Integrating Technologies to Protect the Home Front against Ballistic Threats and Cruise Missiles

Yossi Arazi and Gal Perel

This article discusses active protection in response to the rocket threat to Israel's home front. The defense establishment anticipates that in an all-out war, the home front would be attacked for about thirty days, and that every day there would be about one thousand rocket and missile hits that would cause thousands of casualties as well as damage to infrastructures and strategic sites. Israel has an active protection system with five layers of interceptor missiles, and in cooperation with the United States, it developed Nautilus, a chemical-laser-based defense system from which the Skyguard system is derived. In 2007, the Iron Dome system, whose missiles are more expensive, was chosen over it for reasons both economic and operational. Yet only an integrated response that includes anti-missile defense systems and chemical laser systems will offer a comprehensive solution for active protection against all threats, without causing any significant economic difficulties.

Keywords: Iron Dome, active protection, high trajectory weapons, Skyguard system, Operation Pillar of Defense

Background

Operation Pillar of Defense took place in November 2012 and highlighted once again the growing rocket threat to the State of Israel. Although there has been a significant reduction in the threat of ground maneuvers against

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Israel by neighboring enemy states, the operation showed that there is a real threat to the country's population centers.[1] As Lieutenant General (ret.) Gabi Ashkenazi said at the time, "He who creates an advantage in this fighting succeeds in preparing first for the next threat."[2]

The Israeli defense establishment anticipates that in an all-out conflict, an attack on the home front by Syria, Hizbollah, and Hamas would last for some thirty days. The expectation is that the Israeli civilian front would be struck by approximately 1,000 missiles, rockets, and cruise missiles every day,[3] some of them GPS guided and accurate to within several meters. The estimated harm caused would be thousands wounded, destruction of infrastructures, and damage to strategic sites. To counter this threat, Israel is developing and implementing a defensive system that would operate from the moment the missiles or rockets are launched until they hit the ground. This system is based on five layers of missile defense: Iron Dome, Magic Wand, Arrow 2, Arrow 3, and Patriot. The working assumption is that the Defense Ministry is planning to complete the development processes, including for radar and communications systems, and that it will acquire the various defensive missiles in quantities sufficient for several days of fighting.

In the mid-1990s, the government of Israel, in close industrial and operational cooperation with the United States, began to develop Nautilus, an anti-Katyusha defense system based on a high-energy chemical laser. Nautilus was intended to protect Kiryat Shmonah, where it was planned to be positioned prior to the withdrawal from Lebanon. From 2000 to 2004, there were 46 tests of the system against various ballistic threats, including mortars, different rockets, and artillery shells. All of them, without exception, were intercepted. At the same time, the planning of the Skyguard system – the immediate derivative of Nautilus – was completed and ready for production. In early 2007, the Nagel Committee concluded that the Iron Dome system was preferable to Skyguard for various reasons, one of which being the conclusion that the kinetic interception option has clear financial and operational advantages over laser interception. The development and testing of Skyguard was, therefore, stopped. Significantly, the 2008 state comptroller's report 59A criticized the manner in which the recommendation was formulated, as well as the fact that no operational need had been defined that delimits the operational gap or defines the requirements for an active defense system. This led to an expansion of

the threat reference from Qassam rockets to all types of short-range high-trajectory fire.[4]

This article aims to show that only an integrated solution that includes anti-missile and anti-rocket defense systems together with high-energy chemical laser systems will result in the implementation of a comprehensive defense solution and protect the entire civilian front from all types of threats. This response would provide protection for the period of fighting regardless of how long it is, and could be implemented without significant economic difficulty. Furthermore, a system that is based only on defensive missiles is not practicable for financial reasons because it cannot provide protection in some of the operational scenarios.

The Threat Reference Scenario

Israel's security concept holds that if a future campaign presents a threat that is defined as a clear and present danger, Israel would have to carry out a preventative action as soon as possible and aim to shorten the fighting's duration to the extent feasible. This is due to the state's lack of strategic depth and its limited ability to absorb economic damage, as well as a large number of civilian casualties. Hence, the goal must be to defeat the enemy on its territory quickly and decisively in order to avoid battles that would take place near Israel's civilian population.[5] From the offensive standpoint, the Israeli Defense Force (IDF) has prepared for this by means of a combat doctrine that rests on three pillars: "(1) a destructive strike of firepower against the enemy's core assets; (2) a quick maneuver to damage the enemy and paralyze its launching capabilities in the area of the maneuver; and (3) stamina and defensive capabilities on the civilian front."[6] This doctrine is based on the assumption that in the case of a military conflict on the scale of the Second Lebanon War or Operation Cast Lead, Israel will not have great latitude in time, space, or legitimacy for the use of force regardless of the intensity and severity of hundreds of rockets and missiles being fired on the state every day. A better solution for Israel would be to strike the enemy, as in the attack on Hizbollah's headquarters in Beirut during the 2006 Second Lebanon War in order to achieve the *Dahiya* effect and deter the enemy.[7] As Lieutenant General Benny Gantz said, "In reality, when we seriously damage the enemy's launching capability, and when our achievements on the ground are clear, and the other side begs for a ceasefire, there will be no doubt as to who is the victor and who the vanquished."[8]

