The Washington Quarterly

ISSN: 0163-660X (Print) 1530-9177 (Online) Journal homepage: www.tandfonline.com/journals/rwaq20

Can the Iron Dome Be Transmuted into a Golden Dome?

Steve Fetter & David Wright

To cite this article: Steve Fetter & David Wright (2025) Can the Iron Dome Be Transmuted into a Golden Dome?, The Washington Quarterly, 48:2, 95-114, DOI: 10.1080/0163660X.2025.2514916

To link to this article: https://doi.org/10.1080/0163660X.2025.2514916

Published online: 07 Jul 2025.

Steve Fetter and David Wright

Can the Iron Dome Be Transmuted into a Golden Dome?

Israel's apparent success in defending against Iranian ballistic missile attacks in April and October 2024 has stimulated renewed interest in missile defense. Immediately after the April attacks, an Israeli Defense Forces (IDF) spokesperson claimed that 99 percent of the attacking drones and missiles were intercepted, calling the outcome "a very significant strategic success."[1] Similarly, the IDF attributed the relatively minor damage from the October attacks to "high-quality defenses."[2]

Some have asserted this demonstrates a technological breakthrough in missile defense in general. According to Matthew Kroenig, a member of the recent Congressional Commission on the Strategic Posture of the United States, "For decades, critics have argued that missile defenses do not work, but the facts have changed. Missile defense technology has greatly improved in recent years. The world has witnessed the remarkable success of Israel's Iron Dome system, which successfully defended Israel against massive Iranian salvos of missiles and drones."[3]

The Israeli experience appears to have been a major factor in prompting President Trump to issue an executive order in January 2025, "The Iron Dome for America," which calls for deployment of a "next-generation missile defense shield" to defend all US territory against any foreign attack.[4] In announcing the initiative, which was later rebranded "Golden Dome," Trump said,

Steve Fetter is a professor in the School of Public Policy at the University of Maryland and a senior fellow at the Center for International and Security Studies at Maryland. He can be reached by email at sfetter@umd.edu. David Wright is a researcher with the Laboratory for Nuclear Science and Policy at MIT. He can be reached by email at dcwright@mit.edu. The authors thank Jeffrey Lewis and Sam Lair for useful discussions and for sharing their videos.

The Washington Quarterly • 48:2 pp. 95–114
https://doi.org/10.1080/0163660X.2025.2514916

"Ronald Reagan wanted to do it many years ago … We didn't have the technology then … Now we have phenomenal technology. You see that with Israel, where out of 319 rockets they knocked down just about every one of them. So I think the United States is entitled to that."[5] Commenting on the announcement, former deputy national security advisor Victoria Coates said, "Like Israel's highly effective system of the same name, President Trump's Iron Dome will provide an impenetrable defense for the American people."[6]

Here, we review the 2024 Iranian attacks and the various missile defense systems used to stop the Iranian ballistic missiles. We then use press stories, published reports, and analysis of videos of the attacks to estimate the number of missiles successfully launched by Iran and the number of warheads that penetrated the defenses to estimate the effectiveness the defensive systems demonstrated in blunting the attacks.

We find that Israel appears to have stopped 80 to 85 percent of the attacking missiles that were engaged in the April and October attacks, and was able to achieve this level of defense effectiveness because it was protecting a small area from medium-range missiles that carried no countermeasures. Damage to Israeli territory was reduced by the presence of defenses, but was low primarily because the missiles had poor accuracy and carried conventional warheads, the public was alerted to take shelter, and Iran did not focus its attacks on densely populated areas.

Israel was protecting a small area from medium-range missiles that carried no countermeasures

This experience has little or no relevance to the missile defense challenges the United States faces. It says nothing about defending against long-range missiles, which would require different defensive systems than those used in Israel. Moreover, long-range nuclear-armed missiles would be equipped with countermeasures, which would lead to intercept rates much lower than in the Israeli case. And unlike in the Israeli case, even a small number of nuclear weapons penetrating the defense would result in massive damage and loss of life.

We conclude that while missile defense may in some cases provide a modest but useful level of protection against conventional attacks with medium-range missiles, there is no basis for believing that an effective defense is possible against nuclear-armed missiles, especially long-range ones.

Iranian Missile Attacks

Iran launched attacks against Israel on April 13 and October 1, 2024. The April 13 attack was in retaliation for the April 1 killing of Mohammad Reza Zahedi in

Damascus, who headed the Iranian Quds Force that assisted militant groups in Syria and Lebanon. Iran said the targets of its attack were Nevatim and Ramon Air Bases in the south of Israel and an intelligence center on Mount Hermon in the far north.[7] None of these sites are located near densely populated areas.

The April attack consisted of more than 200 unmanned aerial vehicles (UAVs) and 110 to 130 ballistic missiles.[8] The UAVs had relatively slow speeds and essentially all were shot down by military aircraft from Israel, the United States, Britain, France, and Jordan.[9] The ballistic missiles appear to have been primarily Emads—a single-stage, liquid-fueled missile based on the Shehab-3—with a range of about 1,700 kilometers and a payload of 750 kilograms. Iran claims these missiles have an accuracy of 50 meters, but based on observed impacts, analysts estimated the accuracy was closer to 1 kilometer.[10] Some reports claim Iran also fired Ghadr missiles, a Shehab variant similar to the Emad, and the newer Kheibar Shekan, a solid-fueled missile that is reported to have a range of about 1,450 kilometers with a 500-kilogram payload.[11]

Iran launched a second large attack on the evening of October 1, reportedly in retaliation for Israeli strikes in Lebanon, including one that killed Hezbollah leader Hassan Nasrallah.[12] Israeli officials said Iran launched 181 ballistic missiles in this attack which, unlike the April attack, did not include UAVs.[13] US officials stated that all of the missiles appeared to have been fired from Iranian territory.[14] Analysis of videos suggests that missiles were launched from five locations within Iran, ranging from about 1,250 to 1,700 kilometers from targets in Israel.[15]

Iran stated that it fired four different types of medium-range missiles: the liquid-fueled Emad and Ghadr (also launched in the April attack) and the solid-fueled Kheibar Shekan and Fatah-1 missiles.[16] The Fatah-1 includes a reentry vehicle with a small solid rocket motor as well as fins and uses the Kheibar Shekan as the first-stage booster. It has a reported range of 1,000 to 1,400 kilometers with a 350 to 450 kilogram payload.[17] While it is sometimes called a "hypersonic weapon," it appears to be a ballistic missile with some ability to glide and maneuver at low altitudes.

Israeli and US Missile Defenses

Israel and the United States had several missile defense systems deployed in the region around Israel at the time of the 2024 Iranian attacks. These defenses can be divided into two types: systems intended to intercept longer-range missiles above the atmosphere, or exo-atmospheric systems, and systems intended to intercept shorter-range missiles in the atmosphere, or endo-atmospheric systems.

