive Summary, p. xxix.
- ^{cxvi} Independent Working Group, (note 91). For a very critical review see Teresa Hitchens, 'Return of the Star Warriors', Bulletin of the Atomic Scientists, January/February 2007, Vol. 63, NO. 1, pp. 76-78.
- ^{cxvii} Independent Working Group, (note 91), p. 15.
- ^{cxviii} *Ibid*, p. 19.
- ^{cxix} *Ibid*, p. 20.
- ^{cx} *Ibid*, p. ix.
- ^{cxxi} The first test failed due to incomplete separation from the booster, the third from a booster nozzle failure. See Donald R. Baucom, 'The Rise and Fall of Brilliant Pebbles', The Journal of Social, Economic and Political Studies, Vol. 29, No. 2 (Summer 2004), pp. 143-190, at 167-68, 180-81.
- ^{cxvii} *Ibid*, p. 187.
- ^{cxviii} Henry F. Cooper, 'Why Not Space-Based Missile Defense?', Wall Street Journal, May 7, 2001.
- ^{cxviii} Some of the key critiques, for each era, are Wiesner and York, (note 2); Philip J. Farley, David Holloway and Sidney D. Drell, The Reagan Strategic Defense Initiative: A Technical, Political and Arms Control Assessment (Ballinger, 1985); and Gronlund et al, (note 108).
- ^{cxviii} See George N. Lewis, and Theodore A. Postol, 'Video Evidence of the Effectiveness of Patriot during the 1991 Gulf War', Science and Global Security 4, pp. 1-63; Collins and Pinch (note 8), Chapter 1.
- ^{cxv} MacKenzie (note 10).
- ^{cxvi} See Gronlund et al (note 108). A new intercept trajectory, which also changed the position of the sun, was used in the tests of September 2006 and September 2007.
- ^{cxvii} A particularly strong critique is that realistic decoys and warheads could have infrared signatures that twinkle like stars because of the wobbling and other movements of these objects as they travel through space, and their signatures overlap too much to be reliably distinguishable by the kill vehicle's infrared sensor. See Broad, 'Antimissile Testing Is Rigged to Hide a Flaw'.

^{cxviii} Thus Dave Montague, who worked for Lockheed on both HOE and ERIS, argues ‘that the long viewing time available during midcourse flight when threat objects are subject to variations between night and day, passage over land and sea and varying cloud cover affords the ability, using proven multi-spectral sensors closing on the target, to distinguish between the light decoys postulated by the UCS and real warheads with high thermal mass and unique motion induced by their deployment.’ Email for Dave Montague, 28/2/08/

^{cxix} Whereas the midcourse of strategic range missiles lasts between twenty and twenty-five minutes, the boost phase is typically four minutes for liquid-fueled missiles, but only three minutes for solid-fueled ones. However, detecting and tracking the target would eat into this time (using 45-65 seconds, according to the authoritative APS study), requiring almost instantaneous political decision-making to enable the interception to be carried out.

^{cxx} Email from Dave Montague, 28/2/08.

^{cxxi} Broad, (note 48) p. 233.

^{cxxii} Email from Bill Davis. See Spinardi (note 112).