The drive to shorten the combat's duration does not, however, insure that the battle will indeed be short.[9] An examination of the Second Lebanon War, in which the IDF fought against Hizbollah for 34 days, shows that in the course of the fighting, the organization fired some 4,000 rockets of various kinds at the Israeli home front – close to 250 rockets a day toward the end of the war – thus bringing everyday life to a halt for the residents of northern Israel.[10] The defense establishment, therefore, anticipates that in the future, the fighting against Syria, Hizbollah, and Hamas will continue for up to 30 days.

The threat to the State of Israel is evolving and ongoing in every aspect.[11] The weaponry is becoming much more destructive and precise in its hits, and the threat is expanding in range. Today's high-trajectory weapons threaten the entire country, unlike in the past, when they only threatened Israel's northern border. The launching sites have also expanded to include the Gaza Strip, the Sinai Peninsula, and Iran, and cover an area ranging from hundreds of meters from the border for mortar shells to distances of 1,500 kilometers or more for Iranian Shihab missiles. The amount of weaponry in the possession of the enemy is also increasing,[12] and currently they have between several thousands and hundreds of thousands of missiles and rockets. These include mortar shells for ranges of up to several kilometers, which are one of the main threats to the Gaza perimeter communities; Qassam and Grad rockets, which are fired to distances of between 3-40 kilometers; Fajr short-to-medium-range rockets that range some 60-90 kilometers; F110 and M600 rockets, which are fired to distances of 200-300 kilometers and have 200-kilogram warheads and GPS accuracy; and Scud missiles that reach distances of 200-700 kilometers and have warheads of hundreds of kilograms that could be armed with chemical or biological weapons. To this range of threats we can add the Iranian Shihab-3 and Shihab-4, which also have the potential to be armed with nuclear warheads, and Russian made P-800 cruise missiles (Yakhont) that are in Syrian possession, have GPS accuracy, and cruise at an altitude of 10-15 meters at a speed up to Mach 2.5. These missiles could potentially destroy all strategic targets in Israel as soon as the conflict begins.

As a basis for planning the defense system, this article relies on the defense establishment's assumption that a quantitative model should be developed for every type of threat that may be launched at Israel during a 30-day fighting period. It can be expected that as the fighting continues,

the rate of missile fire will decrease, as in the case of Operation Cast Lead, where Hamas began by firing hundreds of rockets per day, a number that decreased to 13 rockets per day towards the end of the Operation.[13]

Nevertheless, this assessment holds that on any given day Israel will be attacked with hundreds of mortar shells, some 800 short-range rockets from the Qassam-1 to the enhanced Grad, about 100 short-to-medium-range threats (including Fajr rockets, the F110, and Zelzal missiles), approximately 100 medium-range or higher threats (including M600 rockets, Scud missiles, and Shihab missiles from Iran), and several dozen cruise missiles.[14]

Basic Requirements for an Optimal Defense System

The defense system required for this task would optimally be able to cope with a large quantity of high-trajectory threats and rockets of various kinds and destroy them before they reach the ground in a way that will be affected as little as possible by the duration of the conflict. Iron Dome, for example, was developed for short-range threats, Magic Wand for threats fired from ranges of 100-200 kilometers, and Arrow 3 is currently being developed as a response to threats fired from ranges of some 1,000 kilometers or more.

The ideal defense system, however, should be able to intercept all threats the enemy is capable of launching – including firing in volleys – and maintain this capability over time. The cost of destroying a threat should be as low as possible in order to avoid economic restrictions on the use of the system. It would need to be available for use against all types of ballistic threats and cruise missiles and in any type of weather, and its response time – from the moment the threat is launched or enters the security envelope to the moment it is destroyed – would be as short as possible in order to allow action against threats fired from especially short ranges. Finally, the system's rearming at the end of the fighting in preparation for the next conflict would not require a massive investment, and technological development would not be needed every time a new threat appeared on the scene. In this article, we examine and evaluate the various solutions available and their integration with a focus given to their ability to meet the requirements.

Advantages, Disadvantages, and Feasibility of a Missile Defense System

The main operational advantage of a system that is based only on defensive missiles is its ability to operate in all weather conditions, if it was designed accordingly. An additional advantage is that such systems are currently in different phases of implementation – from completed development (Iron Dome and Arrow 2) through initial development (Magic Wand and Arrow 3) to procurement (Iron Dome, Arrow 2, and Patriot) – which allows for more rapid procurement.

The problem with this type of system is that when a new threat appears, a defensive missile must be developed to counter it. In addition, a defensive system that relies only on defense missiles is fundamentally flawed, as budgeting for procurement of defensive missiles that could cope with the number of threats the enemy presents requires enormous funds the state cannot allocate for this purpose. In fact, Israel and the IDF will only have a relatively small quantity of anti-missile missiles, resulting in partial protection that will be reduced as the fighting continues.