Exo-atmospheric systems can only engage missiles outside the atmosphere, above about 100 kilometers altitude. At these altitudes, missiles follow a predictable path because the air is too thin to allow for aerodynamic maneuver. These systems are also called "midcourse" defenses because they attempt to intercept missile warheads in space, after the end of the boost-phase but before they reenter the atmosphere. The exo-atmospheric systems used in the 2024 attacks were the Israeli Arrow-3 and the US Standard Missile 3 (SM-3) Block IB interceptor, which is part of the Aegis defense system aboard some US ships. Both interceptors attempt to destroy targets by colliding with them, which is called "hit-to-kill." Both can engage missiles with ranges up to a few thousand kilometers.[18] Missiles with ranges of only a few hundred kilometers do not spend enough time above the atmosphere for these defenses to engage them. Reports place the cost of each interceptor at $2 to 4 million for Arrow-3 and $10 to 12.5 million for SM-3.[19]

Endo-atmospheric systems can only operate within the atmosphere, below a few tens of kilometers' altitude. These systems are also called "terminal" defenses because they attempt to intercept missiles during the final part of their trajectories. They are intended to intercept missiles with relatively low speeds and therefore short ranges. During engagements at low altitudes, both the interceptor and missile can maneuver using aerodynamic forces. The intercept probability depends on the relative maneuverability of the two, which in turn depends on the speed of each object. These systems can intercept aircraft as well as short-range missiles.

Israel had several missile defense systems deployed in the region

The endo-atmospheric systems used in the 2024 attacks were the Israeli Arrow-2 and David's Sling. (The Israeli Iron Dome system is intended to intercept very short-range weapons, such as artillery shells and mortars, and is not able to intercept ballistic missiles.) Most sources say Arrow-2 is designed to operate at 10 to 50 kilometers' altitude, although one source suggests it may be able to engage missiles at significantly higher altitudes.[20] It has a defensive range of about 90 kilometers and the interceptor uses an explosive warhead that attempts to destroy the incoming missile warhead with high-speed fragments. It is reported to be able to intercept targets with speeds up to about 3 kilometers per second,[21] and interceptors are reported to cost about $3 million each.[22] David's Sling uses hit-to-kill interceptors to defend against aircraft and ballistic missiles at distances up to 300 kilometers. The interceptor is reported to engage incoming warheads from short-range missiles at altitudes up to 15 kilometers, and each interceptor is reported to cost about $1 million.[23]

Missile Defense Effectiveness

Israeli and US government officials have not released detailed information on how many Iranian ballistic missiles were engaged by Israeli or US missile defense systems, how many interceptors of what type were fired at those missiles, or how many Iranian missiles were successfully intercepted. Here, we rely on media reports and video analysis to estimate the overall effectiveness of missile defenses in the 2024 attacks.

By estimating the number of missiles that threatened Israeli territory in each attack and comparing that to an estimate of the number of missiles that penetrated the Israeli and US missile defenses and hit the ground, we can estimate the overall effectiveness of those defenses in reducing the number of attacking missiles. Because we do not know how many of each type of interceptor were fired, we cannot estimate interceptor effectiveness for the different systems.

April 2024 Attack

In the April attack, US officials told ABC News that of the missiles Iran attempted to fire, "about half of those missiles either failed to launch, failed in flight or crashed before reaching their targets in Israel."[24] If that is correct, about fifty to seventy missiles threatened Israeli territory. According to various reports, four or five missiles hit the Nevatim Airbase,[25] four hit the Ramon Airbase,[26] and one hit near a radar site in northern Israel.[27] Thus, a total of nine to ten missiles appear to have hit targets in Israel. If fifty to seventy missiles threatened Israeli territory and all were engaged by missile defense systems, and if nine to ten got through, the intercept rate was 80 to 87 percent.[28] Reports of higher interception rates likely refer to the total number of missiles and UAVs that were shot down or failed in flight. If we assume 110 ballistic missiles and 220 UAVs were launched, and that nine to ten missiles and no UAVs hit Israel, then 97 percent of the attacking weapons were either intercepted or failed in flight.

Most of the intercepted Iranian missiles were engaged by Israeli defense units using Arrow-2 and Arrow-3 interceptors. One missile was reportedly intercepted by a David's Sling interceptor.[29] Two US missile destroyers deployed in the Eastern Mediterranean, the USS Arleigh Burke (DDG-51) and USS Carney (DDG-64), reportedly shot down between four and six missiles.[30] This was the first reported combat use of SM-3 interceptors.[31]

October 2024 Attack

During the October attack, "a sizable number" of the 181 reported missiles failed before reaching Israeli airspace, according to a US official.[32] Video analysis of the

launches suggest that about 10 percent of the missiles may have failed during launch,[33] which implies that the number of missiles successfully launched against Israel was about 165. The failure rate was lower than in the April attack, presumably because Iran used a larger fraction of its newer generation of missiles, the Kheibar Shekan and Fatah-1, in this attack.

Iran stated that it targeted three Israeli airbases: Nevatim, Tel Nof, and Hatzerim.[34] Analysis of satellite imagery after the attack showed that Nevatim Airbase was struck by at least thirty-two missiles.[35] Damage, however, was reportedly small enough that it did not close the base. Tel Nof Airbase was reportedly hit by three missiles.[36] There are no reports of missile impacts at Hatzerim.[37] Photos of a missile that hit a house in Tel Sheva, east of the Hatzerim Airbase, appear to show an intact Kheibar Shekan that did not explode.[38] That and other missile debris reported east of Hatzerim suggest that this base may have been targeted by Iranian missiles that either failed to hit it or were intercepted. Debris was also reported in other locations, including Beersheba, Hura, Dimona, and Arad, which all lie about 20 kilometers from Nevatim Airbase, and around the Dead Sea.[39]

The large number of impacts at Nevatim Airbase does not say much about the effectiveness of missile defenses. Because the base is not in a heavily populated area, and because air bases are difficult to damage with conventional warheads of the size used in this attack, Israeli and US missile defenses may have engaged few of the missiles targeting Nevatim to reserve interceptors for the defense of targets in more populated areas. Prioritizing the use of interceptors is important both because of their expense and limits on the number of available interceptors.[40]

It is, however, highly likely that missiles targeting the more populated areas around Tel Aviv would have been engaged by missile defense systems. We therefore use estimates of the number of missiles targeted on this area and the number of reported missile hits to estimate the effectiveness of the missile defense.

