Global Studies/Physics 280: Session 21

Plan for This Session

RPv1 is due tomorrow, 10pm !

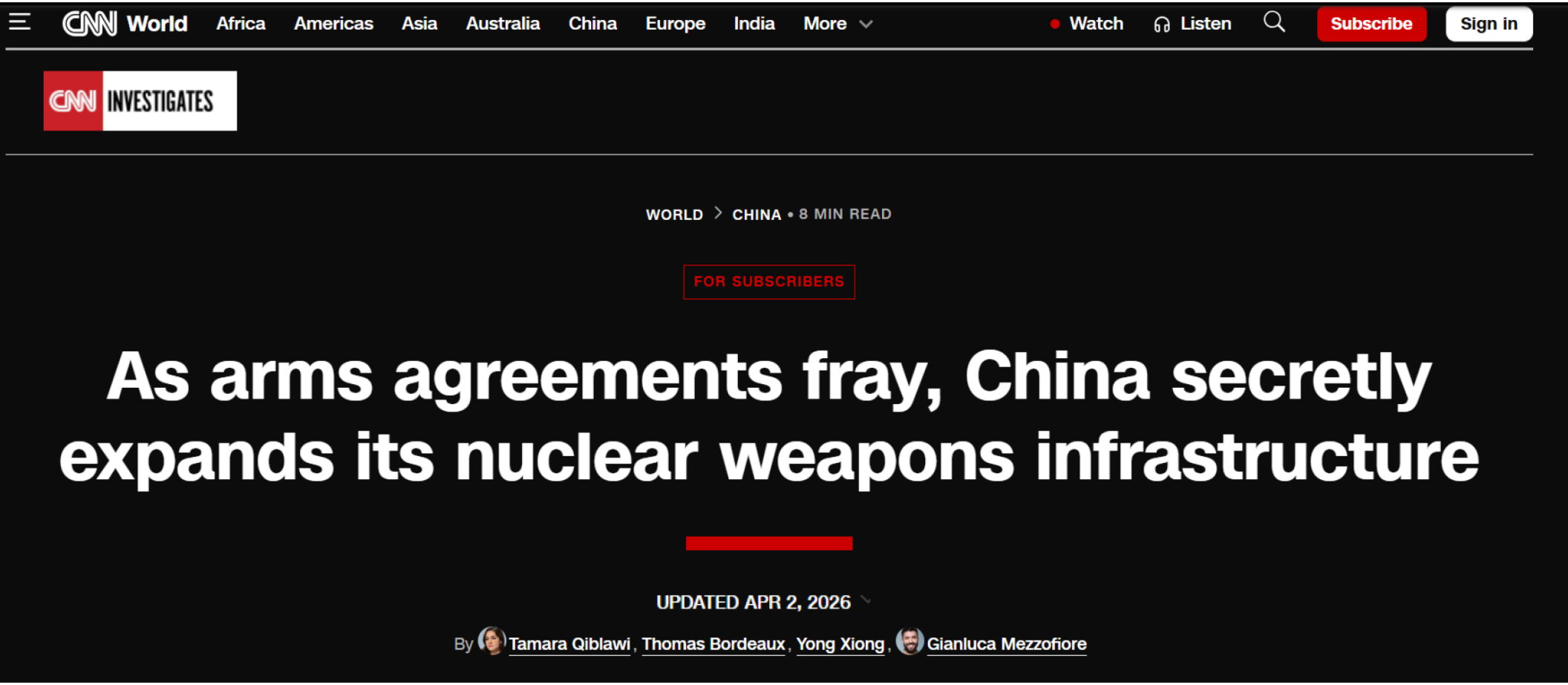
RE4v1 peer review due Sunday at 10pm

Extra Credit: Professor Fred Lamb will be presenting a seminar on the Golden Dome in the ACDIS Seminar Series on Tuesday, Apri 14th. This talk will take place at 5:00 PM in Coble Hall – Room 306.

News

Module 7: Efforts to Defend Against Nuclear Attacks

News



https://web.archive.org/web/20260402103909/https://www.cnn.com/2026/04/01/china/investigates-china-secretly-expanding-nuclear-weapons-infrastructure-intl-invs

The facility known as Site 906 in China's Sichuan province, seen in images spanning from 2019 to 2025. *(Credit: Airbus)*

When three villagers from China's Sichuan province wrote to local officials in 2022 asking why the government was confiscating their land and evicting them from their homes, they received a terse reply: It was a "state secret."

That secret, a CNN investigation has found, centered on China's covert plans to massively expand its nuclear ambitions.

More than three years after the evictions, satellite images show, their village has been flattened and, in its place, new buildings erected to support some of China's most important nuclear weapons production facilities.

The expansion of the sites in Sichuan province, observed in satellite imagery and a review of dozens of Chinese government documents, supports **recent claims by the administration of US President Donald Trump** that Beijing has been conducting its most significant nuclear weapon modernization campaign in decades.

Trump is set to visit Beijing on a landmark trip next month where he is expected to try to begin a dialogue about a deal to curb Chinese leader Xi Jinping's nuclear ambitions. Earlier this year, the latest arms reduction agreement between Russia and the United States – known as New START – expired, with Trump wanting to strike a new and improved deal with Moscow that would also include China.

But the dramatic changes seen at sites in Sichuan suggest that the nuclear weapons development of China's military, known as the People's Liberation Army (PLA), shows little sign of abating.

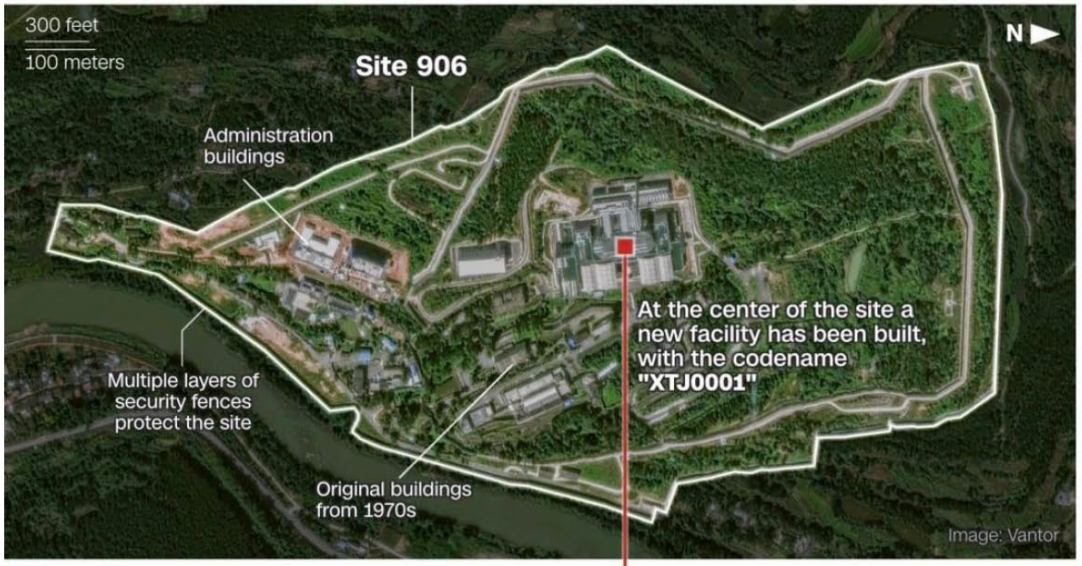
One of the most substantial additions to the area is an enormous dome, unusually shaped like a Tic Tac, emerging from the banks of the Tongjiang River in less than five years. It appears to continue to be outfitted with equipment, suggesting it may not yet be in use.

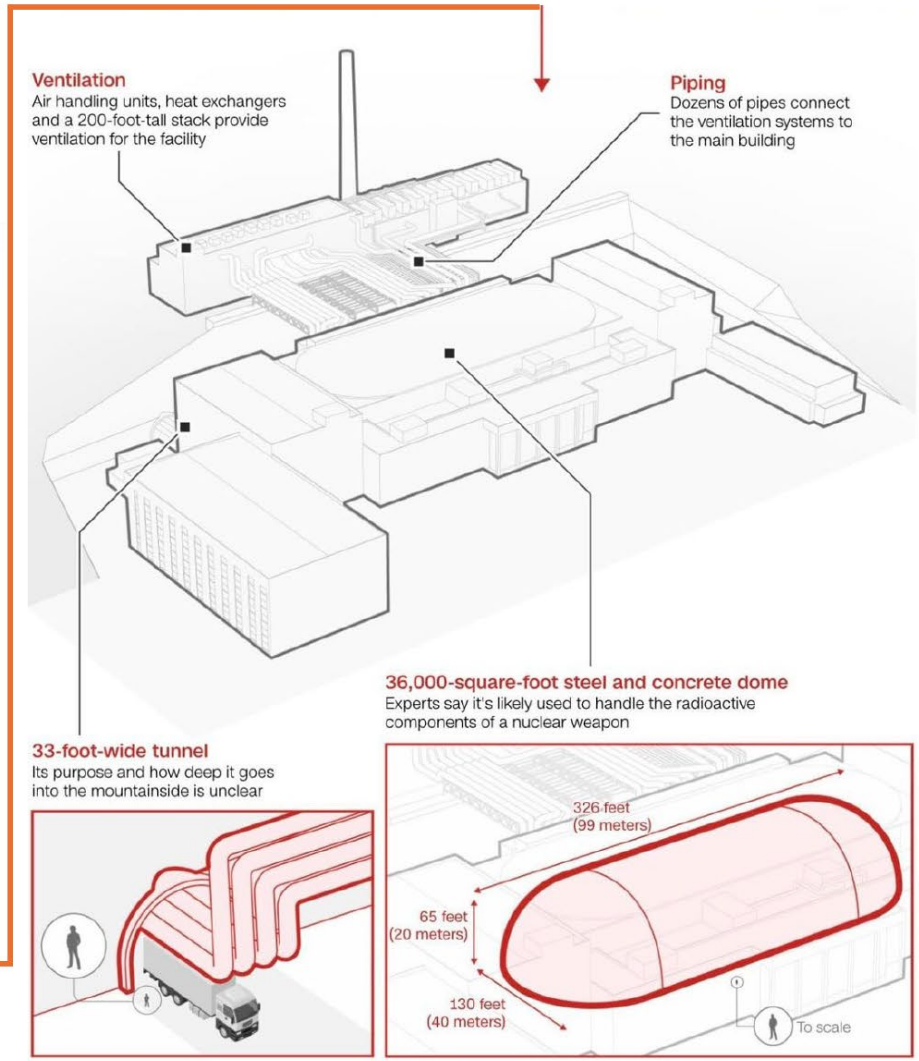
At 36,000 square feet – the size of 13 tennis courts – the reinforced dome is enclosed by a concrete and steel structure with radiation monitors and blast doors, its network of pipes snaking out of the facility and into a building with a tall ventilation stack. These and other features, including extensive air handling equipment, are designed to keep highly radioactive materials such as uranium and plutonium trapped inside the dome, according to multiple experts.

The facility, which was built inside a nuclear weapons base long known to the CIA, is encircled by three layers of security fencing. A nearby tunnel disappears into the side of a mountain. To analyze individual features of the site known as 906, CNN compiled more than 50 snapshots from different phases of the facility's construction into a 3D model.

New construction at Site 906

Discovered by US intelligence in 1971, the site was believed to be involved in nuclear weapons production, and has seen little growth — until now. CNN analysis of satellite imagery identifies new buildings and underground facilities.





Note: Measurements are approximate.

Sources: CNN analysis of satellite imagery, Airbus, Vantor, Planet Labs PBC, Chinese government documents

"This building is almost a Rorschach test for people's worst nightmares about what China is up to," said Jeffrey Lewis, a distinguished scholar of global security at Middlebury College, one of three experts who reviewed CNN's findings.

"You're looking at a reconfiguration of this complex," Lewis added, referring to the network of nuclear weapons sites in and around Zitong county. "**This facility is a centerpiece. It is emblematic of all these changes. It does seem that there's going to be a much bigger capacity to produce at the end of this."**

Newly refurbished roads link Site 906 to at least three other nuclear weapons bases strung along narrow valleys in and around Zitong county. The construction project of the dome facility inside 906 was designated XTJ0001, according to Chinese government documents reviewed by CNN.

Another of these production facilities is Site 931, which expanded into Baitu village, prompting the evictions of its inhabitants. The nearby village of Dashan was also torn down to make way for the development of the base.

A road to rail transfer point connecting the network to the west of the country **has also been dramatically overhauled** since 2021 – another telltale sign of a comprehensive revival of the Zitong facilities.

The road to rail transfer point is located at Jiangyou city, north of Mianyang. *(Credit: Airbus)*

April 16, 2020

The road to rail transfer point is located at Jiangyou city, north of Mianyang. *(Credit: Airbus)*

April 23, 2025

When **spy satellites first captured images of the Zitong network in 1971**, US intelligence deemed the sites a gamechanger. Declassified documents concluded that they set Beijing on course to become the world's third largest producer of the deadly warheads.