Other problems arise from the failure of the systems to meet the operational requirements in the face of the threat. The Iron Dome system does not have the ability to cope with certain threats, such as the various Qassam rockets and the regular and enhanced Grad missiles, which are fired from short distances of about 3-15 kilometers,[15] as well as mortar shells, which means that protection for over 1 million people living up to 10-15 kilometers from the borders is deficient.[16] The various types of defensive missiles lack the ability to contend with cruise missiles, particularly the Russian made P-800. Increasing the accuracy of the rockets will cause the collapse of the "selective fire" concept – not intercepting threats that fall in open areas will make it necessary to intercept all threats. This will surely have a severe economic impact. When the fighting ends, it will be necessary to replenish the supply of all defensive missiles fired during the conflict, a process that would take many years to accomplish, be very expensive, and leave Israel exposed to threats until it is completed.

Proponents of the system hold, as GOC Northern Command Gadi Eizenkot stated, that the system "must be directed first and foremost at preserving the IDF's offensive capability and not at defending civilians" and that it should protect Israel's critical infrastructures, IDF bases, and military forces' gathering points. Within approximately three days, an

offensive move carried out by the IDF would lead to a significant reduction in the firing and extensive damage that would result in a ceasefire.[17] Hence, the system would not be required to cope with a large quantity of rockets. According to Brigadier General (ret.) Danny Gold, former head of the Research and Development Department in the Ministry of Defense, the existing system is proof of Israel's willingness to protect its civilians and their property and enable the economy to continue functioning during a time of war.[18] This system also allows the political echelon greater room to maneuver during a military operation.[19] A study by former head of the Wall Missile Defense Program Uzi Rubin indicates that while in the Second Lebanon War Hizbollah needed to fire an average of 75 rockets to kill one person, the Iron Dome system raised the ratio so that it now takes 375 rockets to kill one person.[20]

Advantages, Disadvantages, and Feasibility of Defense Based on High-Energy Chemical Lasers: Ground and Airborne Skyguard

Ground-Based Laser Systems: Nautilus and Skyguard

Development of the Nautilus system began in June 1996 and ended in June 2000, with two successful tests that included the destruction of rockets in mid-flight. Dozens of additional tests were conducted from June 2000 to November 2004, in which the system intercepted all 46 of the threats that were launched against it: 31 Katyushas and other rockets, five 152-mm. artillery shells, and 10 mortar shells, three of which were shot in one volley.[21]

The Skyguard system is a direct development of the Nautilus. Its detailed engineering design was carried out between 2000 and 2005 and was presented to the US army and representatives of Israel's Ministry of Defense in August 2005. Skyguard is four times smaller than Nautilus[22] and directs four to five times more energy against the target. This increases the system's effective range by some 10 kilometers (15 with adaptive optics). Hence, with eight Skyguard systems operating, all of the Gaza perimeter communities would be protected; with 26 systems, the entire northern part of Israel (from Kiryat Shmonah to the Haifa-Afula-Beit Shean line) could be protected; and with a total of 80 systems, all 40 large population centers and strategic sites in Israel could be protected.[23] Northrop Grumman, the company that developed the system, has committed to meet the full military standards of availability, reliability, maintainability, and transportability.

The Skyguard system consumes five different types of gases – nitrogen fluoride, hydrogen, ethylene, helium, and oxygen – along with jet aircraft fuel. All materials are sold in the open market and are inert, non-toxic, and non-explosive (though they could ignite if directly hit). The by-products of lasing – that is, a steady transfer of laser energy to the target in order to destroy it – include hydrogen fluoride and deuterium fluoride, which are hazardous to health. The required safety zone is 100 meters, which can be reduced to 20-30 meters if a special filter is installed on the system. Next to every Skyguard ground unit there are two tanks (the size of a standard fuel-supply tank), which contain the gases and the fuel required for 40 seconds of continuous lasing (suitable for the destruction of 20 threats on average). Switching from one tank to another takes a number of seconds, while replacing an empty tank with a full one takes about two-three minutes.

When the company completed the engineering design,[24] it committed to supply the Skyguard systems to the Ministry of Defense 18 months after the decision was made and at a fixed price. The company also agreed to pay fines for falling behind schedule.

The ground-based Skyguard system has advantages in the basic concepts of firing. Missing a target is not possible due to the system's use of a laser beam that locks on to the reflected energy of the target. The system is able to destroy any target that enters its 10-15 kilometers cover range, and actually has a perpetual and accessible magazine of the fuels and gases required for its operation, which can be supplied in the same way that air force planes are refueled.