A wide-angle video—shot from Amman, Jordan and posted online—shows the sky over Israel from north of Tel Aviv to well south of Nevatim Airbase during both waves of the October attack.[41] Analysis of the video shows forty-five to fifty-five missiles descending over the Tel Aviv area, including Tel Nof. It also shows the launch of what appear to be eighteen exo-atmospheric interceptors, some of which were defending the Tel Aviv area. Some of these appear to be Arrow-3 interceptors. In addition, the US Navy reported that it fired about a dozen SM-3 interceptors from ships in the Mediterranean Sea during the October attack and said that "multiple missiles are believed to have been successfully engaged."[42] If we assume that the Arrow-3 and SM-3 interceptors may have destroyed another five to ten missiles targeting Tel Aviv at altitudes above those seen in the video, this would suggest that fifty to sixty-five missiles threatened the Tel Aviv area.

As noted above, the Tel Nof Airbase, which is in the southern part of Tel Aviv, was reportedly hit by three missiles. In addition, a nearby school building in Gedera was damaged by a missile hit.[43] There also appear to have been five or six missile impacts in the northern part of Tel Aviv, in the region around the Mossad Headquarters (HQ) and the nearby Israeli military intelligence center, Unit 8200, which were likely targets of the strike. This includes two craters found within about half a kilometer of the Mossad HQ;[44] a third hit reported 1.5 kilometers southwest of the HQ;[45] a fourth reported 5 kilometers south of the HQ near the Ayalon Mall shopping center;[46] and a fifth in the town of Hod Hasharon 7.5 kilometers east of the HQ, where the blast reportedly damaged 100 homes.[47] There is also a report of a hit on a medical facility on George Wise Street, 3.5 kilometers south of the Mossad HQ, but it is not clear whether this was a missile strike or a hit by debris.[48] In addition, there are reports of impacts in the coastal area of Netanya, 20 kilometers north of the Mossad HQ, and in the nearby town of Sharon, although it is possible these are debris impacts.[49] Reports also say that a missile blast caused a power outage in Bnei Atarot.[50] In all, at least nine or ten missiles impacted areas around Tel Aviv.

These figures give a rough estimate of the effectiveness of missile defenses in the October attack. As in the April attack, most Iranian missiles were engaged by the Arrow-3 and Arrow-2 systems. If all fifty to sixty-five missiles threating the Tel Aviv area were engaged by missile defenses and there were at least nine or ten impacts in this area, that implies the overall defenses intercepted no more than 80 to 86 percent of the missiles engaged.

As noted above, we do not have detailed or authoritative information about the number of Iranian missiles engaged by missile defense systems, the number of interceptors fired at each missile, or the number of missiles successfully intercepted. Nevertheless, the consistency of our estimates for the April and October attacks adds confidence to our conclusion that 80 to 85 percent of Iranian missiles engaged by missile defenses were intercepted.

It appears that 80-85 percent of Iranian missiles engaged by missile defenses were intercepted

This estimated effectiveness is the overall probability of destroying incoming missiles. To increase the likelihood of destroying a warhead, multiple interceptors may be launched against each missile that is engaged. If two interceptors were used against each missile, then an 80 to 85 percent overall interception rate would mean that each interceptor had about a 55 to 60 percent probability of intercepting a missile.

Because ample warning of the impending attack was available and people were able to take shelter, the October attack caused very few serious injuries in Israel. But insurance claims filed after the attack give a sense of the level of damage that was caused both by the missile explosions and falling debris. The Israeli Tax Authority reported receiving about 2,500 claims for damage, for an estimated total of about $50 million.[51] Of these, some 2,200 were for damage to buildings, with the rest for damage to vehicles, and more than half were in northern Tel Aviv.[52] Some 1,000 claims were reportedly from the Hod HaSharon area and another $13 million in claims came from "a luxury complex on the northern Tel Aviv beachfront," which is likely the area southwest of the Mossad HQ.[53] Another group of claims were reportedly from the area around the missile strike in Gedera.[54] We requested but were unable to obtain additional details about the insurance claims from the Israeli Tax Authority, which could provide more information about the locations of the missile strikes and how much of the damage was due to debris rather than explosions.

Lessons for Theater Missile Defense

The 2024 Israeli experience demonstrated that a combination of missile defense and civil defense can provide protection of a relatively small region against inaccurate medium-range ballistic missiles armed with conventional warheads, in the absence of effective countermeasures. It also showed that, against this type of attack, this level of protection can be strategically important. As one analyst noted, "if Israel had sustained serious damage without such defenses, then Israeli leadership likely would have, of necessity, retaliated more significantly against Iran. This wider retaliation could have forced a wider war between Israel and Iran."[55] In a protracted conflict, the protection provided by missile defenses could help avoid a substantial diversion of military effort, as happened in the 1991 Persian Gulf War when up to one-third of the missions scheduled for the air campaign were redirected to hunting Scud missile launchers.[56]

The populated area of Israel is the size of Delaware

Israel was able to mount an effective defense partly because it was defending a small area. Israel is five times smaller than South Korea, eighteen times smaller than Japan, thirty times smaller than Ukraine, and 470 times smaller than the United States. Most of Israel is desert; the populated area is the size of Delaware. The defended areas of Arrow-2 batteries located at two or three locations can cover the entire Israeli population. Many more would be required to provide an endo-atmospheric defense of a larger country.

Israel was also able to provide a relatively effective defense because Iran's missiles lacked countermeasures. Countermeasures could include light decoys or ballons to overwhelm exo-atmospheric defenses, jammers or heat sources to confuse radar or infrared sensors, depressed trajectories or glide vehicles that limit intercept opportunities for exo-atmospheric defenses, and submunitions that overwhelm exo- and endo-atmospheric defenses.

Most importantly, the level of defense Israel could provide was effective because Iranian missiles were armed with conventional high-explosive warheads, so that the warheads that penetrated the defense did relatively little damage. These warheads can destroy or damage reinforced concrete structures (the majority of Tel Aviv's housing stock) out to distances of only 10 to 20 meters, limiting the damage from missiles that penetrate the defense to a relatively small area around the explosion.[57] And because this distance is small compared to the accuracy of the missiles, they cannot be used effectively against small targets, and are therefore not useful for counterforce strikes, as was demonstrated in the 2024 attacks.

In addition, the relatively small damage caused by the warheads that penetrated the defense, along with the warning provided by radar systems, allowed for effective sheltering by the public, greatly reducing the potential for death and injury. Simple measures, such as sheltering on the west side of a wall, can provide a high degree of protection against conventional missiles coming from the east.

Israel also sustained relatively light damage because of the type of attacks that Iran launched. Iran may have shaped its attacks to send a message in response to Israeli strikes while minimizing civilian deaths and reducing the chance of major escalation. It targeted most of its missiles against air bases in sparsely populated areas. This meant that Israel could allow many missiles in the October attack to fall without firing interceptors at them, as indicated by the large number of hits at Nevatim Airbase which caused relatively little damage. Had Iran focused its attack on Tel Aviv, it would have resulted in significantly more damage. In this case, Israel would likely have fired significantly more interceptors, depleting its interceptor stocks.