This prediction bore out around 2020, when China's warhead stockpiles overtook those of France. Beijing is the fastest producer of nuclear weapons in the world, according to the Pentagon, though, with just over 600 warheads, it continues to trail far behind the US and Russia, each of which commands a stockpile at least four times the size of China's.

In February, Undersecretary of State for Arms Control Thomas DiNanno accused China of having violated a ban on explosive nuclear testing. Beijing vehemently denied that claim.

US intelligence officials also assessed that Beijing had been testing a new generation of nuclear warheads.

Chinese defense ministry spokesman Jiang Bin said those remarks "distort facts and smear China."

"It is known to all that China pursues a nuclear strategy of self-defense and follows a nuclear policy of no first use of nuclear weapons," Jiang said. "China pledges not to use or threaten to use nuclear weapons against non-nuclear-weapon states and nuclear-weapon-free zones."

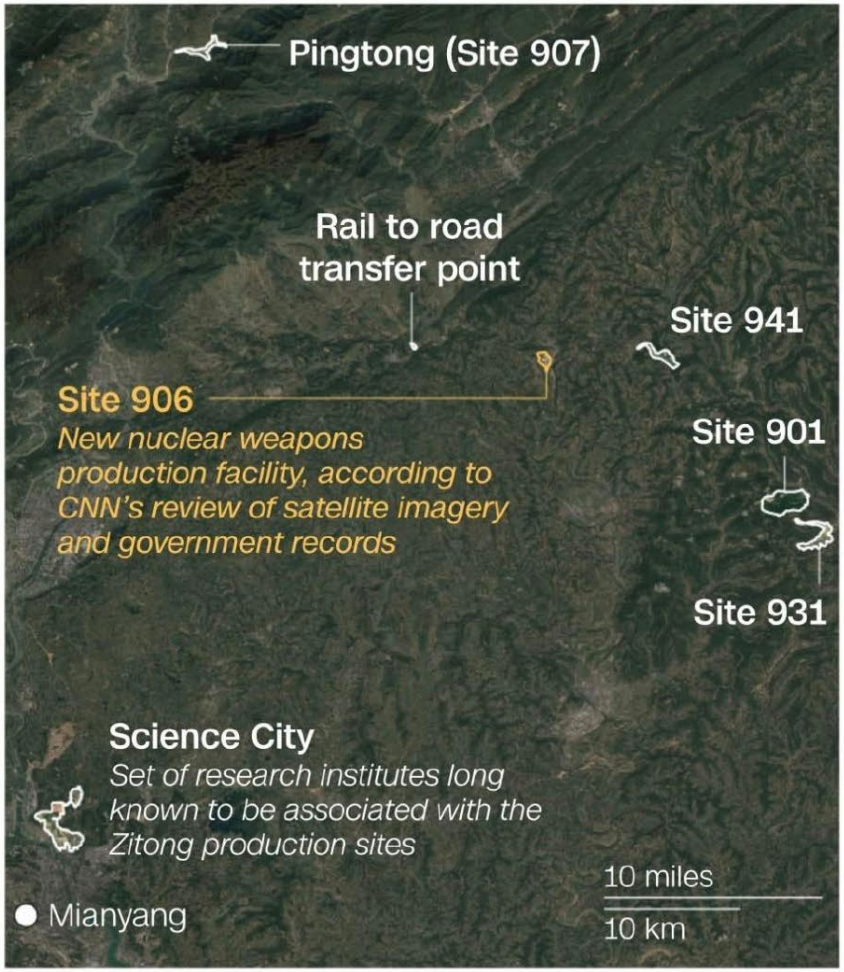
But unusual designs of some of the facilities, such as that of the Zitong River dome, lend some credence to DiNanno's claims that China is overhauling its nuclear weapons program.

"It might be that there are new processes being established at these locations, new types of things being made," said Renny Babiarz, vice president of Analysis and Operations for AllSource Analysis, who reviewed satellite imagery for CNN.

"It's clear that there are a lot of changes happening on the ground."

A massive nuclear weapons overhaul in China's mountains

CNN analyzed nuclear weapons research and production sites in and around Sichuan's mountainous Zitong county. All have undergone a massive expansion in the last five years as part of a modernization effort.



Sources: Google (image), CNN reporting
Graphic: Annette Choi and Thomas Bordeaux, CNN

Those developments may have created blind spots for Western adversaries. **"It used to be that we could make some educated guesses about how many nuclear weapons the Chinese could produce,"** said Decker Eveleth, a nuclear and deterrence analyst at CNA Corporation, who also reviewed CNN's findings.

"The fact that this modernization is so extensive suggests a fundamental overhaul in the technology that underlies the entire system."

Further supporting the contentions of a modernization drive is a massive overhaul seen in a collection of research institutes some 40 miles southwest of the Zitong network. The area, known as Science City, is considered the brains of China's nuclear weapons program.

The growth of the campuses is so extensive that **over 600 buildings were torn down to make way for the facilities in 2022**, according to satellite imagery.

There are also concerns that the US may overestimate China's capabilities, exacerbating nuclear proliferation.

"**There will be people in the US who will argue that we need to radically expand our own ability to produce nuclear weapons to match China**," Lewis said. "**But we're not going to match what they're doing. We're going to match what we think they're doing. We're going to match our own nightmare. And that's potentially very dangerous."**

Meanwhile, Trump may find himself in a bind in Beijing. China's infrastructure – and Xi's increasingly consolidated rule over its military as evidenced by recent purges of top generals – gives it some advantage in the event of an arms race, and Beijing may see little reason to concede.

Science City hosts more than a dozen research institutes that are part of CAEP, China's main nuclear weapons developer. CNN processed this satellite image to reduce the effects of clouds and haze. *(Credit: Airbus)*

Feb 23, 2021

Science City hosts more than a dozen research institutes that are part of CAEP, China's main nuclear weapons developer. CNN processed this satellite image to reduce the effects of clouds and haze. *(Credit: Airbus)*

Feb 5, 2026

The US and Israel's ongoing war on Iran may have hardened China's resolve to expand its nuclear weapons program, experts say.

"**If you are the Chinese… in hindsight, you don't look at what's happening and think it makes sense to disarm or get weaker**," Lewis said.

"One consequence of what the Trump administration is doing in Iran is not going to be to cow or intimidate the Chinese, but it will be to frighten them into building more nuclear weapons," he added.

In case the US makes concessions on core strategic issues such as Taiwan, Xi may "make a symbolic commitment to launching a broad bilateral strategic security dialogue in which nuclear issues would be one component," Zhao said.

"**Even in this optimistic scenario, Beijing would be unlikely to pursue any serious arms control negotiations**," he added. "**But its willingness to initiate a broad-based dialogue could be sufficient to satisfy Trump**."

Module 7: Efforts to Defend Against Attacks

- Introduction to Defending Against Nuclear Attacks
- History of Defending Against Ballistic Missiles
- Current and Proposed Missile Defense Programs

Module 7: Efforts to Defend Against Attacks

Introduction to Efforts to Defend Against Nuclear Attack

Types of Defenses Against Nuclear Attacks

Passive defenses ("civil defense")

- Seeks to deter or mitigate rather than defeat an attack
- Requires sheltering and crisis relocation
- Has been embraced and discarded several times (1950s, 1960s, 1980s)

Active defenses (weapons to destroy weapons)

- Seeks to prevent nuclear weapons from detonating at their targets
- Requires destruction of delivery vehicles (aircraft, ICBMs, SLBMs, reentry vehicles, cruise missiles, etc.) before they reach their targets
- Must be nearly perfect to avoid enormous death and destruction (offensive weapons costing ~$10M can kill 1 million people and destroy $10B worth of property)

Passive Defenses Against Attacks

Sheltering (1950s,1960s,1980s) —

- Blast shelters (could withstand ~ 50–100 psi overpressures)
  - — Only a very small fraction of the land area of the US would be subjected to 50 psi, even in an all-out attack
  - — However, most people live in cities and hence would likely be subject to blast, fire, etc.
- Fallout shelters (could have protection factors of 100 against fall out)
  - — Radiation from fallout decays rapidly with time
  - — Cumulative exposure would still be serious
  - — Submarine attacks might continue for weeks or months
  - — Problems and costs of providing adequate sanitation, ventilation, food, and water are enormous
- Warning time could be very short (~ 10 minutes or less), so most people would not reach shelters

Passive Defenses Against Attacks

Crisis relocation (Reagan,1980s) —

- Plans developed by Federal Emergency Management Agency (FEMA)
- Plans called for evacuation of all urban and other “high risk” populations and quartering of evacuees in “host” communities
- There was confusion over whether many communities were high-risk or low-risk
- Feasibility of successful evacuation is doubtful
- Many urban areas and host regions refused to participate in planning, finding the concept unworkable and dangerous
- 1985, passive defense was again dropped

Current Direct Threats to the United States Posed by Nuclear-Armed Ballistic Missiles

Two countries currently have nuclear-armed ballistic missiles that can threaten the territory of the United States —

- *Russia*: currently has about 1,550 strategic warheads on delivery vehicles on high alert.

- *China*: DoW estimates about 400 ICBMs with estimated ranges > 5,500km

The United States currently has about 1550 strategic warheads on delivery vehicles on high alert.

Country of concern —

- *North Korea*: has launched successfully two satellites, in principle such rockets should be able to reach Pacific Islands and the continental US. Payload unclear. 60 nuclear warheads according to latest FAS estimates. Warheads may have been miniaturized to fit on ballistic missiles. Short and medium range and long-range missiles have been tested.

Delivery Methods Other Than Long-Range Ballistic Missiles May Pose Greater Threats

Several countries are capable of developing mechanisms to launch SRBMs, MRBMs, or land-attack cruise missiles from forward-based ships or other platforms.

U.S. intelligence and national security assessments consistently judge that the most likely form of attack on the U.S. homeland would involve terrorism, including the potential use of weapons of nuclear weapons delivered by covert, non-missile means:

Non-missile delivery means are —

- less costly
- easier to acquire
- more reliable and accurate

They also can be used without attribution.

Reducing the Threat of Long-Range Nuclear-Armed Ballistic Missiles

Different ways to reduce the threat of nuclear-armed missiles, such as —

- Developing friendly relations
- Use cooperative diplomacy, incentives, and disincentives to prevent the development and spread of nuclear and missile capabilities and to reduce and eliminate existing threats
- Plan to destroy threatening missiles on the ground (preemptive strike: “left of launch”).
- ***Attempt to destroy attacking missiles in flight***

Programs to Intercept Nuclear-Armed Ballistic Missiles Have Been Controversial. Why?

U.S. programs to intercept nuclear-armed long-range ballistic missiles have often been used for other purposes —

- As political bargaining chips
- To sidetrack or destroy arms control agreements
- To create a (false) sense of security
- To receive lucrative defense contracts

Programs to intercept nuclear-armed long-range ballistic missiles would *not* be controversial *if* —

- An effective defense was clearly possible using near-term technology
- Such a system could be built for an acceptable cost
- ABM programs would not cause other countries to do things that would end up decreasing our security
- ABM programs would not distract the U.S. from taking other steps that would be more effective in increasing our security

Phases of Flight of a Long-Range Ballistic Missile

Phases of flight —

- Boost phase (rocket motors burning) ~ 1 to 4 min
- Post-boost phase (MIRVed missiles) ~ 5–10 min
- Midcourse phase (ballistic flight) ~ 20 min
- Terminal phase (within atmosphere) ~ 30–40 sec

Types of re-entry vehicles —

- MRV = multiple RV (not independently targetable)
- MIRV = multiple, independently targetable RV
- MARV = maneuverable RV

Types of ABM Systems

'Terminal' defenses would attack RVs during re-entry —

- Traditional (radars & rockets armed with conventional or nuclear warheads)
- 'Simple/novel' systems (curtains of projectiles, 'dust defense' using buried bombs)

'Mid-course' defenses would attack RVs in space —

- Kinetic-kill vehicles, particle beams, x-ray lasers

'Boost-phase' defenses would attack missiles during powered flight, when their rocket motors are burning —

- IR sensors
- Kinetic-kill vehicles (KKVs), lasers, particle beams

ABM System Requirements

- Sensors
  - —Goal: detect, identify, and track targets
  - —Passive (optical, IR)
  - —Active (radar, particle beams)
- Weapons
  - —Goal: destroy missile boosters or warheads in flight
- Battle management capability
  - —Detection
  - —Identification
  - —Tracking
  - —Discrimination
  - —Targeting
  - —Damage assessment
  - —Retargeting

Consequences of a Single Warhead Penetrating a Missile Defense System Would Be Horrific

A large (100 kiloton – 1 Megaton) nuclear explosion in a major city would —

- kill millions of people
- reduce a hundred square miles to rubble

Very little can be done before or after a nuclear explosion to lessen the deaths, injuries, and destruction it causes.

Consequently, failure to intercept even a single nuclear warhead would have horrific consequences beyond anything in human history.