As was proven in tests, the system will be effective against mortar shells, various types of missiles and rockets, such as Shihab 4 missiles that are fired from ranges of up to 2,000 kilometers, and will also respond to the threat of cruise missiles. The average rate of target destruction is about one per three seconds, which includes the time it takes to move on to the next target and allows the destruction of volleys of missiles fired simultaneously. For example, it takes about 38 seconds for an enhanced Grad rocket fired at a distance of 40 kilometers from the moment it enters the effective range of Skyguard (15 kilometers) until it hits the ground. One system can destroy a volley of about eleven such rockets fired simultaneously. Since the system works at the speed of light, it will not be necessary to upgrade it when more advanced threats appear. It enables interception of the target immediately after its discovery and does not require reevaluation of the

target's interception point. Hence, threats can be destroyed within less than five seconds from the moment they are launched or enter Skyguard's effective range.

The cost of interception is very low, some 1,000 to 3,000 dollars[25] (the price of the gases and fuel used to create the laser beam varies depending on the range). In comparison, the cost for two Iron Dome missiles to hit one target starts at hundreds of thousands of dollars and can go up to several million dollars for two missiles such as Magic Wand or Arrow. The system has the ability to defend itself against any ballistic threat fired at it. The technology is available and has been proven in dozens of tests, and an official request from the government of Israel to the US government could lead to a resumption of activity on the issue.

The main drawback of the Skyguard system is that the effective range of the laser beam decreases significantly when it needs to penetrate thick, dense clouds (from 5/8 and up), in which case defensive missiles would be relied on. Nevertheless, the Skyguard system can still intercept ballistic threats when they are below the cloud base. In that case, the laser beam "waits" for the threat until it is exposed again.

The Airborne Skyguard System

In the early 1990s, the United States started developing the Airborne Laser (ABL), a high-energy laser system, which was installed on Boeing 747 planes. Its mission was defined as destroying ballistic missiles during the boost phase of flight at ranges of hundreds of kilometers from the interceptor aircraft. In February 2010, after a lengthy development process, the first system test was carried out, and two ballistic missiles were intercepted at a range of nearly 100 kilometers from the ABL aircraft.[26] The test was significantly successful: for the first time in history, ballistic missiles were destroyed in the air and at very long ranges, proving the technological feasibility of the system.

Threats can also be destroyed at the penetration phase, of course. The interceptions take place above the clouds and therefore above weather effects. Any missile that is launched at ranges of 30 kilometers or more reaches heights exceeding 40,000 feet. The greater the range the missile is launched from, the greater the height it reaches. The airborne Skyguard system is designed to destroy any threat that is launched from ranges

between 30 to 2,000 kilometers, which is the maximum range from which Israel is threatened.

The start of the interception will be at very large ranges from the interceptor aircraft, which will be able to destroy fragmentation warheads with each fragment being intercepted separately. In 2003, Northrop Grumman made a proposal to the Israeli defense ministry to install the "regular" Skyguard system on a medium transport aircraft. This configuration enabled destruction of threats at ranges of about 130-150 kilometers from the interceptor plane, and was called ARIEL.

This article proposes that an examination of the airborne Skyguard system's enhanced configuration takes place, as was done on the ABL, and increase the output to 3 megawatts and the optical diameter to 1.5 meters. If installed on a large aircraft like the Boeing 747-300, the system would be able to carry an ample quantity of fuel and gases in order to perform a number of interceptions. A few aircraft flying around the clock could intercept any ballistic threat in combination with the defensive layers of anti-missile missiles.

Similar to ABL, the enhanced ARIEL system's anticipated capability is its ability to intercept ballistic threats that are found at a range of some 400 kilometers from it and above 30,000 feet. Initial calculations show that lasing can be produced approximately 200 or more times before the aircraft needs to be refueled with the gases and fuel that are needed for lasing. Thermal calculations show that for Shihab and Scud D missiles, we can assume a required lasing time of some five seconds to destroy the threat and approximately another two seconds to move to the next threat. For the other threats, like Scud C, the required lasing time is about three seconds, with another two seconds to move to the next threat. The gross interception times will be seven seconds and five seconds, respectively. ARIEL aircraft will be able to intercept any ballistic threat launched from a range exceeding about 30 kilometers and in dense volleys. The other tactical rockets, from a regular Grad to smaller threats, do not exceed an altitude of 30,00 feet during flight and will be intercepted by the ground-based Skyguard systems and Iron Dome missiles.[27]

Work on the ABL system was stopped in 2011 due to the system's lack of sufficient power to enable an aircraft to operate outside the borders of Iran, as explained by former US Defense Secretary Robert Gates.[28] This limitation is not relevant to Israel, however, as the aircraft would remain

in the air over the country and intercept threats at the penetration phase, when they are at a distance of approximately 400 kilometers or less from the target.[29]