Defensive systems that intercept 80-85 percent are of little value against nuclear missiles

In stark contrast, defensive systems that intercept 80 to 85 percent of incoming missiles are of little value against missiles armed with nuclear warheads. A single Hiroshima-sized weapon detonated above Tel Aviv would kill 100,000 and injure 200,000.[58] A single ground-level detonation would kill even more, while contaminating thousands of square kilometers—an area greater than the entire populated area of Israel—with fallout at levels requiring

evacuation and decontamination. (A US government analysis concluded that 8,000 km^2 would require decontamination following a 10-kiloton ground-level detonation. For comparison, the entire area of Israel north of the Negev Desert is 5,000 km^2 and the area of all cities and towns is less than 2,000 km^2.) [59] Nine or ten such weapons—the number of missiles that penetrated defenses in both the April and October attacks—could kill or injure half the Israeli population and render the country uninhabitable for years, if not decades. Even the most robust civil defenses would be unable to reduce casualties from such an attack to a tolerable level.

An effective defense of Israel against nuclear attack would require systems with leakage rates ten to one hundred times smaller than the 15 to 20 percent demonstrated in the 2024 attacks. If just ten nuclear-armed missiles were launched against a defense with 85 percent probability of intercepting each missile, there would be an 80 percent chance that at least one warhead would penetrate the defense. Reducing this to a 10 percent chance of one warhead penetrating the defense would require an intercept probability of 99 percent, or a leakage rate fifteen times less than demonstrated in the 2024 attacks. For fifty attacking missiles, the intercept probability would have to be 99.8 percent to achieve a similar level of confidence. It is extremely unlikely that such high levels of performance are achievable, especially against a more sophisticated attack.

Even against the relatively unsophisticated Iranian missile threat, the defense was costly. Missile interceptors are highly sophisticated and therefore expensive systems—more sophisticated and expensive than the ballistic missiles they attempt to destroy. For example, if two interceptors are used against each missile, the cost per missile engaged is $4 to 8 million for Arrow and $20 to 25 million for SM-3.[60] For comparison, Iran probably can produce medium-range missiles for less than $1 million each. Reports at the time of the April attack estimated that defending against the missiles may have cost Israel about $1 billion, while Iran's cost may have been about one-tenth of that amount.[61]

Such an unfavorable cost-exchange ratio could be important in an extended conflict with an adversary who can spend amounts comparable to a defender. In addition, the total cost of the Arrow interceptors and damage in the October 2024 attacks was at least as great, and up to three times greater, than the total property damage if no interceptors had been fired. If SM-3 Block IB interceptors were used rather than Arrows in this situation, the cost with missile defense would be five to nine times greater than the property damage without missile defense.

Defense systems like these might also be useful in other theaters, such as Europe and East Asia, if US allies or US forces faced attack by conventionally armed short- and medium-range missiles. Whether missile defenses would provide important strategic or tactical advantages would depend on many

details, including the range and accuracy of the attacking missiles, whether they were equipped with countermeasures, and the nature of targets.[62] In some cases, such as conventional attacks against cities or civilian infrastructure, a modestly effective missile defense could be important in maintaining the support and morale of allies while controlling escalation. In other cases, such as North Korean conventional attacks on US bases in South Korea or Japan, missile defense might play a less important role and hardening and rapid repair of facilities would be necessary in any case due to the inevitable leakage through a missile defense. As noted above, Israel's Nevatim air base remained operational during and after the October 2024 attacks despite sustaining dozens of impacts.

From Iron Dome to Golden Dome?

The Israeli experience provides no information on the potential effectiveness of missile defense systems against the kinds of missile threats the United States would face, which would be longer range and more sophisticated. Defense against longer-range missiles would require different missile defense systems than were used in Israel. Long-range missiles—such as the intercontinental and submarine-launched ballistic missiles fielded by Russia, China and North Korea—reach velocities more than twice that of the medium-range missiles fired by Iran against Israel.

Intercept of long-range missiles requires higher-velocity interceptors, which are significantly larger and more expensive that the Arrow-3 and SM-3 Block IB. For example, the SM-3 Block IIA interceptor, which has been tested once against a long-range missile, has a maximum speed one and a half times that of Arrow-3 and is reported to cost nearly $30 million each.[63] The Ground-Based Interceptors (GBI) fielded by the United States in Alaska and California, which are intended to intercept long-range missiles, have a maximum velocity of 7.2 kilometers per second (more than twice that of Arrow-3 or SM-3 Block IB) and cost about $70 million each (roughly twenty times more than Arrow).[64] Highly scripted tests of GBI have intercepted targets in only about half of tests, all of which occurred under favorable conditions for the defense. In response to concerns about the reliability and effectiveness of GBI, the United States is developing a replacement, the Next Generation Interceptor, which is estimated to cost $110 million per interceptor.[65]

Moreover, any country capable of building long-range missiles is also capable of building lightweight decoys and other penetration aids which could confuse and overwhelm an exo-atmospheric defense system.[66] Russia and China are more than capable of deploying effective countermeasures, and the US intelligence community stated that North Korea and Iran could develop penetration

aids and countermeasures by the time they flight test a long-range missile.[67] A 2012 review by the National Academies of Science, Engineering, and Medicine (NASEM) concluded: "The hard fact is that no practical missile defense system can avoid the need for midcourse discrimination—that is, the requirement to identify the actual threat objects (warheads) amid the cloud of material accompanying them in the vacuum of space. This discrimination is not the only challenge for midcourse defense, but it is the most formidable one, and the midcourse discrimination problem must be addressed far more seriously if reasonable confidence is to be achieved."[68]

Although the review identified potential approaches, reliable discrimination has not been demonstrated by any country. The review also noted that decoys are not the only countermeasures a midcourse defense system must face, and that other possible countermeasures include "attacks on key components of the defense, notably its sensors."[69] A particularly effective countermeasure is to equip nuclear warheads with "salvage fuzing" so they detonate before being destroyed by interceptors, blinding missile defense radars and infrared sensors to subsequent attacking warheads. Recently, concern has arisen that Russia might station nuclear weapons in space, to be detonated early in a conflict to destroy a range of US satellite capabilities. Russia has reportedly developed a long-range hypersonic glide vehicle that can underfly exo-atmospheric defenses with speed sufficient to penetrate endo-atmospheric defenses. We see no reason to believe that it is possible to mount a highly effective defense against nuclear-armed long-range missiles.