The Ongoing Dream of and Quest for a Technological Solution to the Threat of Nuclear-Armed Ballistic Missiles

- Over the last 50 years the U.S. has spent more than $300 billion in 2016 dollars on technologies intended to intercept nuclear-armed long-range ballistic missiles in flight.
- In recent years, the US is has been spending about $7-10 billion per year on missile defense.
- As of now, this enormous effort has not significantly enhanced the security of the United States.

iClicker Question

1/2 of the scripted tests of GMD interceptors were successful. Assume that this measures the kill efficiency of a GMD interceptor to be 50.0%. How many interceptors need to be fired to take down a single incoming warhead with a probability of greater than 90%?

A. One
B. Two
C. Three
D. Four
E. Five

iClicker Question

Half of the scripted tests of GMD interceptors were successful. Assume that this measures the kill efficiency of a GMD interceptor to be 50%. How many interceptors need to be fired to take down a single incoming warhead with a probability of greater than 90%?

A.	One	Probability to hit is 0.05
B.	Two	$1.0-0.5^2 = 0.75$
C.	Three	$1.0-0.5^3 \sim 0.88$
D.	Four	$1.0-0.5^4 \sim 0.94$
A.	Five	$1.0-0.5^5 \sim 0.97$

Past and Current U.S. Missile Defense Programs

Eisenhower Nike-Zeus Program (1950s) ➔ nuc. armed interceptors: small # of incoming missiles

Kennedy Nike-X Program (1960s) ➔ nuclear armed interceptors inside atmosphere, protect cities

Johnson Sentinel Program (1966–68) ➔ nuclear armed interceptors: protect against limited attack

Nixon Safeguard Program (1969–76) ➔ nuclear armed interceptors: protect missile fields

Reagan Star Wars Program (1983–1990)➔ broad research program for new technologies for ABM

Bush-I and Clinton Programs (1991–1997)

Clinton National Missile Defense Research Program (1997–2001)

Bush-II Missile Defense Program (2001–2009)

Obama Missile Defense Program (2009–present)

Trump's Golden Dome (2025 – present)

Total spent so far: > $400 billion in 2026 dollars.

Most of these systems were never deployed.

None were found to be effective.

The Nixon Safeguard Program

Based on Sentinel Defense System with reduced scope: defend missile sites and not the general population

Precision Approach Radar System (PAR) detects incoming RVs over artic sea and launches:

(1) Long range nuclear armed Spartan missiles to engage incoming RVs outside the atmosphere.
(2) Short range hypersonic Sprint missiles to engage RVs that have penetrated the Spartan defense.

Both Spartan and Sprint missiles carried nuclear warheads.

One Safeguard site in North Dakota went into operation on October 1st, 1975. The house voted to terminate the Safeguard program on October 2nd, 1975 and the North Dakota site was deactivated in February 1976.

Module 7: Efforts to Defend Against Attack

Reagan's 'Star Wars' Program (1980s),

R&D program broadly studying technologies for missile defense: historic example for the challenges related to missile defense

Reagan's ABM Weapon Program Motivated by Vision to Render Nuclear Weapons Impotent – Not Based on Evaluation of Current or Future Technological Capabilities

Began with Reagan's speech on March 23rd, 1983 expressing hope to render nuclear weapons impotent —

- Expressed a grand vision to make nuclear weapons "impotent and obsolete", replacing nuclear deterrence by a defensive weapons system
- Surprised experts in the US government and was a radical departure from previous US policy
- Contradicted the results of just-completed studies by the White House and the DoD
- Did not say success was assured, but implied it was highly likely and could be achieved soon
- Launched a major, long-term research and development program: the Strategic Defense Initiative (SDI)

Reagan's ABM Weapon Program Motivated by Vision to Render Nuclear Weapons Impotent – Not Based on Evaluation of Current or Future Technological Capabilities

Why was almost everyone surprised? —

- The President consulted with only a few advisors (not including his Secretary of Defense or his Science Advisor) before giving his speech.
- The U.S. already had a very large research program that was investigating ABM weapons.
- The White House Science Council had recently completed a study which concluded that missile defense would be technologically infeasible for the foreseeable future.
- The Defense Department had completed a series of detailed studies that concluded the prospects for success were very poor and recommended reducing the funding of the existing ABM research program - DDR&E (Defense Department Research & Engineering Enterprise) had testified about them earlier that same day).

Consequences of Reagan's ABM Weapon Program

Some consequences of Reagan's ABM politics —

- Raised public hopes and expectations that could not be fulfilled ("protection of our population against nuclear attack is a practical possibility and might even be accomplished soon")
- Led to doubling and tripling of expenditures on ABM weapon research and development, increasing budget deficits
- Closed off pursuit of alternative approaches to reducing the threat of nuclear weapons
- Started expensive programs to develop and deploy extensive missile defenses that continue unsuccessfully to this day

Reagan's ABM Weapon Program: Challenges

Sensors, computers, and weapons would have had to be integrated into an enormously complex system that—

- Would have had to attack ballistic missiles within seconds after having been dormant for years
- Would have had to work almost perfectly the first time it was used, even though it could not be tested under realistic conditions
- Would have had to work almost perfectly while being attacked by Soviet nuclear and in the future possibly space based weapons

Reagan's ABM Weapon Program: Challenges

Some technical realities of the time —

- A system that was 90% effective would have allowed a Soviet attack to kill 75% of the US population immediately, with millions of later deaths
- IR laser weapons would have required space-based mirrors 10 times larger than the largest ever built on the ground and lasers > 10^6 times brighter
- Midcourse intercept would have required detection, tracking, and discrimination of ~ 100,000 objects in space, at *existing* Soviet force levels
- Battle management computer programs would have required more than 100,000 labor-years to write using the most advanced techniques then available and would have had to work almost flawlessly the first time they were used

Reagan's ABM Weapon Program: Challenges

For every SDI weapon concept that was proposed or imagined, including all space-based weapons, a counter-measure had already been identified.

Unlike the weapons themselves, these counter-measures were —

- Possible with existing technology
- Relatively cheap

The SDI program did not even attempt to address nuclear weapons carried by —

- Air-, sea-, or ground-launched cruise missiles
- Submarine-launched ballistic missiles
- Bombers
- Ships

Reagan's ABM Weapon Program: Public Perception and Response vs Expert Advise

Knowledgeable people inside and outside the government knew the goal of complete protection was impossible —

- Knowledgeable scientists and others outside the government spoke out strongly
  - —Gave public speeches, talks, articles, etc.
  - —Pledged not to participate
- Knowledgeable people inside government spoke out
  - —Made cautious public comments
  - —Some gave forceful secret advice
- Allies of Reagan tried to "move the goal posts" to —
  - —Enhancing deterrence
  - —Causing the Soviets to spend money on countermeasures
- However, all this had little impact on the public's perception

FKL,Dep.of Physics

Physics 280: Session 22

Plan for This Session

Questions

Peer Review for RE4v1 due Sunday at 1pm

Extra Credit Opportunity:

> Professor Fred Lamb will be presenting a seminar on the Golden Dome in the ACDIS Seminar Series on Tuesday, Apri 14th. This talk will take place at 5:00 PM in Coble Hall – Room 306.

Module 7: Efforts to Defend Against Nuclear Attacks (cont'd)

What Are Israel's Defenses Against Iran? - The New York Times

News

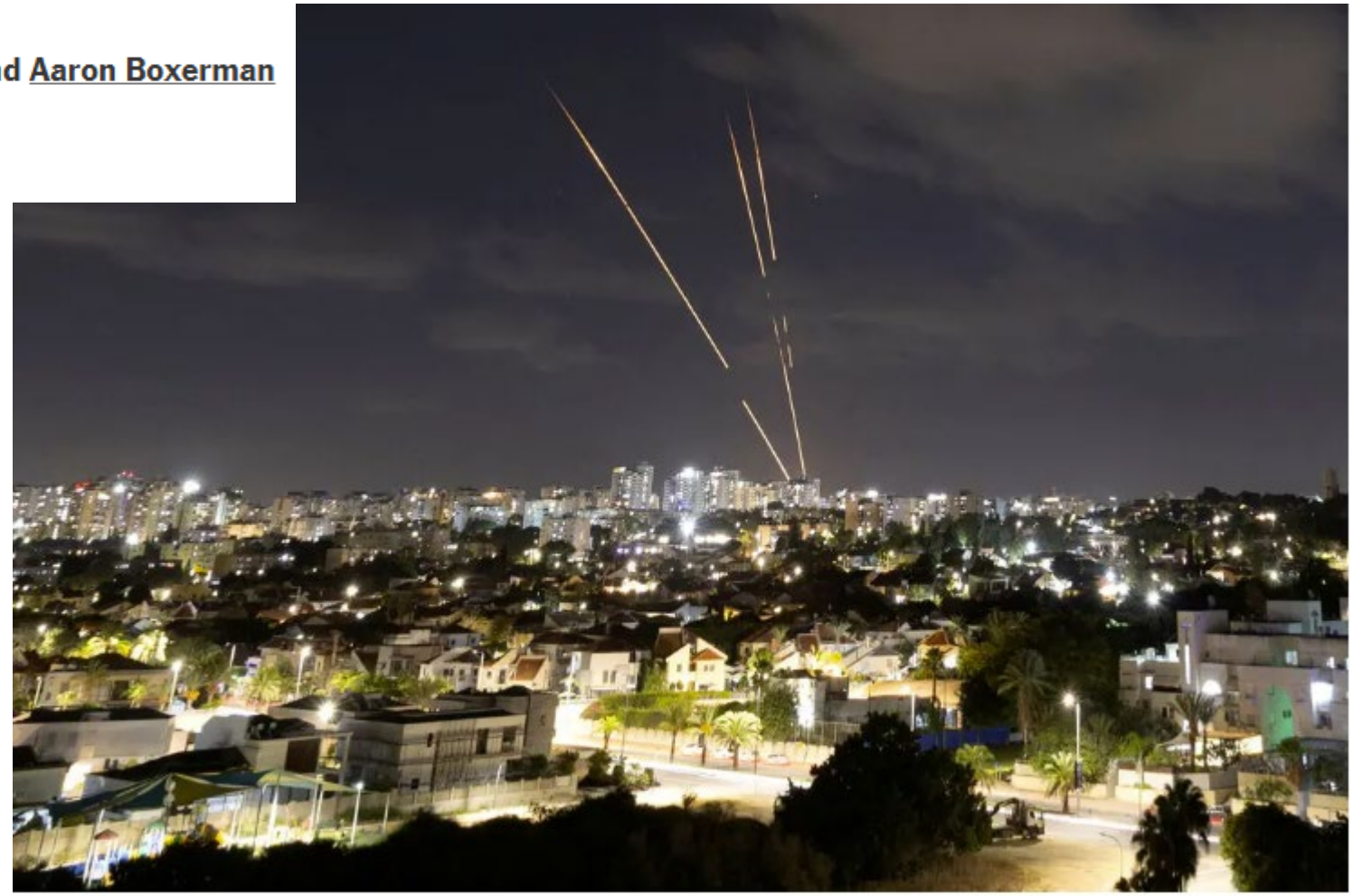
How Does Israel Defend Against Iran's Missiles?

Iran launched dozens of missiles on Friday and hit several sites in Israel, after waves of Israeli strikes against Iran's nuclear facilities and military leaders.

The New York Times


By Lara Jakes and Aaron Boxerman

June 13, 2025



Israel's Iron Dome defense system over Ashkelon, Israel, in October, following a launch of missiles from Iran. Amir Cohen/Reuters

News

How Does Israel Defend Against Iran's Missiles?

The New York Times

Iran launched retaliatory strikes against Israel on Friday, less than a day after Israel's military carried out a mass attack targeting Tehran's nuclear program and top commanders.

With billions of dollars worth of sophisticated and multilayered aerial defenses, Israel has long been prepared for a full-scale assault by Iranian missiles and drones.

Those layers of protection are now being put to the test, with Israeli authorities confirming that missiles hit multiple sites. In previous exchanges between the two countries, Iran mostly targeted Israeli military bases. But the scope of Israel's assault, which devastated Iran's military chain of command, could prompt a much wider Iranian counterstrike.

"One of the most effective tactics to inflict maximum damage on the Israeli home front would be to overwhelm its air defense systems," said Joe Truzman, a senior analyst at the Foundation for Defense of Democracies' Long War Journal.
He said Israel will have "only a brief window to detect, assess, and respond to this looming threat."

Here's what to know about Israel's defenses against Iranian attack.

News

How Does Israel Defend Against Iran's Missiles?

The New York Times

What are Israel's air defense systems?
Israel's anti-missile systems include:

Iron Dome: Israel's best-known air defense system fires interceptors to take down short-range rockets.

David's Sling: This stationary weapon can shoot down short- and medium-range ballistic and cruise missiles. It has a range of about 185 miles. Like the Iron Dome, it is a "hit-to-kill" weapon that takes down targets by flying into them.

Arrow 2 and 3: These ground-based mobile launchers fire fragmentation warheads packed with explosives that blow up near incoming missiles. The Arrow 2 can intercept targets high in the atmosphere, at an altitude of about 30 miles and a range of about 60 miles.
The Arrow 3 can go beyond the atmosphere into space, with a range of up to 1,500 miles. It is one of Israel's most advanced defenses.