Budgetary Scenario

Basic Assumptions

- The fighting scenario is as described in the Threat Reference Scenario section.
- The defense establishment will continue to invest in missile defense systems.
- The cost estimate for procurement of defensive missiles only is based on the assumptions that inventory will be prepared for 40 days of fighting and that missiles fired in the course of 30 days of fighting will be replaced. In order to have a reasonable chance of success in intercepting a threat, two defensive missiles will be needed. The cost of an Iron Dome missile is 100,000 dollars,[30] of a Magic Wand missile, 1.25 million dollars, and an Arrow 2 or Arrow 3 missile, about 3 million dollars.
- The expected cost of the airborne and ground-based laser element in the integrated system will be presented, that is, five airborne Skyguard systems and 80 ground-based Skyguard systems. The radar and communication infrastructures for missile defense systems will also support the laser systems.
- The investment required for procurement of defensive missiles alone (not including launchers, support systems, and infrastructures) is as follows: to intercept 250 short-range rockets every day that are likely to fall in various premises (out of the 800 that will be fired), 500 Iron Dome missiles will be required. The cost of preparing for 40 days of fighting will reach approximately 2 billion dollars. Interception of the 100 medium-range missiles and rockets will require the use of 200 Magic Wand missiles per day at a total cost of 10 billion dollars for 40 days of fighting. The cost of 200 Arrow and Patriot missiles to intercept long-range threats every day will reach 24 billion dollars. For 40 days of fighting then, the total sum of 36 billion dollars will be needed for procuring inventory. The cost of just "pressing the trigger" on one day of fighting will get to approximately 900 million dollars. Following the fighting, the cost of procuring inventory to replace the missiles fired during 30 days of fighting will reach 27 billion dollars (3/4 of the cost

of procurement for 40 days). The total cost of preparing an inventory of missiles alone for 40 days and replacing inventory after 30 days of fighting will reach up to 63 billion dollars. These are prohibitive sums that will never be allocated.

Investment in Ground-Based and Airborne Skyguard Systems

Ground-Based Systems

The specification submitted by Northrop Grumman in a letter sent in 2007 quotes the following prices:

- 310 million dollars for the first three systems.
- 40-50 million dollars for a system in production (depending on the quantity ordered). The price includes communications and also unique radar for each Skyguard system, which costs approximately 15 million dollars. One radar will feed four or five systems, so it can be assumed that some 30 million dollars would be necessary for a Skyguard system in serial production. The price of the 77 remaining systems will be approximately 2.3 billion dollars.

In addition, the following will be required:

- 200 million dollars (estimated) for fueling infrastructures.
- 300 million dollars (estimated) for administrative and maintenance infrastructures and spare parts.

The total cost is estimated at about 3.1 billion dollars for 80 ground-based Skyguard systems to protect all critical sites and population centers in Israel.

Airborne Laser Systems

The figures given in the letter from Northrop Grumman quote the price of 177 million dollars for the first ground-based Skyguard system. Based on this figure, it can be assumed that the development phase for airborne systems will require an estimated 100 billion dollars for the purchase of a used Boeing 747 and some 250 million dollars to build a prototype of the first airborne Skyguard systems. The airborne system is simple to implement compared to the ground-based system due to the low atmospheric pressure that exists at an altitude of 40,000 feet and is required for production of the laser beam. An additional 100 million dollars will be added for purposes of planning and implementing installation in the aircraft and another 100 million dollars for testing. In addition, about 100 million dollars will be

needed for infrastructures, maintenance, and refueling of the laser systems on the ground, and another 50 million for other expenses. This is a total of some 700 million dollars for the development phase and production of the first aircraft. Procurement of another four airborne Skyguard systems, including their installation, will cost about 120 million dollars per aircraft, 50 million dollars for the laser system (20 million more than for the ground-based Skyguard system), and approximately another 20 million dollars for spare parts, maintenance support, and other expenses. The total price of one aircraft will be approximately 190 million dollars, and the price of the four additional aircraft will be about 760 million dollars. The overall price of procurement of the ground-based and airborne laser systems, including maintenance support, operational auxiliary systems, and the like is expected to reach up to 4.6 billion dollars, an investment that will be spread over about eight years and is economically feasible.

Cost of 30 Days of Fighting with Skyguard Systems Alone

Cost of one day of fighting

- 1,000 lasing to destroy all 1,000 threats – 2 million dollars
- 72 flight hours (3 aircraft in a row at 15,000 dollars an hour) – 11 million dollars

The total cost comes to 13 million dollars per day, compared to 900 million dollars per day for partial protection with missile defense systems. The cost of 30 days of fighting would be some 400 million dollars, compared to a cost of 63 billion dollars for the defensive missiles alone.