Space-based boost-phase interceptors are unattractive because of limitations imposed by physics

Missile defense advocates point to the promise of new technologies, such as rockets or lasers based in space to intercept missiles in their boost phase. These and other exotic missile defense technologies were explored and rejected as part of the Reagan administration's Strategic Defense Initiative in the 1980s. Although it is tempting to think that technological advances in the last forty years might have changed assessments, these approaches are unattractive because of fundamental limitations imposed by physics, not shortcomings that can be overcome by improvements in technology.

Any defense interceptors based in orbit will continually move with respect to the Earth, requiring that many platforms be deployed to have one near a missile launch site at all times. For example, about 1600 interceptors would be required in orbit to ensure that just one would be in position to engage a single solid-fuel ICBM launched from Russia, China, North Korea or Iran.[70] Taking multiple

shots against multiple ICBMs launched from the same area on Earth would increase proportionately the number of on-orbit interceptors needed. Because the cost-exchange ratio strongly favors the offense, even a less capable adversary could overwhelm the system by building more missiles. Space-based lasers would be vulnerable to preemptive attack and would suffer from limits on beam strength, control, and propagation of laser light through the atmosphere—limits that caused the United States to abandon efforts to develop an airborne laser for missile defense, which is much less technically challenging than a space-based laser. These factors led the 2012 National Academies' review to conclude that "boost-phase missile defense—whether kinetic or directed energy, and whether based on land, sea, air, or in space—is not practical or feasible" and to recommend that "the Department of Defense should not invest any more money or resources in systems for boost-phase missile defense."[71]

Missile defense optimists might hope that improvements in existing and emerging technologies since 2012 may have changed this assessment, but that is not the case.[72] Indeed, a report by the American Physical Society released in March, which included a review of the effectiveness of missile defenses in countering the 2024 Iranian missile attacks, stated that "creating a reliable and effective defense against even the small number of relatively unsophisticated nuclear-armed ICBMs that we considered remains a daunting challenge. The difficulties are numerous, ranging from the unresolved countermeasures problem for midcourse warhead-intercept to the severe reach vs. time problem of boost-phase missile intercept." It concluded that "our analysis of published work has led us to conclude that few of the main challenges involved in developing and deploying a reliable and effective ballistic missile defense have been solved, and that many of the hard problems we have identified are likely to remain unsolved during, and probably beyond, the 15-year time horizon we considered."[73]

Conclusion

The 2024 Iranian attacks demonstrated that Israel was able to stop 80 to 85 percent of the missiles attacking it, but at a significant cost relative to the cost of the attack and the damage that would have been sustained in the absence of a defense. Israel was able to achieve this level of defense effectiveness because it was protecting a small area from medium-range missiles that carried no countermeasures. The damage resulting from the attacks was limited because the missiles had low accuracy and carried conventional warheads, the public was alerted to take shelter, and Iran did not focus its attack on densely populated areas.

The Israeli experience says nothing about defending against long-range, nuclear-armed missiles equipped with countermeasures, which would lead to intercept rates

much lower than in the Israeli case. Even if intercept rates of 90 percent or higher were possible, missile defenses could not prevent massive damage and loss of life from the detonation of a small number of nuclear warheads. There is no reason to believe that new technologies will lead to very high interception rates.

The 2024 defense of Israel may have inspired Kroenig and Trump to envision a highly effective defense of the United States and its allies from all adversaries, including nuclear-armed Russia, China and North Korea, but it provides no basis or reason to believe that vision is achievable. There is no technological fix to the threat posed by nuclear-armed long-range ballistic missiles. That threat is best addressed through diplomacy: arms control and confidence-building measures that reduce the number of such weapons and incentives to use them in a crisis. The quixotic pursuit of an impenetrable defense is likely to degrade US security by prompting adversaries to move in the opposite direction.

The quixotic pursuit of an impenetrable defense is likely to degrade US security

Notes

1. Josef Federman and Jon Gambrell, "Israel Says Iran Launched More than 300 Drones and Missiles, 99% of Which Were Intercepted," Associated Press, April 14, 2024, https://apnews.com/article/strait-of-hormuz-vessel-33fcffde2d867380e98c89403776a8ac.
2. Emanuel Fabian, "Following Mass Iran Attack, Medics Say Just 2 Lightly Wounded by Shrapnel in Tel Aviv," *Times of Israel*, October 1, 2024, https://www.timesofisrael.com/liveblog_entry/following-mass-iran-attack-medics-say-just-2-lightly-wounded-by-shrapnel-in-tel-aviv/; Israel Defense Forces, "The Chief of the General Staff Regarding Iranian Attack at Tel Nof Airbase," October 2, 2024, https://www.idf.il/en/mini-sites/idf-press-releases-israel-at-war/october-24-pr/the-chief-of-the-general-staff-regarding-iranian-attack-at-tel-nof-airbase/.
3. Matthew Kroenig, "The United States Needs an Iron Dome," *Foreign Policy*, February 5, 2025, https://foreignpolicy.com/2025/02/05/trump-reagan-missile-defense-star-wars-iron-dome/.
4. The White House, "The Iron Dome for America," Executive Order 14186, January 27, 2025, https://www.whitehouse.gov/presidential-actions/2025/01/the-iron-dome-for-america/.
5. "Donald Trump Addresses the House GOP Issues Conference in Miami," Roll Call, January 27, 2025, https://rollcall.com/factbase/trump/transcript/donald-trump-speech-house-gop-conference-miami-january-27-2025/.
6. Tyler O'Neil, "President Trump to Sign Executive Order Launching US Iron Dome," The Daily Signal, January 27, 2025, https://www.dailysignal.com/2025/01/27/fulfilling-reagans-vision-trumps-new-us-iron-dome-project-will-prevent-deaths-rather-avenge-them-expert-says.
7. Uzi Rubin, "'Operation True Promise': Iran's Missile Attack on Israel," Perspectives Paper No. 2,281, Begin-Sadat Center for Strategic Studies, June 18, 2024, https://besacenter.org/operation-true-promise-irans-missile-attack-on-israel/.