Iron Beam: This high-powered laser was developed to intercept rockets, drones and anti-tank missiles. It was first deployed in the field after Hamas's 2023 attack on southern Israel, which prompted wars in Gaza and Lebanon.

News

How Does Israel Defend Against Iran's Missiles?

The New York Times

What are the biggest threats to Israel's defenses?

One of the most serious threats posed by Iran comes from its heavyweight ballistic missiles, which fly at the edge of space at many times the speed of sound. They can cross the roughly 1,000 miles between Iran and Israel in just a few minutes.

Antimissile systems like Arrow 3, which have a limited supply of expensive interceptors, do not always hit their ballistic missile targets.

Last October, analysts at the Middlebury Institute of International Studies at Monterey, in California, concluded that Israel had run low on interceptors, after about 30 Iranian ballistic missiles landed near a military base in southern Israel unscathed. Last month, a Houthi missile launched from Yemen evaded Israeli and American air defense systems to strike near Ben Gurion Airport in Tel Aviv.

It can take years to produce enough missile interceptors to keep them reliably stockpiled, and Israel "has been expending them," said Tom Karako, a missile defense expert at the Center for Strategic and International Studies in Washington.

Another problem for Israel will be tracking and destroying unmanned drones, which fly low and slow, making them much harder to detect. In the past, Israel has scrambled fighter jets to shoot down drones beyond Israel's borders; failing that, Israeli forces have used the Iron Dome system, which is most effective against short-range rockets.

News

Israel's Missile Defense Under Scrutiny After Iranian Attack

Two missiles landed hours apart, wreaking havoc in two towns near a heavily guarded nuclear site in the Negev Desert.

The New York Times

By Isabel Kershner
Reporting from Jerusalem

March 22, 2026

Peering Sunday at damage where a missile struck the night before in Arad, Israel. Amit Elkayam for The New York Times

News

Israel's Missile Defense Under Scrutiny After Iranian Attack

The New York Times

Few sites in Israel are better protected than its main nuclear research facility and reactor, eight miles from the town of Dimona in the southern Negev Desert.

So when two Iranian ballistic missiles crashed into residential neighborhoods of Dimona and another nearby city, Arad, on Saturday night, evading the country's vaunted air defenses, even battle-hardened Israelis seemed rattled by the scenes of destruction.

As alarming, perhaps, as the damage was the military's admission that it had tried to intercept the missiles, which struck about three hours apart. The failures raised discomfiting questions about Israel's multilayered missile defense system and its ability to protect its citizens.

News

Israel's Missile Defense Under Scrutiny After Iranian Attack

The New York Times

Emergency workers on Sunday in Dimona. Scores of people were hurt in the weekend missile strikes there and in Arad. Amit Elkayam for The New York Times

News

Israel's Missile Defense Under Scrutiny After Iranian Attack

The New York Times

And it renewed concerns that the military might be holding back on firing its most costly and sophisticated missiles, after reports that its stockpiles might have been drained in the 12-day war with Iran last year. Those concerns may deepen further in coming weeks if the current campaign against Iran is only "midway," as Lt. Gen. Eyal Zamir, the Israeli military's chief of staff, said on Saturday.

....

While the military puts the interception rate of Iran's ballistic missiles at more than 90 percent, officials and experts emphasize that the defenses can never be 100 percent hermetic.

"Dimona is protected with multilayered defense systems — Israeli and American," said Ran Kochav, a brigadier general in the reserves and former commander of Israel's air and missile defense forces, "but nothing is perfect. There was an operational failure."

Reagan's ABM Weapon Program: Challenges Result in Shifting Focus on Different Technologies

As a result of its technological unreality, the emphasis of the SDI program moved from year to year —

- Space-based X-ray lasers
- Space-based particle-beam weapons
- Space- and ground-based optical and UV lasers
- Space-based kinetic energy weapons
- Brilliant pebbles (smart rocks)
- High- and low-altitude rocket interceptors

None of the resources spent on these exotic technologies contributed significantly to subsequent ABM programs.

Reagan's ABM Weapon Program: Costs and Demise

Some consequences of the SDI ABM weapon program —

- Spurred the race in offensive strategic weapons, until ~ 30,000 were deployed, increasing further cost of strategic armament
- Complicated arms control efforts
- Large opportunity cost
  - —Diverted money, manpower, and other resources from education and internationally competitive civilian industries and products
  - —SDI ended up costing more than $150B in 2016 dollars, but accomplished very little that was useful

The SDI program was greatly reduced by Bush and terminated in 1994 by Clinton. However, Clinton felt compelled to restart a program to defend against long-range ballistic missiles in 1998. Missile defense programs have been pursued by the Bush-II and Obama administrations.

FKL,Dep.of Physics

The 'Nitze Criteria' for Deploying an ABM System (Important)

In the early 1980s, Paul Nitze argued convincingly that to be considered for deployment, an ABM system must first meet the following three criteria —

1. The system must be effective
2. The system must be able to survive attack
3. The system must be cost-effective at the margin

These criteria were officially adopted ~ 1985 and have become known as the "Nitze criteria" for it to make sense to deploy a missile defense system.

Adoption of these criteria effectively ended any chance of deploying a missile defense system during the 1980's and 1990's, because no system then under development could come close to meeting them.

Bush-II departed from the Nitze Criteria in 2001 in order to deploy a missile defense system (see "capability-based development and deployment").

Lessons from Reagan's ABM Program (Important)

- Missile defense technology is highly challenging
- Technology cannot be coerced by good intentions, ideology, or policy (engineering programs must be consistent with technical realities, because nature cannot be fooled)
- It is important to understand what technology can and cannot do in a given situation, because to be successful, policies must be consistent with the available technology
- An R&D program without clear goals will always waste time and money
- Frequent testing is critical and the budget for tests must therefore be large; if there is no commitment to such an effort, the program will fail
- An independent evaluation and review process is critical

Patriot in the 1991 Gulf War

Events that formed the US public's impression—

- TV videos of Patriot "engagements" and enthusiastic reports by military spokesmen and news reporters of the Patriot's successes.
- General Schwarzkopf: "The Patriot's success is 100%—so far, of 33 Scuds engaged, there have been 33 destroyed."
- President Bush, during a celebratory visit to Raytheon, said "Patriot is 41 for 42, 42 Scuds engaged, 41 intercepted... **Patriot is proof positive that missile defense works**."
- These statements also were aimed at the public in Israel to build trust towards US abilities to defend Israel from Iraqi aggression. Finally, they were aimed at Iraqi leadership to frustrate Iraqi efforts to widen conflict.

Patriot in the 1991 Gulf War

Later studies showed the Patriot's actual performance was *very* poor —

- The First Army study (February 1992) was found to have serious flaws by the GAO (Government Accountability Office) and the CRS (Congressional Research Service).
- In April 1992, Pedatzur (Tel Aviv) reported only 1 Scud hit by a Patriot based in Israel; found that 4 Patriot warheads had fallen and exploded in populated areas.
- A corrected Army study (April 1992) reported a 'success rate' > 70% in Saudia Arabia and > 40% in Israel (success = incoming WH destroyed, dudded, or deflected).
- A September 1992 GAO study reviewed the corrected Army study and found only 4 engagements (9% of the total) in which there was strong evidence of a Patriot 'kill'.
- A detailed study by Postol & Lewis (MIT, 1991–92) found *evidence of 3 hits but no evidence of any 'kills'.* An independent study by the APS largely agreed.
- **In the end, there was not a single well-documented intercept but many well-documented complete misses**

Careful studies came late and had limited impact on the public's perception that Patriot had succeeded.

Israel: Iron Dome ➔ Short Range Rocket Defense System

- Sub-theater missile defense system for missiles with ranges up to 45 miles. One battery consists of 3 rocket launchers with 20 interceptors, controlled by a single battle control station.
- Developed and built by Israel Rafael Advanced Defense Systems with significant support from the United States. Israel has ordered 15 batteries at an estimated $1 billion.
- After visit to Israel in August 2012, Defense Secretary Leon Panetta reported that the Iron Dome interceptors had a rate of successful interceptions above 80%.
- Example (from news media reports): attack from Gaza on March 9th 2012 with over 300 rockets: 177 hit targets in Israel, Iron Dome identified 71 rockets and successfully intercepted 56.

Israel: Iron Dome ➔
Will the Early Reports of Success Hold?

MIT Technology Review

Interview with Ted Postol, MIT
Expert on ballistic missiles and defense

Why Israel's "Iron Dome" Missile-Defense System Actually Works

Successful intercepts show that missile defense can work against relatively slow-moving rockets.

By David Talbot on November 26, 2012

Intercept course: An Israeli battery launches a missile to intercept a Palestinian rocket.

Does this mean missile-defense systems may be more reliable than in the past?

Let's say you are batting .750 against a fastball pitcher. That's tremendously good. But a fastball pitcher can throw a pitch at only 160 kilometers per hour. So how well are you going to do against a pitcher who can pitch at 800 kilometers per hour? It's not a minor difference.

The actual speed of these Hamas rockets is in the range of 500 meters per second. Scuds that can travel 600 kilometers are traveling at 2,200 meters per second. An ICBM [intercontinental ballistic missile] is traveling at 7,000 meters per second, so 13 or 14 times as fast. With ICBMs, the main weakness of missile-defense systems is that they can be fooled by decoys that can be released in the near-vacuum of space and travel with the ICBM.

By David Talbot on November 26, 2012

Intercept course: An Israeli battery launches a missile to intercept a Palestinian rocket.

Delivery vehicle	Speed in [meters/second]
Mach-2 fighter	680
Hamas rocket	**500**
SCUD missile	2200
ICBM	7000

Short range rockets present a significantly smaller challenge to missile defense …

iClicker Question

In which situation might a Iron Dome defense be useful?

A. Defend against single ICBM attack from North Korea on US base in the Pacific.

B. Defend Seoul against attack with artillery from North Korea.

C. Defend Seoul against attack with rocket launchers from North Korea.

D. Defend Washington DC against short range missile attack from forward naval platform.

E. Defend Washington DC against SLCM attack from forward naval platform.

iClicker Question

In which situation might a Iron Dome defense be useful?

A. Defend against single ICBM attack from North Korea on US base in the Pacific.

B. Defend Seoul against attack with artillery from North Korea.

C. **Defend Seoul against attack with rocket launchers from North Korea.**

D. **Defend Washington DC against short range missile attack from forward naval platform.**

E. Defend Washington DC against SLCM attack from forward naval platform.

Module 7: Modern Efforts on Missile Defense

Boost-Phase Intercept System ?

Why is There Interest in Boost-Phase Intercept?

Boost-phase intercept has been described as easier than midcourse intercept, because

- ICBMs are slowly-moving targets during boost phase
- ICBMs have bright exhaust plumes that are easy to track
- An ICBM is a unitary target if it can be intercepted before it deploys its warheads and decoys
- It is usually assumed that there are few if any effective countermeasures to boost-phase intercept

It is also argued that boost-phase intercept . . .

. . . would reduce the challenge faced by the midcourse layer if it were the first layer of a layered defense

Requirements for a Successful Boost-Phase Intercept

- The interceptor rocket must reach the target missile before it has a velocity that will carry its warheads to the defended area.

- The interceptor's final stage ("kill vehicle") must be able to maneuver to hit the ICBM while it is in powered flight.