Effectiveness of the Integrated Solution

The integrated solution makes it possible to economically and operationally implement a comprehensive system of protection that is effective and efficient at protecting the entire home front. As concluded above, an investment of about 4.6 billion dollars in ground-based and airborne laser systems will make it possible to save more than 55 billion dollars over the cost of missile defense alone, and create a feasible system. The integrated system would include about five high-energy laser aircraft (ARIEL), five defensive layers of anti-missile missiles (Iron Dome, Magic Wand, Arrow 2, Arrow 3, and Patriot) in quantities and deployment to be determined by the defense establishment, and 80 ground-based Skyguard systems. This combination meets all the necessary requirements for the ultimate, ideal

Table 1. Comparison – Performance and Cost[31]

Interceptor/Type of Threat, Characteristics, and Costs	Iron Dome	Magic Wand	Arrow 2	Arrow 3	Ground-Based Skyguard System	Airborne Skyguard System	Comments
Mortar Shells	/	/	/	/	V[1]	/	[1] Destroys a threat every 3 seconds.
P-800 Cruise Missiles	/	/	/	/	V[1] Volley of 4-5 missiles	/	
Qassams and Grads up to 12-15 kilometers	/	/	/	/	V[1]	/	
Grads to a range of 15-40 kilometers	V	/	/	/	V[1] Volley of 10-12 missiles	V[1,2] Volley of 10-30 missiles	[2] Firing from a range of over 30 kilometers
Fajr-3, Fajr-5	V	Maybe	/	/	V[1] Volley of 9-10 missiles	V[1,3] Volley of 15-23 missiles	[3] Threats will be intercepted under a range of 400 kilometers and over 30,000 feet
Zelzal, M600, F110	/	V	Maybe	/	V[1] Volley of 4-5 missiles	V[1,3] Volley of 18-52 missiles	
Scud B, C	/	Maybe	V	Maybe	V[1] Volley of 2-3 missiles	V[3,4] Volley of 56-64 missiles	[4] Estimated lasing time 3-5 seconds
Scud D, Shihab 3, 4	/	/	/	V	V[1] Volley of 1-2 missiles	V[3,4] Volley of 15-33 missiles	
Cost of 1 interception (2 missiles)	200,000 dollars	2.5 million dollars	6 million dollars	6 million dollars	Up to 3,000 dollars	Up to 5,000 dollars	
Cost of 1 day of fighting	50 million dollars (250 interceptions)	250 million dollars (100 interceptions)	300 million dollars (50 interceptions)	300 million dollars (50 interceptions)	2-3 million dollars	2-3 million dollars, including 72 flight hours	

system, which will provide protection against mortar shells and cruise missiles, defend communities near the border, and allow a dual defensive response in most cases using the laser system and defensive missiles. As a general rule, it is always preferable to use the laser system due to its low cost. Defensive missiles will be a backup for the ground-based laser system in the event of bad weather and when it is necessary to defend against especially dense missile volleys. The radar, communications, and control systems that are intended to support defensive missiles will also support laser systems, both ground based and airborne.

Operation Pillar of Defense – Protection from All Threats Fired from the Gaza Strip as a Case Study

Operation Pillar of Defense is unique in the sense that it was the first conflict in which the State of Israel used an active defense system − Iron Dome − rather extensively. At the recommendation of the military and political echelons, the operation began as a planned and orderly move whose objectives were to strengthen deterrence, to strike a hard blow at the rocket array, to inflict a painful blow on Hamas and the other terrorist organizations involved, and to stop the rocket fire directed at Israel from Gaza.[32] The start of the operation included an aerial attack to assassinate Ahmed Jabari, commander of Hamas's military wing in the Gaza Strip, and another aerial attack whose targets were warehouses and missile-launching pits for Fajr-5 rockets ranging some 75 kilometers. The IDF was working to shorten the duration of the fighting, which was reflected in the political echelon's pursuit of a mechanism for ending the operation[33] and in the directive by Chief of Staff Benny Gantz "to continue to attack with every bit of force and to step up the pace,"[34] in accordance with the approach of achieving the objectives quickly.

There is no doubt that during the fighting the system made a significant contribution to the home front's morale. And indeed, the more effective the defensive system is, the greater the home front's morale, as well as its ability to cope with the situation. In the course of the operation, Hamas fired 1,506 rockets at Israel, but only 479 of them were fired at populated areas. Iron Dome succeeded in intercepting 421 rockets, achieving the success rate of 84 percent.[35]

It is important to examine the limitations and disadvantages of using a system that is based on defensive missiles alone versus the advantages of

combining two technologies – defensive missiles and a high-energy laser – in an integrated defense system. Within this discussion, there are two main points: the inability of defensive missile systems to protect communities near the border and the cost of defensive missiles, which limits the number of missiles that can be purchased.

Two Israeli governments have recognized Iron Dome's limitations in protecting sites near the border. In early 2008, after Iron Dome's limitations were made clear, the Olmert government decided to secure all homes up to 4.5 kilometers from the border, which were, at the time, threatened by the somewhat slow Qassams. The current government decided in mid-2012 to secure all homes up to 7 kilometers from the border. Minister Matan Vilnai even stated in November 2011 that all communities up to a distance of 15 kilometers from the border would be fully secured.[36] But the system's limitations were revealed during Operation Pillar of Defense. Aside from isolated instances in the Sderot area, when rockets fired from southern Gaza were indeed intercepted by Iron Dome– possibly due to the large distance that allowed the interception – Sderot and the Gaza perimeter communities were, for the most part, not actually protected. Though Iron Dome protected communities far from the border such as Beersheba, Ashdod, and Ashkelon, the protection was not thorough. The fact is that Operation Pillar of Defense ended before all the IDF's Tamir interceptor missiles had been launched. Nevertheless, it is easy to imagine what would have happened if the operation had gone on for another few days and the IDF had reached the "bottom of the barrel" in the inventory of defensive missiles. There is no question that both the government of Israel and the IDF command were forced to face very significant pressures to end the operation before all the missiles ran out. This surely would have affected any negotiations connected to ending the fighting. Even worse, if the fighting had not been stopped in time, it is easy to imagine how despondent Israelis would have been and what a great blow this would have been to their morale, in addition to the physical damage.