8. See, for example, Rubin, "Operation True Promise"; Sune Engel Rasmussen, Carrie Keller-Lynn, Catherine Lucey, Michael R. Gordon, and Dov Lieber, "Iran Launches Drone and Missile Attack at Israel," *Wall Street Journal,* April 14, 2024, https://www.wsj.com/world/middle-east/iran-tries-to-calibrate-response-against-israel-after-deadly-bombing-abb38b57?mod=article_inline; Gordon Lubold, "Many Iranian Missiles Failed to Launch or Crashed Before Striking Target, U.S. Officials Say," *Wall Street Journal,* April 15, 2024, https://www.wsj.com/livecoverage/israel-iran-strikes-live-coverage/card/many-iranian-missiles-failed-to-launch-or-crashed-before-striking-target-u-s-officials-say-TCd4YP2fiODhl1t9QDrL.
9. Ronen Bergman, Farnaz Fassihi, Eric Schmitt, Adam Entous, and Richard Pérez-Peña, "Miscalculation Led to Escalation in Clash Between Israel and Iran," *New York Times*, April 17, 2024, https://www.nytimes.com/2024/04/17/world/middleeast/iran-israel-attack.html; Brad Lendon, "How Israel and Allied Defenses Intercepted More than 300 Iranian Missiles and Drones," CNN, April 14, 2024, https://www.cnn.com/2024/04/14/middleeast/israel-air-missile-defense-iran-attack-intl-hnk-ml/index.html; Ken Klippenstein and Daniel Boguslaw, "U.S., Not Israel, Shot Down Most Iran Drones and Missiles," *The Intercept,* April 15, 2024, https://theintercept.com/2024/04/15/iran-attack-israel-drones-missiles/.
10. Jeffrey Lewis and Aaron Stein, "Iran and Israel's Missile War," *Arms Control Wonk* (podcast), May 18, 2024, https://www.armscontrolwonk.com/archive/1219433/iran-and-israels-missile-war/.
11. Rubin, "Operation True Promise"; Joseph Trevithick, "Signs Point to Combat Debut Of Navy's SM-3 Interceptor Against Iranian Ballistic Missiles," The War Zone, April 14, 2024, https://www.twz.com/news-features/signs-point-to-combat-debut-navys-sm-3-interceptor-against-iranian-ballistic-missiles.
12. Stephen Kalin and Carrie Keller-Lynn, "Israeli Airstrike Killed Hezbollah Leader Hassan Nasrallah," *Wall Street Journal*, September 28, 2024, https://www.wsj.com/world/middle-east/israel-brings-fight-to-beirut-still-assessing-whether-hezbollahsleader-is-dead-1bf0d098?mod=article_inline.
13. Adam Taylor and Meg Kelly, "Iran's Missile Attack on Israel Raises Questions about Limits of Arsenal," *Washington Post*, October 5, 2024, https://www.washingtonpost.com/world/2024/10/05/iran-missiles-attack-israel-deterrence/.
14. C. Todd Lopez, "U.S. Assets in Mediterranean Again Helped Defend Israel Against Iranian Missiles," US Department of Defense News, October 1, 2024, https://www.defense.gov/News/News-Stories/Article/Article/3923123/us-assets-in-mediterranean-again-helped-defend-israel-against-iranian-missiles/.
15. Jeffrey Lewis and Sam Lair, personal communication, March 3, 2025. See also Artemis Moshtaghian, "Iran Launches Missile Attack on Israel," CNN, October 1, 2024, https://www.721news.com/2024/10/cnn-iran-launches-missile-attack-on-israel/.
16. Dov Lieber and Rory Jones, "Iran Says It Used Four Types of Ballistic Missiles," *Wall Street Journal*, October 3, 2024, https://www.wsj.com/livecoverage/israel-iran-hezbollah-conflict/card/iran-says-it-used-four-types-of-ballistic-missiles-SXCDtZjZXIP5HUrElsw4.
17. "'Fatah': Iran's New Hypersonic Missile—Technical Assessment," Tal Inbar, July 6, 2023, https://missiledefenseadvocacy.org/wp-content/uploads/2023/06/Iran-Hypersonicc-missile-limited-distribution-7.6.2023-1-1.pdf.
18. "Standard Missile-3 (SM-3)," Missile Defense Project, Center for Strategic and International Studies, June 14, 2016, last modified March 9, 2023, https://missilethreat.csis.

org/defsys/sm-3/; Timur Kadyshev and Moritz Kütt, "Analyzing the Utility of Arrow 3 for European Missile Defense Using Footprint Calculations," *Science and Global Security* 31, no. 1—3 (January 2025): https://doi.org/10.1080/08929882.2024.2444750. Both interceptors have a maximum speed of about 3 km/s.

19. Howard Altman, "More SM-3 Interceptors Needed After Downing Iranian Ballistic Missiles: Navy Secretary," The War Zone, May 3, 2024, https://www.twz.com/sea/more-sm-3-interceptors-needed-after-downing-iranian-ballistic-missiles-navy-secretary; "Missile Interceptors by Cost," Missile Defense Advocacy Alliance (MDAA), February 2024, https://missiledefenseadvocacy.org/missile-defense-systems-2/missile-defense-systems/missile-interceptors-by-cost/; Udi Ezion, "'Defense is More Expensive than Offense': The Cost of Iran's Missile Attack and Israel's Defense," *Jerusalem Post*, October 4, 2024, https://www.jpost.com/israel-news/defense-news/article-823148; Galit Altstein and Dan Williams, "Israel's Arrow says Missile Defense Systems did their Job Against Iran," Stars and Stripes, October 4, 2024, https://www.stripes.com/theaters/middle_east/2024-10-04/israel-arrow-missile-defense-system-iran-15401134.html; Yossi Yehoshua, "Israel Signs Multi-billion Deal to Buy More Arrow-3 Interceptors to Counter Houthi Threat," Ynet News, December 24, 2024, https://www.ynetnews.com/article/rj94ruubyg.
20. "Arrow 2 Theatre Ballistic Missile Defence System, Israel," Army Technology, February 10, 2014, https://www.army-technology.com/projects/arrow2/?cf-view; "Arrow 2: Anti Ballistic Missile Interceptor," Israel Aerospace Industries (IAI), nd, https://www.iai.co.il/p/arrow-2.
21. "Arrow 2," Army Technology.
22. Ezion, "'Defense is More Expensive.'"
23. "What are Israel's Iron Dome, David's Sling, Arrow and Thaad Missile Defences?" BBC News, October 16, 2024, https://www.bbc.com/news/world-middle-east-20385306; Tyler Rogoway, "Israel Is Testing An Air-To-Air Variant Of Its Dolphin-Nosed Stunner Missile," The War Zone, July 5, 2020, https://www.twz.com/11092/israel-is-testing-an-air-to-air-variant-of-its-dolphin-nosed-stunner-missile; "David's Sling (Israel)," Missile Defense Project, Center for Strategic and International Studies, April 14, 2016, last modified July 13, 2021, https://missilethreat.csis.org/defsys/davids-sling.
24. Anne Flaherty, "US to Israel: If you Strike Back at Iran, You'll do it Alone," ABC News, April 15, 2024, https://abcnews.go.com/Politics/us-israel-strike-back-iran/story?id=109226739. See also Rubin, "Operation True Promise"; Yaroslav Trofimov, "Analysis: Israel Repelled Iran's Huge Attack. But Only With Help From U.S. and Arab Partners," *Wall Street Journal*, April 14, 2024, https://www.wsj.com/world/middle-east/analysis-israel-repelled-irans-huge-attack-but-only-with-help-from-u-s-and-arab-partners-a7844065.
25. Rubin, "Operation True Promise"; Lewis, "Iran and Israel's Missile War"; Faris Tanyos, Cara Tabachnick, and Tucker Reals, "Israel says Iran's Missile and Drone Attack Largely Thwarted, with "Very Little Damage' Caused," CBS News, April 14, 2024, https://www.cbsnews.com/news/iran-launches-drone-attack-toward-israel-idf-says/; Martha Raddatz, "Minor Damage Reported at 2 Israeli Air Bases," ABC News, April 14, 2024, https://abcnews.go.com/International/live-updates/israel-gaza-hamas-war/minor-damage-reported-at-2-israeli-air-bases-109221472?id=108860743.
26. Raddatz, "Minor Damage Reported."
27. Tanyos, "Israel Says."
28. This is similar to the estimate in Rubin, "Operation True Promise."
29. Ben-Yishai, "Zero Hits."