Reaching the ICBM in Time

- In many situations the interceptor rocket would have only ~ 2 min (solids) or ~ 3 min (liquids) to reach the target ICBM, even with a state-of-the-art space-based detection and tracking system

- In some situations, the defense would have only seconds to decide whether to fire, and even if its interceptors were fast and fired immediately, they could have difficulty reaching the ICBM in time

Difficulties for Boost-Phase Intercept

ICBM boost phases are short (4 min liquids, 3 min solids)

- The defense has little time to decide whether to fire
- Interceptors have little time to reach the ICBM

Geographical constraints require high interceptor speeds

- Intercept points for ICBMs from North Korea and Iran are 500 to 1,000 km from potential interceptor basing locations

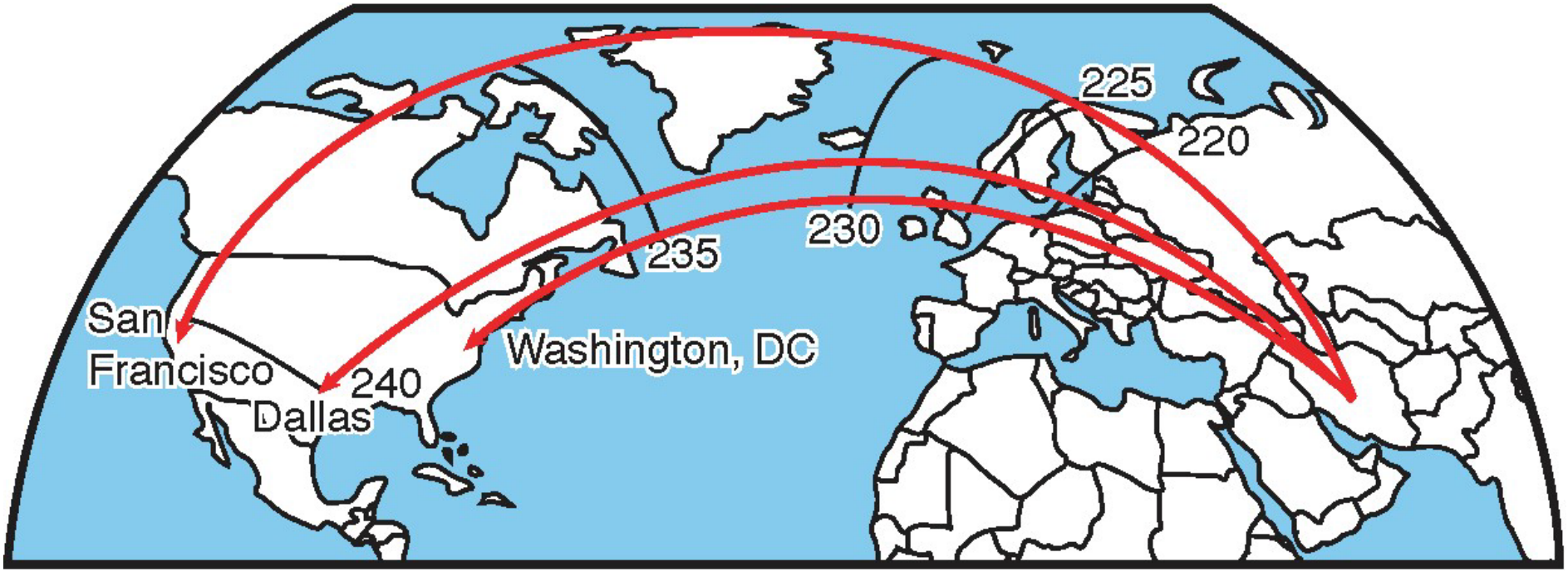
ICBMs in powered flight accelerate unpredictably

- Burn variations, energy management, programmed evasion
- Interceptors would have to be fast and agile

A successful intercept is unlikely to destroy warheads

- Live warheads could impact the territory of the United States or U.S. friends and allies (“shortfall management problem”)

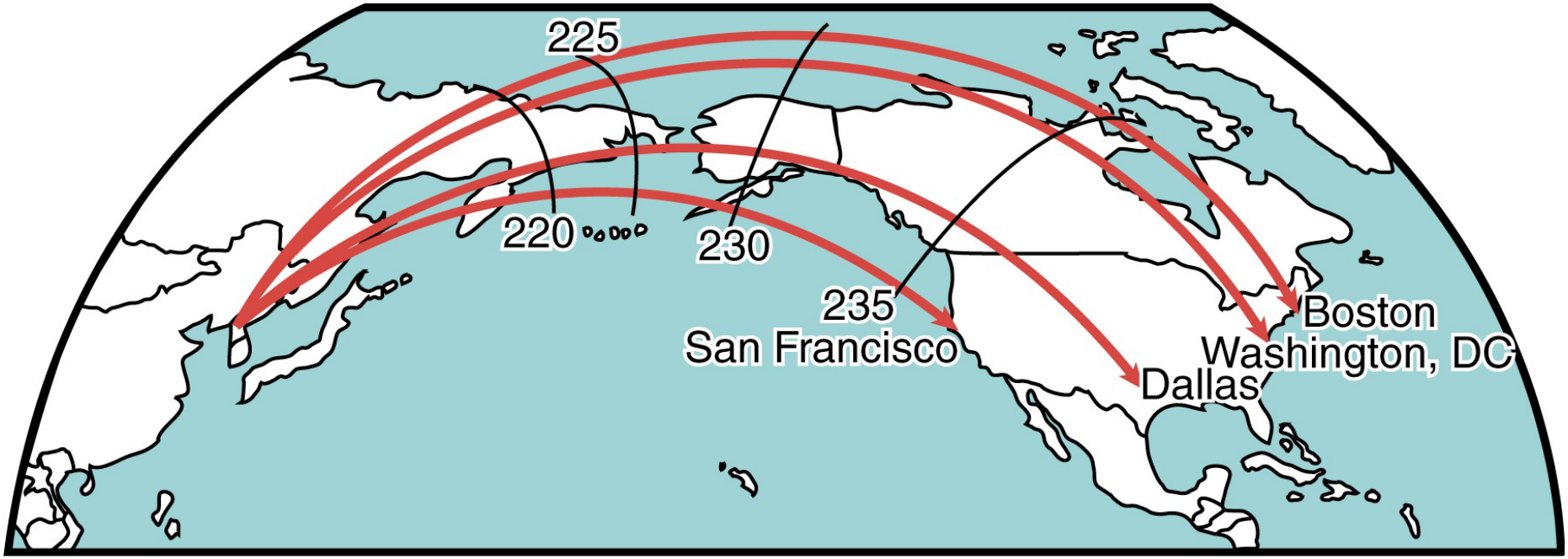
Munitions from Iranian Missiles Could Impact Western Europe or Canada



A successful boost phase intercept (after say 220 seconds of acceleration) may destroy the missile but leave the payload on course (intact or otherwise). The payload then continues in un-propelled ballistic flight with a range corresponding to the length of the shorter boost phase.

The black curves on the plot show the impact location of the payload depending on the length of boost phase before intercept in seconds.

Munitions from North Korean Missiles Could Impact Russia or Canada



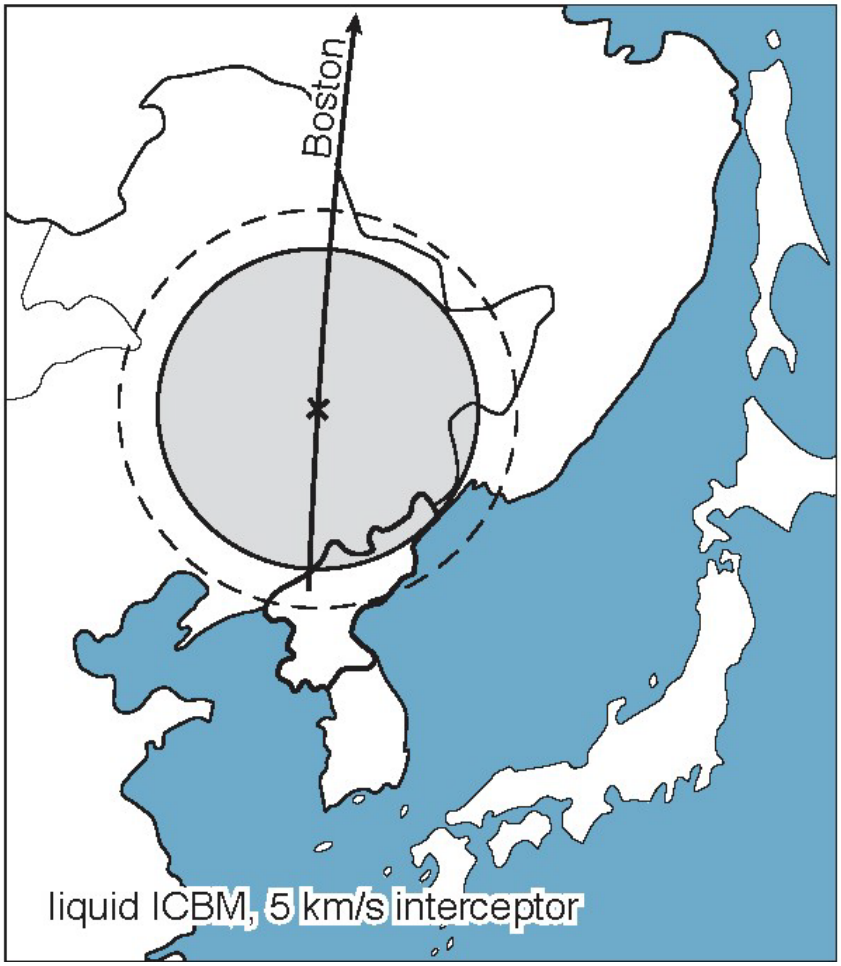
A successful boost phase intercept (after say 220 seconds of acceleration) may destroy the missile but leave the payload on course (intact or otherwise). The payload then continues in un-propelled ballistic flight with a range corresponding to the length of the shorter boost phase.

The black curves on the plot show the impact location of the payload depending on the length of boost phase before intercept in seconds.

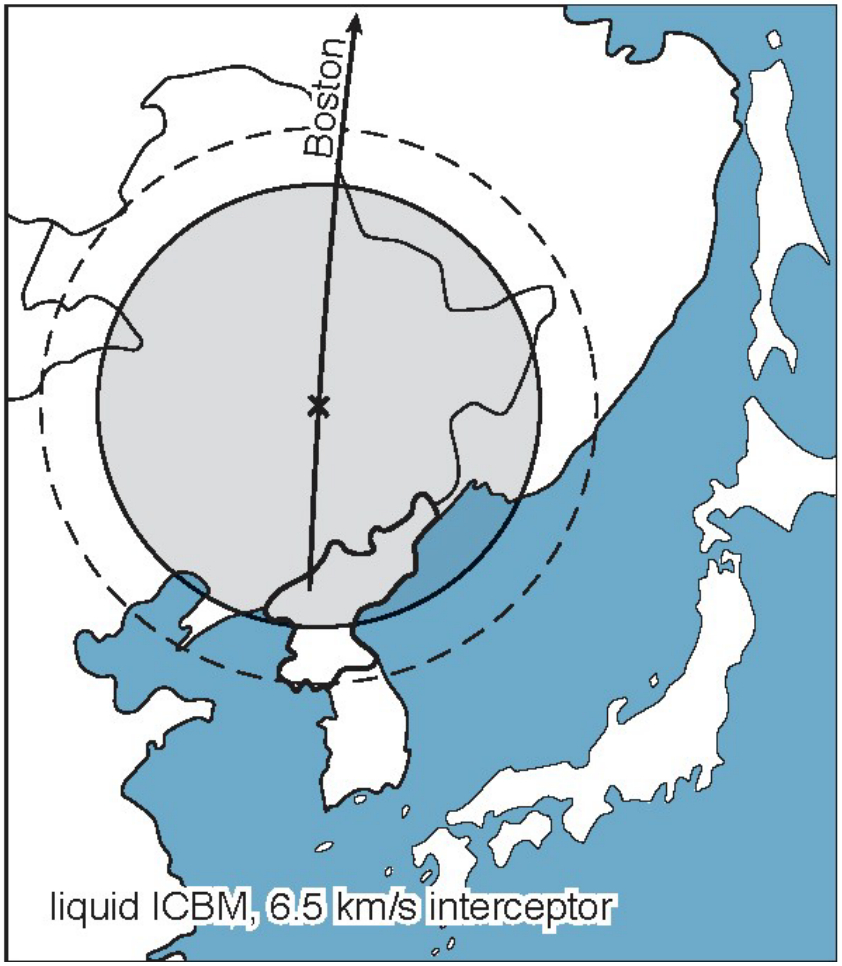
Regional Geography Constrains How Close Interceptors Could Be Based

Solid line: 30 sec. decision time

Dashed line: No decision time

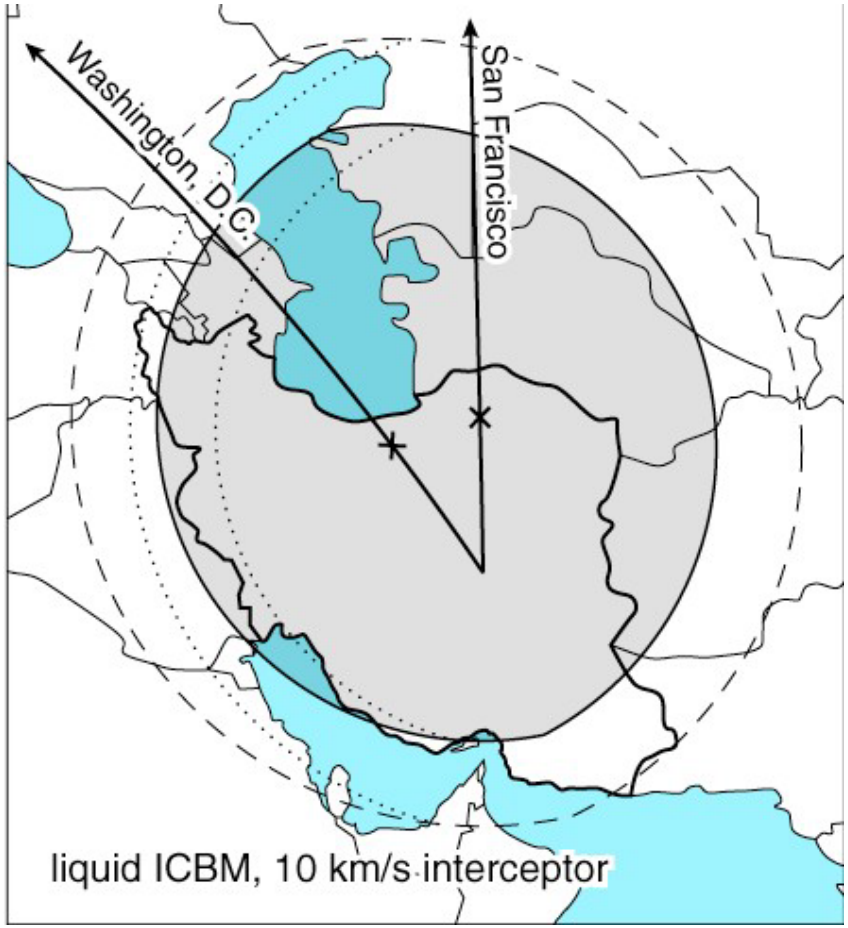


Basing areas for a 5 km/s interceptor to defend Boston against a liquid-propellant ICBM launched from North Korea