We cannot ignore the Property Tax report that presents the list of damage during the operation in cities protected by Iron Dome. Hundreds of buildings and cars were damaged. A report from the Israeli Police notes that sappers from the police in the southern region handled 109 rocket hits in populated areas. The conclusion is that the protection provided by the Iron Dome system was not sufficient.

The Skyguard system could be much more thorough than the Iron Dome system in defending against the threat from Gaza. The Gaza Strip has no strategic depth: its width, almost along its entire length, is about 7 kilometers, aside for its southern part, whose width is about 13 kilometers. Figure I shows the operational coverage of eight Skyguard systems placed around the Gaza Strip at a distance of about 1 kilometer from the border

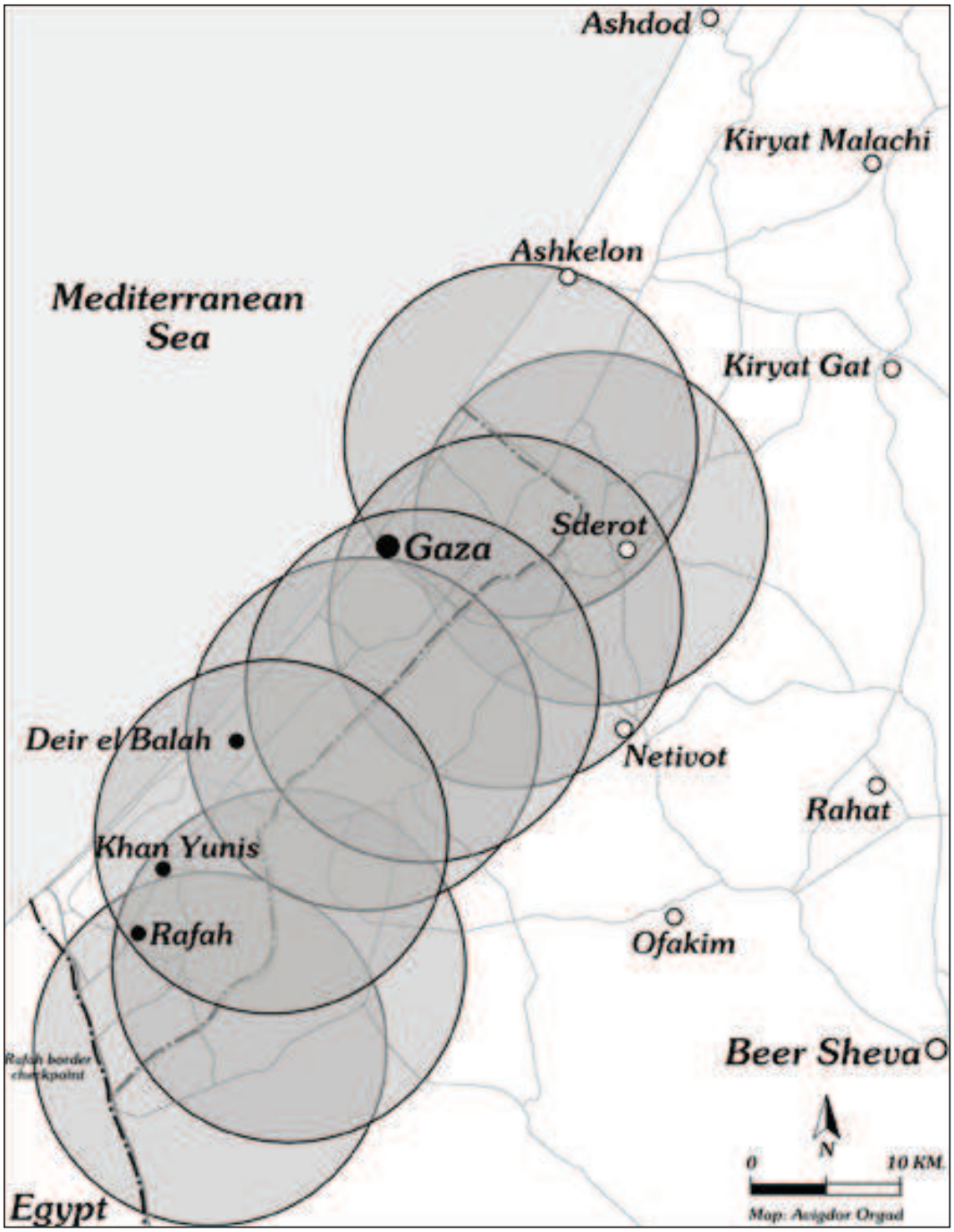

Figure 1. Operational Coverage of the Gaza Perimeter by Eight Skyguard Systems

(behind folds of land, in order to prevent direct fire on them). With the exception of a limited area, all launch points are covered by the Skyguard systems.