30. Klippenstein, "U.S., Not Israel, Shot Down"; Altman, "More SM-3 Interceptors."
31. Trevithick, "Signs Point to Combat Debut."
32. Patrick Kingsley, Eric Schmitt and Ronen Bergman, "After Missile Attack, Israel May Be Ready to Risk All-Out War With Iran," *New York Times*, October 2, 2024, https://www.nytimes.com/2024/10/02/world/middleeast/iran-missile-attack-israel-war.html.
33. Sam Lair, personal communication, March 3, 2025.
34. Alexandra Braverman, et al., "Iran Update, October 1, 2024," Institute for the Study of War, October 1, 2024, https://www.understandingwar.org/backgrounder/iran-update-october-1-2024.
35. Geoff Brumfiel, "Satellite Images Show Dozens of Iranian Missiles Struck Near Israeli Air Base," NPR, October 4, 2024, https://www.npr.org/2024/10/04/nx-s1-5140058/satellite-images-dozens-iranian-missiles-struck-near-israeli-air-base; Decker Eveleth, "IMINT: Iran's Strike on Nevatim Airbase," Hors d'Oeuvres of Battle, October 4, 2024, https://horsdoeuvresofbattle.blog/2024/10/04/imint-irans-strike-on-nevatim-airbase/; Yaroslav Trofimov, "Iranian Missiles Overwhelmed Israeli Defenses at Some Sites, Analysts Say," *Wall Street Journal*, October 4, 2024, https://www.wsj.com/world/middle-east/iran-missiles-israel-overwhelm-defence-a7cbd9af?mod=Searchresults_pos7&page=1.
36. Meg Kelly, Imogen Piper, and Evan Hill, "Iranian Missiles Hit Israeli Military Sites, Visuals Show," *Washington Post*, October 4, 2024, https://www.washingtonpost.com/world/2024/10/04/iran-missile-israel-attack-video/; Tal Schneider, "How Effective Was Iran's Attack? The Israeli Public Doesn't Have the Full Picture," *Times of Israel*, October 6, 2024, https://www.timesofisrael.com/how-effective-was-irans-attack-the-israeli-public-doesnt-have-the-full-picture/.
37. "Iran Bombs Israel, Pokes Hole in Roof at Air Base, Kills One Arab," *Iran Times*, October 25, 2024, https://iran-times.com/iran-bombs-israel-pokes-hole-in-roof-at-air-base-kills-one-arab/.
38. "Videos, Photos Show Craters, Missile Fragments from Iran Attack Spotted Across Israel," *Times of Israel*, October 1, 2024, https://www.timesofisrael.com/liveblog_entry/videos-photos-show-craters-missile-fragments-from-iran-attack-spotted-across-israel/; Tovah Lazaroff, Yonah Jeremy Bob, and Mathilda Heller, "Iran Launches Hundreds of Rockets into Israel in Massive Aerial Attack," *Jerusalem Post*, October 1, 2024, https://www.jpost.com/breaking-news/article-822801.
39. Lazaroff, "Iran Launches Hundreds"; Abby Chitty, "Israel Says Damage from Iranian Missile Attack Minimal Thanks to 'High-quality Defence,'" Euronews, October 3, 2024, https://www.euronews.com/2024/10/03/israel-says-damage-from-iranian-missile-attack-minimal-thanks-to-high-quality-defence; Dov Lieber and Rory Jones, "Israeli Review Shows Minor Damage From Iran's Missile Barrage," *Wall Street Journal*, October 2, 2024, https://www.wsj.com/world/middle-east/israel-assesses-damage-from-irans-missile-barrage-27c26e5e?mod=article_inline; "Israel Under Attack," Yeshiva World News, October 1, 2024, https://www.theyeshivaworld.com/news/israel-news/2320781/israel-under-attack-iran-fires-181-ballistic-missiles-into-israel-palestinian-is-only-fatality.html; "Israel Censors Reporting on Military Sites Hit by Iran, Obscuring Extent of Damage," Middle East Eye, October 2, 2024, https://www.middleeasteye.net/news/israel-censors-reporting-military-sites-hit-iran-obscuring-extent-strikes.
40. Alistair MacDonald, Doug Cameron, and Heather Somerville, "Drone-and-Missile Warfare Tests Supply-Strapped Defense Systems," *Wall Street Journal*, April 17, 2024, https://www.wsj.com/world/middle-east/drone-missile-attacks-threaten-weapons-supply-24356bf4; Trofimov, "Iranian Missiles Overwhelmed."