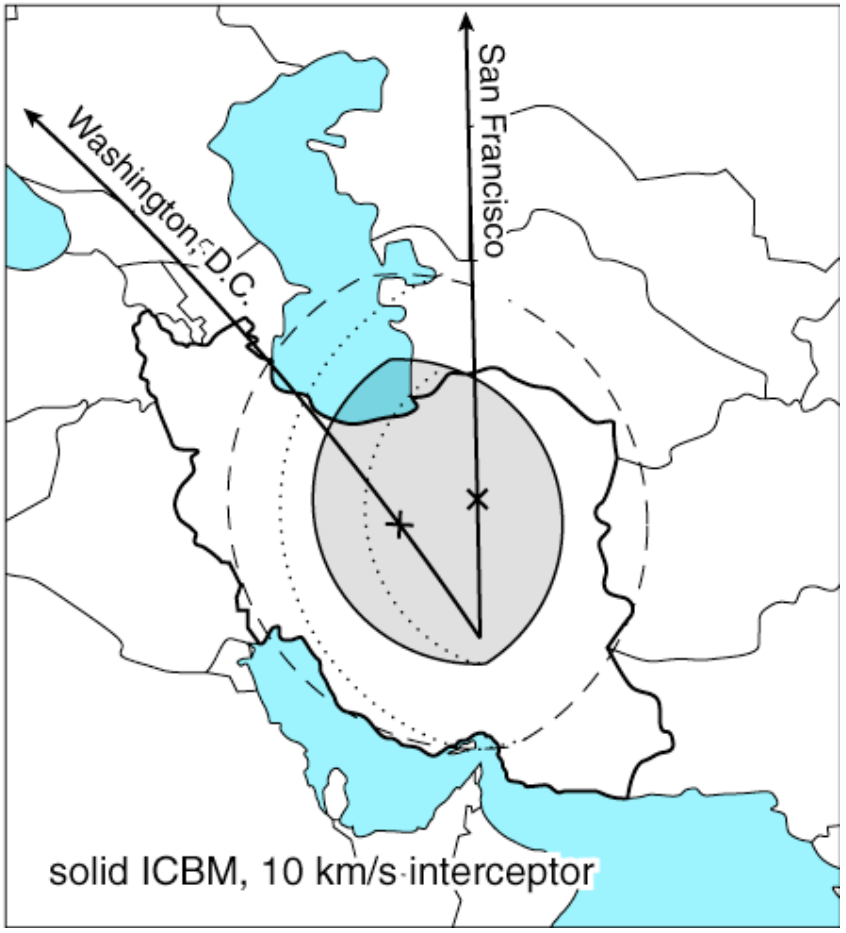


Basing areas for a 6.5 km/s interceptor to defend Boston against a liquid-propellant ICBM launched from North Korea

Regional Geography Constrains How Close Interceptors Could Be Based



Basing areas for intercepting a liquid-propellant ICBM from Iran to the Lower 48 States



Basing areas for intercepting a solid-propellant ICBM from Iran to the Lower 48 States

Implications of the Time Constraints

The very short time available to complete the intercept poses significant command-and-control issues —

- In some situations the decision whether to fire interceptors would have to be made within a few seconds after a firing solution was obtained
- There would generally be too little time to determine using the system's sensors whether the rocket is an attacking ICBM, a theater ballistic missile, or a rocket launching a satellite
- Consequently, interceptors would have to be fired whenever a large rocket in powered flight is detected, without waiting until the nature of the rocket or its trajectory is established
- Giving commanders the ability to divert or destroy interceptors in flight might extend the assessment time by about 100 seconds

A System of Space-Based Interceptors Would Require Many Large Satellites

Placing interceptors in space would avoid geographic restrictions on basing, but global geographic constraints would still determine when ICBM must be intercepted

To counter *solid-propellant ICBMs*, at least 1,600 interceptors would be required, each at 840 kg, for a minimum mass in orbit of 2,000 tonnes

- Would require a 5- to 10-fold increase in the annual U.S. space launch capability

To counter *liquid-propellant ICBMs*, roughly half as many interceptors and space launches would be required

- However, a space-based system designed to counter only liquid-propellant ICBMs could become obsolete quickly

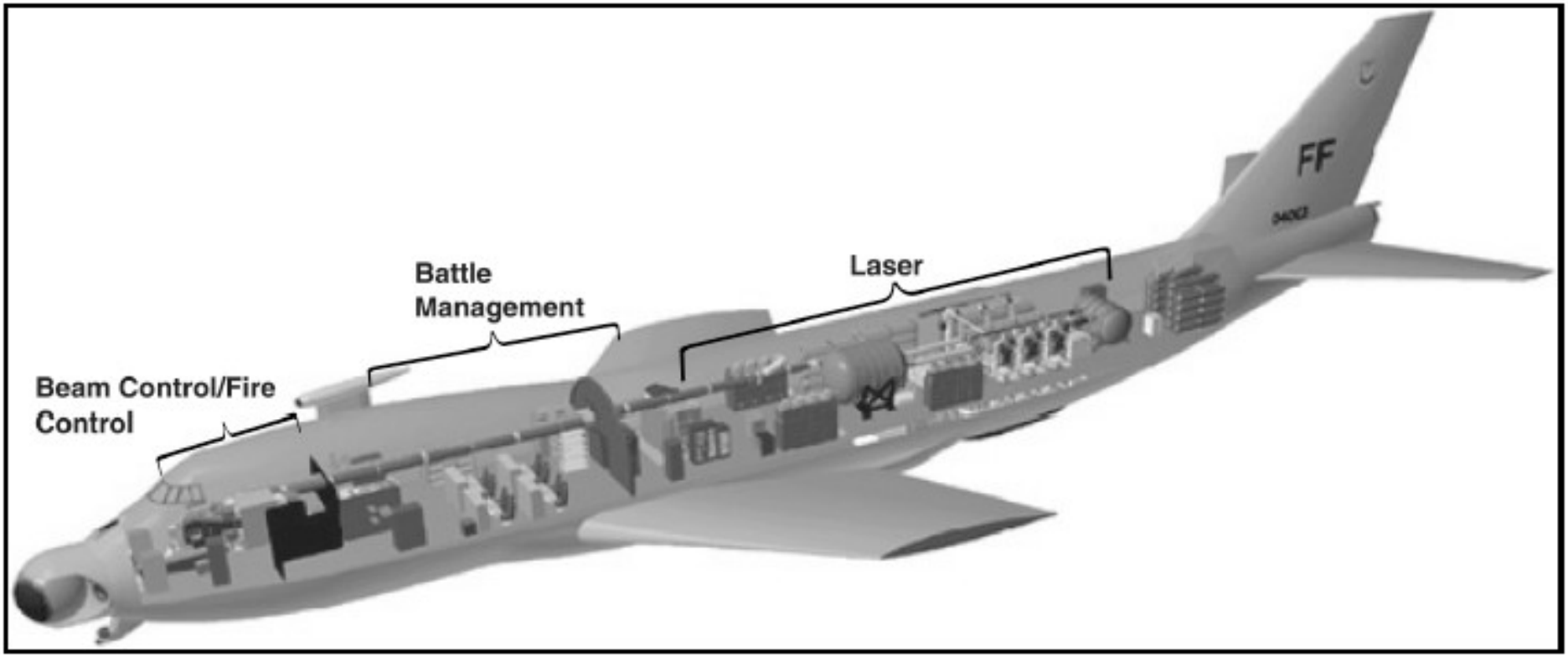
Airborne Laser Boost-Phase Intercept Program

U.S. Missile Defense Agency

The Airborne Laser Test Bed program's laser-armed aircraft takes off on February 14 from Edwards Air Force Base in California on its way to long-term storage at Davis-Monthan Air Force Base in Arizona.

The Airborne Laser Concept

Figure 1: Airborne Laser Aboard Boeing 747 Aircraft



Source: Airborne Laser Program Office.

The Airborne Laser Would Have Only Limited Capability Against ICBMs

The ABL's range would not be limited by time, but by the distance a focused beam could be propagated through the atmosphere

The ABL could in principle be used against ICBMs, if the laser worked as advertised

If it worked as advertised, the ABL would have a range up to 600 km against a liquid-propellant ICBM

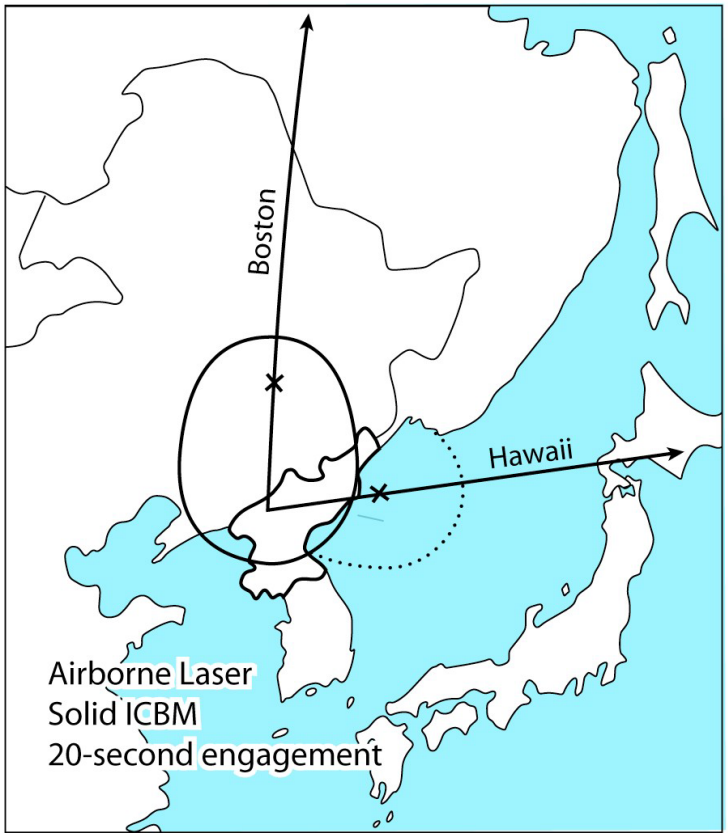
- Could be useful against ICBMs from North Korea, but not from Iran, unless ABL aircraft could fly over the lower Caspian Sea or Turkmenistan

The ABL would have a range of only 300 km against a solid-propellant ICBM (solid propellant ICBMs are more heat resistant)

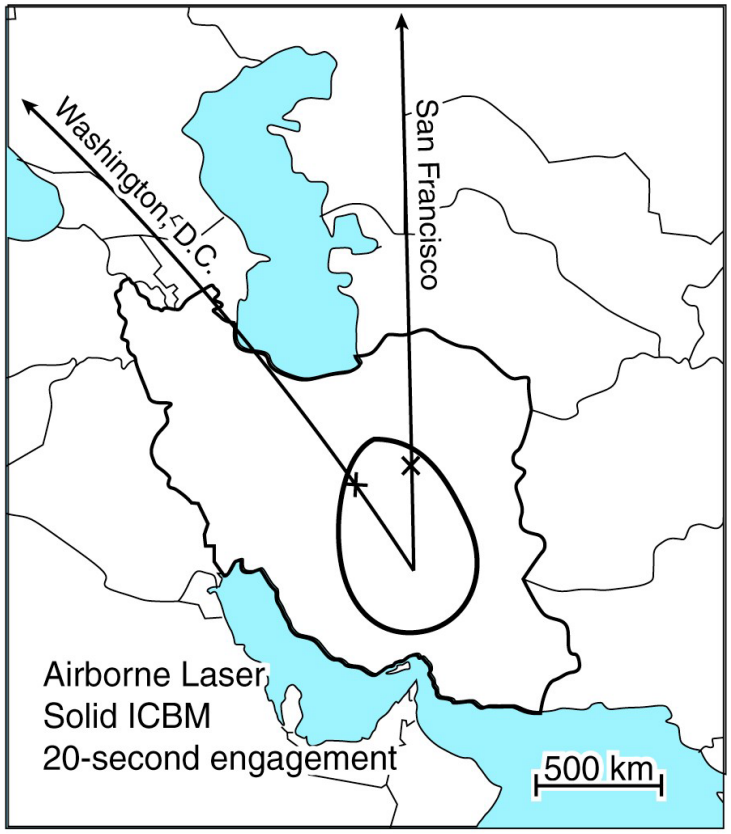
- Would not be effective in any of the scenarios examined by the APS

The Airborne Laser Would Have Only Limited Capability Against ICBMs

Basing areas for intercepting a solid-propellant ICBM from North Korea



Basing areas for intercepting a solid-propellant ICBM from Iran



Countermeasures Would Challenge Boost-Phase Intercept

A boost-phase defense would not be susceptible to some of the proposed countermeasures to midcourse defense, but it would face countermeasures

Examples of countermeasures to both hit-to-kill and the ABL

- Launch several ICBMs nearly simultaneously
- Deploy solid-propellant ICBMs

Examples of countermeasures to hit-to-kill

- Deploy payload during powered flight
- Program evasive maneuvers
- Deploy decoys and jammers
- Deploy fast-burn boosters with multiple upper stages

Examples of countermeasures to the ABL

- Attack the airframe
- Roll the ICBM
- Use ablative coating
- Change the optical properties of the ICBM

Physics 280: Session 23

Plan for This Session

Questions

Peer Review for RE4v2 due Wednesday at 10pm

Extra Credit Opportunity:

> Professor Fred Lamb will be presenting a seminar on the Golden Dome in the ACDIS Seminar Series on Tuesday, Apri 14th. This talk will take place at 5:00 PM in Coble Hall – Room 306.