The Skyguard system does not require estimation processes. The vector to the target is received within one-two seconds from the moment the threat is fired, and will be destroyed within another two-three seconds, usually while still over the Gaza Strip and regardless of where it was originally directed.

Because of the short distances involved, the fire at Gaza perimeter communities is almost entirely flat-trajectory fire. Unlike the threat of Qassam 1, an enhanced Grad, with a range of 15 kilometers, usually reaches a maximum altitude of about 550 meters. This is under the typical cloud base, which begins at about 600 meters. The conclusion is that even in difficult weather conditions, the Skyguard systems will protect the Gaza perimeter communities. In fact, the laser systems surround the Gaza Strip with a kind of "defensive shield" that will intercept any threat fired from the strip at any target in Israel. This also includes the Fajr rockets, which have a range of about 70 kilometers.

The investment required for the incorporation of the Skyguard systems into Israel's security system is approximately 500 million dollars. Delivery would take about two years, and the system's integration with the Iron Dome systems could be elementary. The Iron Dome systems would be placed in locations that are relatively far from the border and which they are able to protect. The initial interception of all threats would be done with the Skyguard systems, which, as noted, have a perpetual magazine, and any threat that gets through, would be handled by the Iron Dome system. This combination would give optimal protection, and would provide the decision makers and government of Israel with breathing room to consider various decisions, knowing that the home front is well protected.

The Irrelevance of Defense Systems Based on Solid-State Lasers

Both the Nautilus and Skyguard chemical-laser systems are currently available and have proven capabilities. Postponing their implementation just because of the expectation for a more advanced solid-state laser has no basis in any technical reality.[37] Solid-state lasers also have a number of significant limitations. First, there is the limitation of output. The

highest output that has been achieved with this technology – only about 100 kilowatts, which Northrop Grumman produced in February 2009 by means of plate technology – is about one-tenth of what is needed to intercept a missile. Reaching an output of 1 megawatt or more would require a technological breakthrough that does not appear to be feasible. Second, the efficiency of the laser system based on solid-state technology is only slightly greater than 10 percent. Creating a beam with the necessary output of at least 1 megawatt then requires an investment of some 9 megawatts of electric output, about 8 of which will turn into heat, which must be dispersed during lasing, that is, in two-three seconds. There is no cooling technology capable of doing this, and therefore, no chance to implement the system in the foreseeable future. Third, the system is hypersensitive to the effects of weather because of the length of the short wave on which these lasers operate (about 1 micron, vs. 3.8 microns for the Nautilus/Skyguard). Attenuation of the beam during passage through the atmosphere will be very great compared with the chemical-laser systems. In addition, there is a danger of blindness from reflected light, which stems from the same wavelength. These limitations are a technological barrier that will prevent implementation of a high-energy laser system based on solid-state technology.[38] There is no forecast that would indicate a date for completion of development of such a system, which would make it possible to protect population centers and strategic sites.

Conclusion

Precision ballistic weapons and cruise missiles have the potential to destroy critical infrastructures in Israel and to threaten the lives of many of its citizens. A system that is based on defensive missiles alone is not applicable to Israel's security needs because of the expenditures involved in procurement and due to the system's failure to meet some of the operational objectives required for basic protection. Nevertheless, the current attempts to build five layers of defense based on defensive missiles should continue in order to bring about an integration of these technologies with high-energy laser systems. An investment of about 4.6 billion dollars in Skyguard systems – 80 ground based and five airborne – continuing for about eight years would lead to creation of an integrated system that would possess all the components of a missile-defense system. This system would meet all the requirements of an ideal system by protecting against

all threats at any time, under any type of weather, for as long as necessary, at minimal cost, and with significant savings.

The government of Israel should go back to the drawing board. It should recognize the advantages of the integrated system and act accordingly – especially toward the US government, with regard to restarting activity on the Skyguard system – lest Israel be forced to cope with a serious crisis in future conflicts.

Notes

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15 Letter from Magen LaOref ("Home-front Shield," a non-profit organization): "Anticipated Performance of Iron Dome," December 15, 2009

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22 Northrop Grumman presentation to Ministry of Defense, January 2007.

23 For purposes of redundancy, the intention is to have two Skyguard systems to protect each site. This would lead, inter alia, to the interception of twice as many threats. If the threat arrival rate is less than 1.5 seconds on average, all threats will be destroyed. See Table of Comparison: Performance and Cost.

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31 Superscript numbers refer to comments in table. For security reasons, no assessments of the capabilities of defensive missiles against missile volleys are presented.

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