41. Jeffrey Lewis and Sam Lair, personal communication, December 19, 2024.
42. Gritten, "What We Know"; Caitlyn Burchett, "2 Navy Destroyers Help Defend Israel, Intercept Ballistic Missiles Launched by Iran, Stars and Stripes, October 1, 2024, https://www.stripes.com/theaters/middle_east/2024-10-01/navy,-destroyers,-iran,-israel,-missile-attack-15371733.html; Howard Altman, "U.S. Navy Destroyers 'Successfully Engaged' Iranian Ballistic Missiles On Their Way To Israel," The War Zone, October 2, 2024, https://www.twz.com/news-features/u-s-navy-destroyers-successfully-engaged-iranian-ballistic-missiles-on-their-way-to-israel.
43. David Gritten, Matt Murphy, and Patrick Jackson, "What We Know About Iran's Missile Attack on Israel," BBC News, October 3, 2024, https://www.bbc.com/news/articles/c70w1j0l488o#.
44. Josephine Franks, "Where Iranian Missiles Struck Israel, What it Means - and What Could Happen Next," Sky News, October 2, 2024, https://news.sky.com/story/where-iranian-missiles-struck-israel-what-it-means-and-what-could-happen-next-13226674#; Alexandra Braverman, Annika Ganzeveld, Kelly Campa, Carolyn Moorman, Siddhant Kishore, Katherine Wells, Ria Reddy, Johanna Moore, and Brian Carter, "Iran Update, October 1, 2024," Institute for the Study of War, October 1, 2024, https://www.understandingwar.org/backgrounder/iran-update-october-1-2024.
45. Schneider, "How Effective."
46. Franks, "Where Iranian Missiles Struck"; Braverman, "Iran Update."
47. Lieber, "Israeli Review Shows."
48. Lazaroff, "Iran Launches Hundreds."
49. "100 Homes Damaged in Northern Tel Aviv by Iranian Missile Attack," Anadolu, October 3, 2024, https://www.aa.com.tr/en/middle-east/100-homes-damaged-in-northern-tel-aviv-by-iranian-missile-attack/3349188;
    "Videos, Photos Show Craters," *Times of Israel*.
50. Lazaroff, "Iran Launches Hundreds."
51. Efrat Neuman, "Iranian Missile Attack Against Israel Caused Up to $53 Million in Damages, Tax Authority Estimates," *Haaretz*, October 13, 2024, https://www.haaretz.com/israel-news/2024-10-13/ty-article/.premium/iranian-attack-against-israel-caused-up-to-53-million-in-damages-tax-authority-estimates/00000192-8629-d2ea-a7be-87790a230000.
52. "Israeli Citizens File for $53 Million for Damage Done by Iranian Missiles," *Iran Times*, November 29, 2024, https://iran-times.com/israeli-citizens-file-for-53-million-for-damage-done-by-iranian-missiles/.
53. Pesach Benson, "Iran's Missile Attack Caused over $40 Million in Damage to Israel," *World Israel News*, October 13, 2024, https://worldisraelnews.com/irans-missile-attack-caused-over-40-million-in-damage-to-israel/; Galit Altstein, "Israel Data Show Hundreds of Structures Damaged in Iran's Attack," *Jerusalem Post*, October 14, 2024, https://www.jpost.com/israel-news/article-824486.
54. "Israeli Citizens File," *Iran Times*; Altsein, "Israel Data Show."
55. Robert M. Soofer, "'First, We Will Defend the Homeland: The Case for Homeland Missile Defense," Atlantic Council, 2024, https://www.atlanticcouncil.org/in-depth-research-reports/report/first-we-will-defend-the-homeland-the-case-for-homeland-missile-defense/.
56. Norman Schwarzkopf and Peter Petre, *It Doesn't Take a Hero: The Autobiography* (New York: Bantam, 1992): 485–86; Colin Powell and Joseph E. Persico, *My American*

Journey (New York: Random House, 1995): 511–12; Rick Atkinson, *Crusade: The Untold Story of the Persian Gulf War* (Boston: Mariner, 1994): 175.

57. Steve Fetter, George N. Lewis, and Lisbeth Gronlund, "Why Were Scud Casualties So Low?" *Nature*, January 28, 1993, https://www.nature.com/articles/361293a0; George N. Lewis, Steve Fetter, and Lisbeth Gronlund, *Casualties and Damage from Scud Attacks during the Gulf War* (Cambridge, MA: Massachusetts Institute of Technology, March 1993).
58. Alex Wellerstein, "Nukemap," 2025, https://nuclearsecrecy.com/nukemap/. A 15-kiloton weapon detonated at a height of 600 meters above Tel Aviv (32.07N, 34.79E) would result in about 133,000 fatalities and 226,000 injuries.
59. See Department of Homeland Security, "National Planning Scenarios," April 2005, 1–11, https://info.publicintelligence.net/national_planning_scenarios.pdf.
60. Ezion, "Defense is More Expensive"; Yehoshua, "Israel Signs Multi-billion Deal"; Altmann, "More SM-3 Interceptors"; MDAA, "Missile Interceptors by Cost."
61. Andrew Macaskill, "Israel's Defences would Trump Iran's in Any Air War, but at a High Cost," Reuters, April 18, 2024, https://www.reuters.com/world/middle-east/any-air-war-israels-defences-would-trump-irans-high-cost-2024-04-18/.
62. Note that Russia has reportedly developed countermeasures to be used with its short-range Iskander-M missiles; see John Ismay, "Russia Deploys a Mystery Munition in Ukraine," *New York Times*, March 14, 2022, https://www.nytimes.com/2022/03/14/us/russia-ukraine-weapons-decoy.html; Thomas Newdick, "Russia's Use Of Iskander Ballistic Missiles In Ukraine Exposes Secret Decoy Capability," The War Zone, March 15, 2022, https://www.twz.com/44760/russias-use-of-iskander-ballistic-missiles-in-ukraine-exposes-secret-decoy-capability.
63. Altmann, "More SM-3 Interceptors."
64. American Physical Society (APS) Panel on Public Affairs, *Strategic Ballistic Missile Defense: Challenges to Defending the United States* (Washington, DC: American Physical Society, February 2025), https://www.aps.org/publications/reports/strategic-ballistic-missile-defense.
65. MDAA, "Missile Interceptors by Cost." The Next Generation Interceptor may carry more than one kill vehicle, however.
66. A.M. Sessler et al., *Countermeaures*, Union of Concerned Scientists/MIT Security Studies, April 18, 2000, https://www.ucsusa.org/resources/countermeasures.
67. National Intelligence Council, "Foreign Missile Developments and the Ballistic Missile Threat to the United States Through 2015," September 1999, https://www.dni.gov/files/documents/Foreign%20Missile%20Developments_1999.pdf.
68. National Research Council, "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, 2012): https://doi.org/10.17226/13189.
69. *Ibid*.
70. D. K. Barton et al., "Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues," *Rev. Mod. Phys.* 76, S1, October 5, 2004, https://journals.aps.org/rmp/pdf/10.1103/RevModPhys.76.S1.
71. National Research Council, "Making Sense of Ballistic Missile Defense." Drone-based boost phase interceptors that might be used against a small country like North Korea

appear more feasible; see R.L. Garwin and T.A. Postol "Technical Refinements in Design Features of the Airborne Patrol Against North Korean ICBMs," MIT Science, Technology, and National Security Working Group, May 10, 2018, https://rlg.fas.org/refine.pdf.
72. Laura Grego, "Do Technology Advances Allow Missile Defences to Make Up Ground?" *Journal of Strategic Studies* 48, no. 2 (2025): 465–509, https://doi.org/10.1080/01402390.2024.2447306.
73. APS Panel on Public Affairs, *Strategic Ballistic Missile Defense*.

ORCID

Steve Fetter http://orcid.org/0000-0002-6589-2586
David Wright http://orcid.org/0009-0001-5958-0172