Module 7: Efforts to Defend Against Nuclear Attacks (cont'd)

CNN Cold War – “STAR Wars” (1981-1988)

https://www.youtube.com/watch?v=cCVZNNYpTz0

iClicker Question

Which of the following is **not** one of the "Nitze criteria" for considering deployment of an ABM system?

A. The system must be effective

B. The system must be able to survive an attack

C. The system must use the most advanced technology

D. The system must be cost-effective at the margin

E. None of the above are "Nitze criteria"

iClicker Answer

Which of the following is **not** one of the "Nitze criteria" for considering deployment of an ABM system?

A. The system must be effective

B. The system must be able to survive an attack

C. The system must use the most advanced technology

D. The system must be cost-effective at the margin

E. None of the above are "Nitze criteria"

iClicker Question

Missile Defenses

Which of the following is not a lesson of the Star Wars program?

A. Missile defense is highly challenging

B. A rational evaluation of technology capabilities is difficult in light of external threats, fear and ideology.

A. An R&D program without clear goals will always waste time and money

B. Frequent testing is unnecessary

C. An independent evaluation and review process is critical

iClicker Question

Missile Defenses

Which of the following is not a lesson of the Star Wars program?

A. Missile defense is highly challenging

B. A rational evaluation of technology capabilities is difficult in light of external threats, fear and ideology.

A. An R&D program without clear goals will always waste time and money

B. Frequent testing is unnecessary

C. An independent evaluation and review process is critical

iClicker Question

Missile Defenses

The reported success of the Patriot missile defense system during the 1991 Gulf War was a key argument used to restart the U.S. program to defend against ICBMs. In the end, how many intercepts of Iraqi short-range missiles were well-documented?

A. 0

B. 5

C. 10

D. 50

E. 100

iClicker Answer

Missile Defenses

The reported success of the Patriot missile defense system during the 1991 Gulf War was a key argument used to restart the U.S. program to defend against ICBMs. In the end, how many intercepts of Iraqi short-range missiles were well-documented?

A. 0

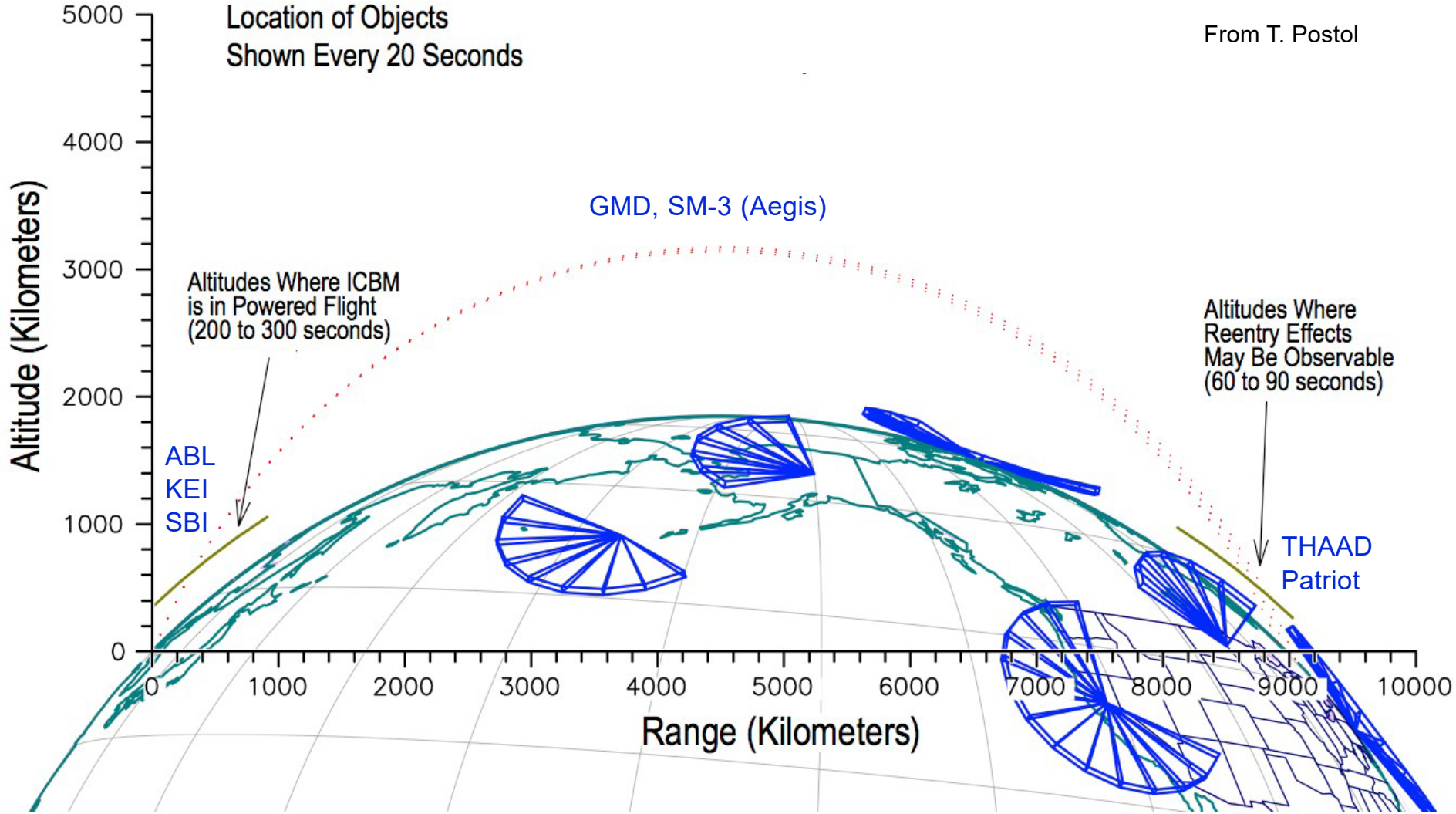
B. 5

C. 10

D. 50

E. 100

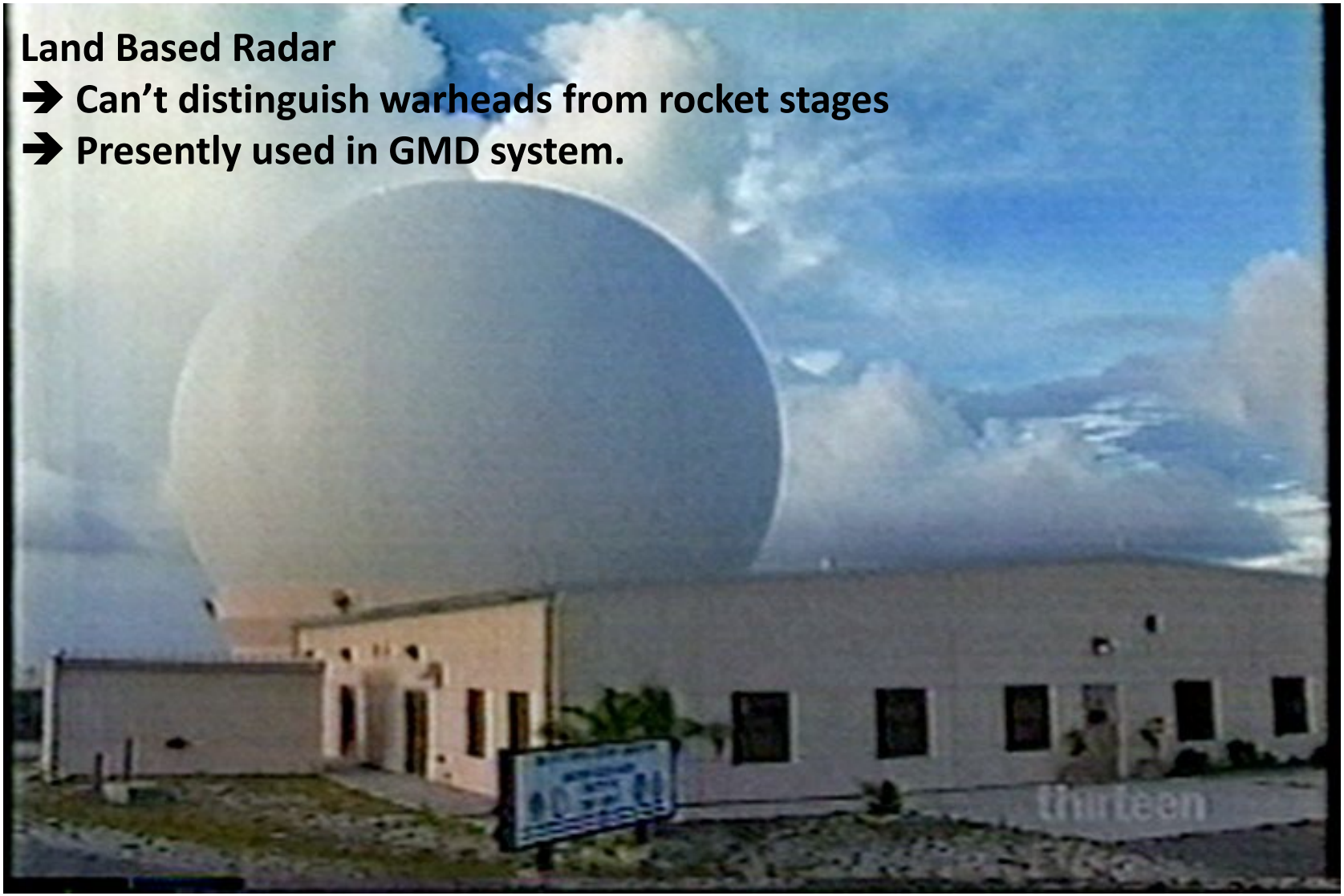
Bush II Defense Initiatives Against Nuclear-Armed Long-Range Ballistic Missiles



Several of the Bush II Missile Defense Programs have been Scaled Back or Cancelled

- Space-based Interceptor (SBI) — cancelled 2003.
- Airborne Laser (ABL) — reduced 2008, cancelled 2012.
- Kinetic-Energy Interceptor (KEI) — cancelled.
- Multiple Kill Vehicle (MKV) — cancelled 2005.
- Terminal High-Altitude Area Defense (THAAD) — scaled back, deployed in 2009 to Hawaii and in April 2013 in response to North Korean Missile Threat . Deployed in March 2018 to South Korea in response to heightened North Korean Missile Threat.

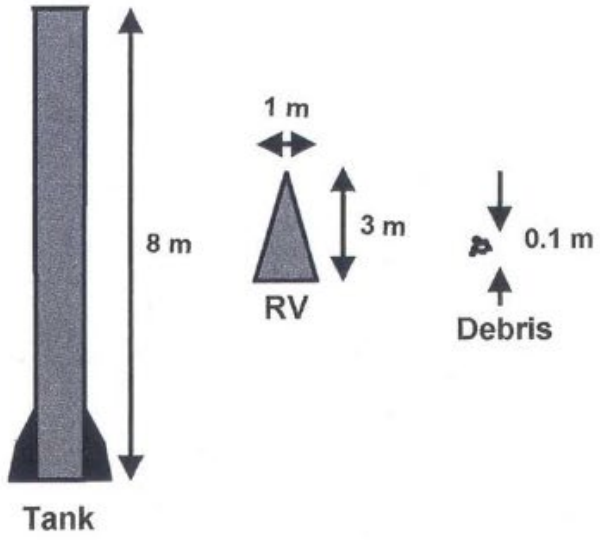
Radar Capabilities for Midcourse Intercept

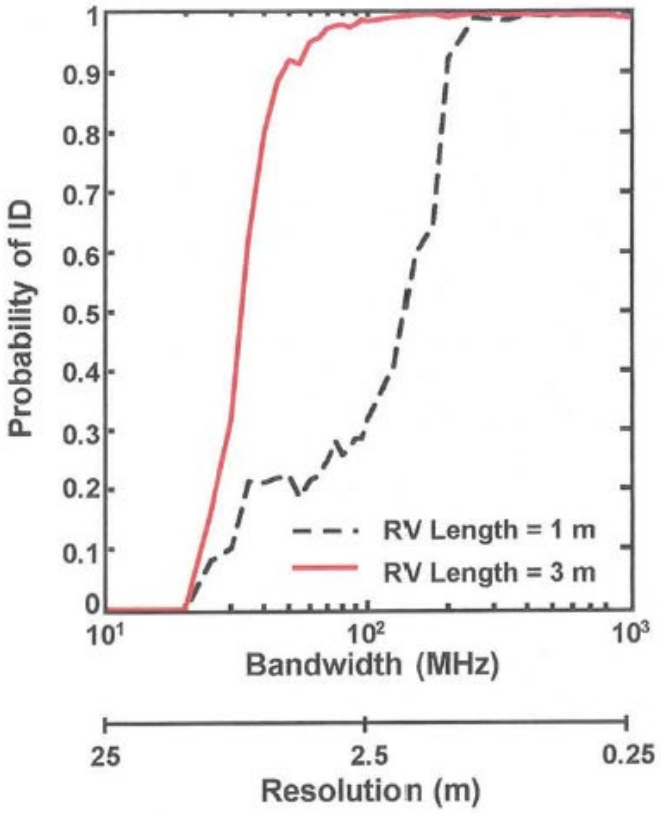


Identification of Re-entry Vehicle Requires Bandwidth higher than 200 MHz

Bandwidth Requirements for TBM Length Discrimination

UNCLASSIFIED





300 MHz Bandwidth (1 m resolution) Required Against Near-Term Threat

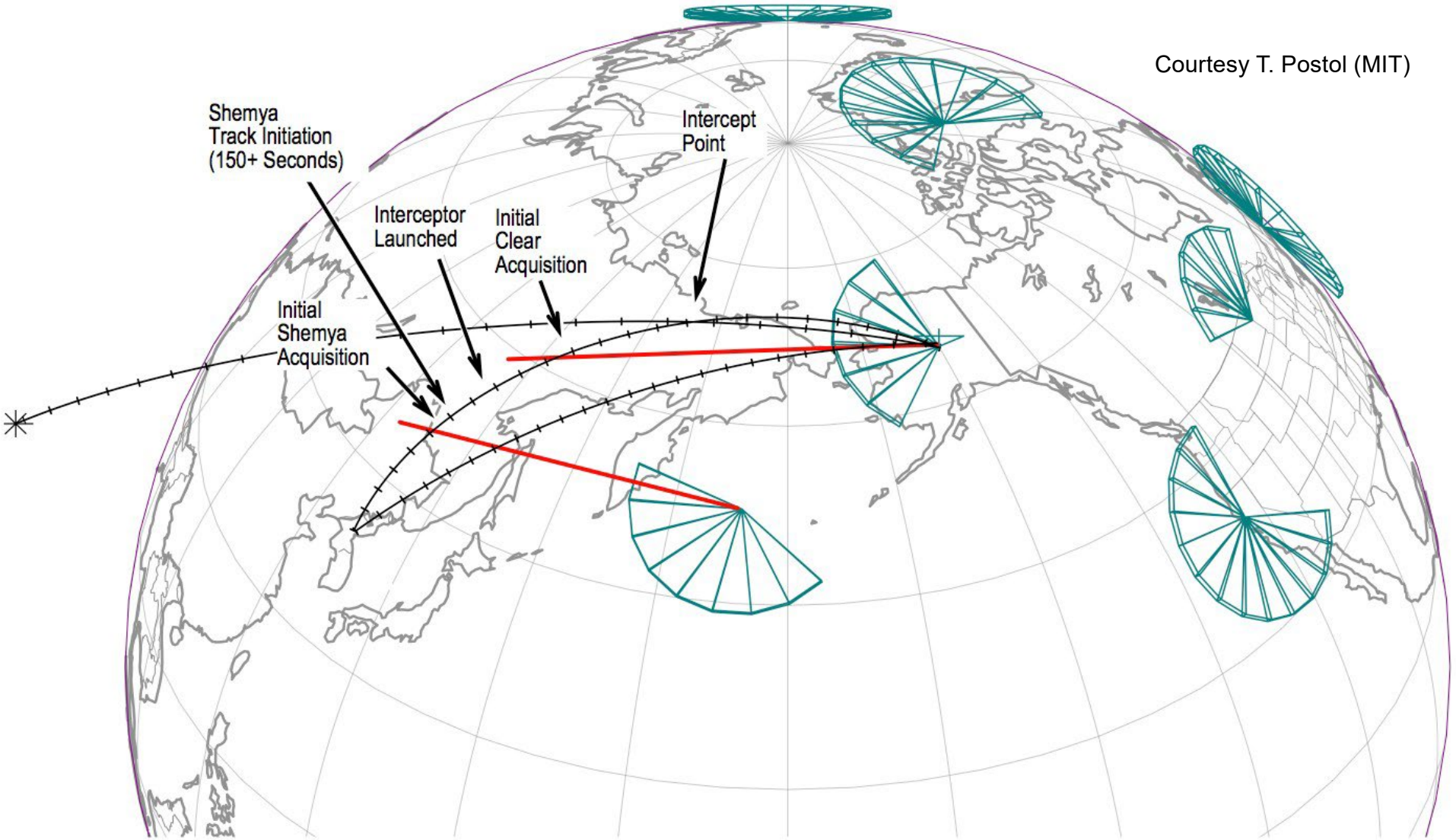
UNCLASSIFIED [Source: S. Wilson, 1996]

Sea Based X-Band Radar SBX-1

➔ **Sufficient resolution to distinguish warheads from rocket stages**

➔ **Used for tests, not active part of the GMD system – annual operating cost $160**

Operational Concept of the Ground-Base Midcourse Intercept (GMD) System



Challenges to Midcourse Intercept

- Each ICBM could launch —
  - —Multiple warheads
  - —Chemical or biological submunitions

A large number of warheads would overwhelm the defense

- Each ICBM could launch —
  - – Countermeasures and penetration aids, including large numbers of lightweight decoys

Outside the atmosphere, these would be difficult to distinguish from warheads and would confuse the defense

Steve Fetter, Richard L. Garwin, and Frank von Hippel

NUCLEAR WEAPONS

Ballistic-missile defense (BMD) has been a contentious issue since the Soviet Union launched the *Sputnik 1* satellite in 1957. The two dimensions of the controversy concern the ability to neutralize BMD systems with relatively inexpensive countermeasures and the fear that BMD systems will prompt potential adversaries to increase their offensive strategic nuclear forces to ensure they can overwhelm the defense. All BMD systems deployed today to defend the continental US involve the intercept of incoming warheads in space. Many relatively simple countermeasures would be effective against such systems. Figure 4 shows one possibility: lightweight decoys. A 2012 National Research Council report, *Making Sense of Ballistic Missile Defense*, noted,

Discriminating between actual warheads and lightweight countermeasures has been a contentious issue for midcourse defense for more than 40 years. . . . Based on the information presented to it by the Missile Defense Agency (MDA), the committee learned very little that would help resolve the discrimination issue in the presence of sophisticated countermeasures. In fact, the committee had to seek out people who had put together experiments . . . and who had understood and analyzed the data gathered. Their funding was terminated several years ago, ostensibly for budget reasons, and their expertise was lost. (page 131)

Of course, counter-countermeasures exist, but after more than 50 years of analysis, the advantage remains decisively on the side of the offense.

Physics Today
April-2018

Steve Fetter,
Richard L. Garwin,
and Frank von Hippel

NUCLEAR WEAPONS

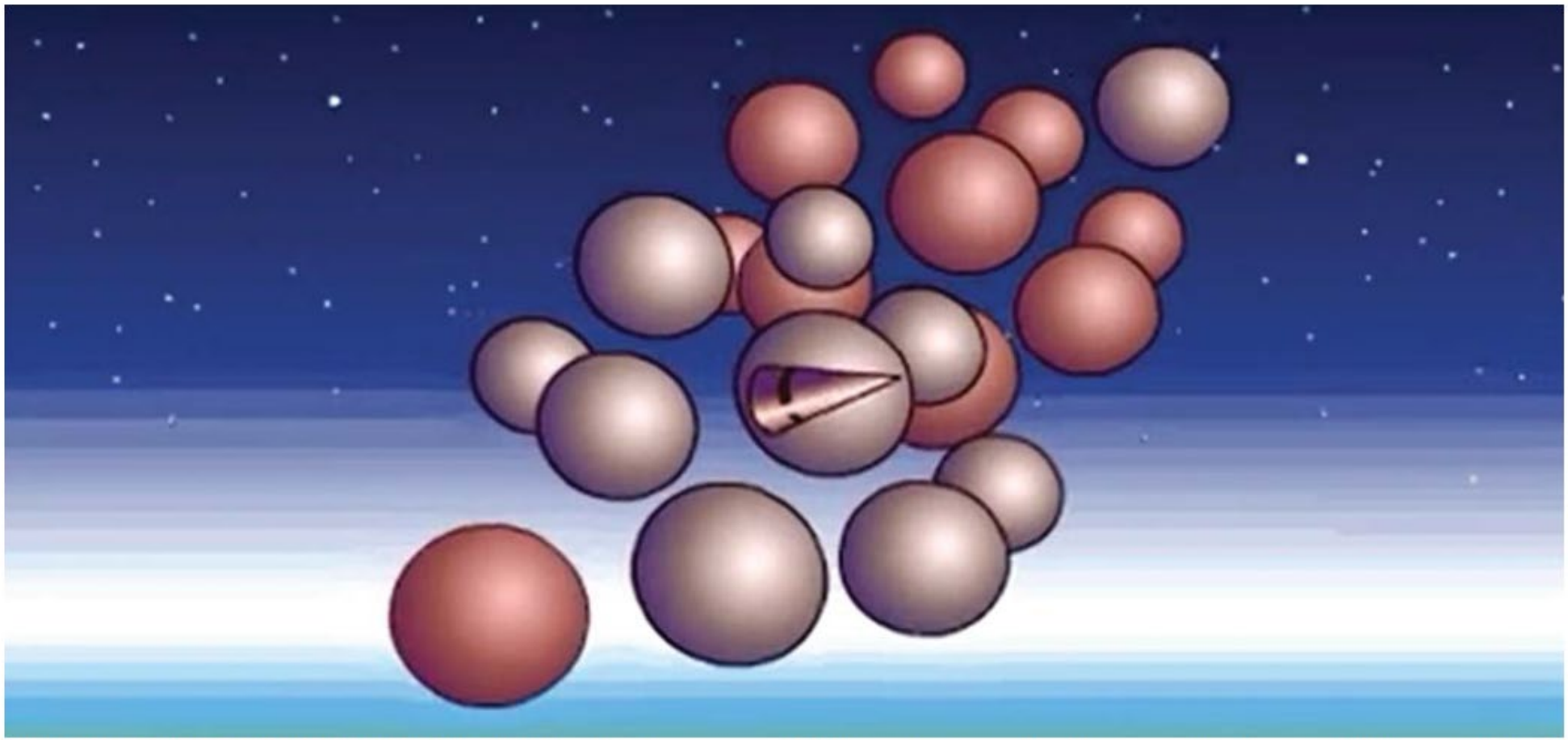


FIGURE 4. ONE POSSIBLE COUNTERMEASURE to the interception of ballistic-missile warheads in space. An aluminized balloon is inflated around a warhead to make it indistinguishable to radar from accompanying decoy balloons. Small, battery-powered heat sources introduced into the decoys make them indistinguishable to IR sensors. (Image from the Union of Concerned Scientists video *Missile Defense Countermeasures*, 2011; see also ref. 16.)

DOT&E 2008 Annual Report on GMD System Evaluation

The January, 2008, DOT&E Annual Report stated:

- Flight testing of the GMD system "is not sufficient to provide a high level of statistical confidence in its limited capabilities."
- "The addition of limited operational realism to BMDS testing against strategic threats has uncovered unanticipated deficiencies that will require additional development and testing."

DOT&E
Office of the Director for Operational Testing & Evaluation

March 2009 Report on the Bush ABM Program by the Government Accountability Office

MDA spent $56 billion researching and deploying elements of the ground-based midcourse defense (GMD) system from 2002–2009.

MDA failed to achieve *any* of its 6 testing objectives for 2008. Two planned GMD tests were not carried out.

Nevertheless, system elements, including 24 modified GMD interceptors, were deployed before being fully tested.

The GAO recommended that MDA —

- Test its GMD interceptor against a complex scene with countermeasures.
- Ensure that items are not manufactured for fielding before their performance has been validated through testing.

[ACA source]

Current Status of the GMD System

- The current GMD system:
  - —44 interceptors have been deployed initially in silos. Requested to increase to 64.
  - —Most are in Alaska, a few are in California
- Test results:

  11 hits in 19 scripted, simplified tests since 1999 (several launch failures— called “no tests” — are not counted)
  - The launch time and trajectory of the “attacking missile” were known and always the same, closing velocities were slow, no countermeasures were allowed
- Current Capability of the GMD system:
  - Single shot kill probability: 56%
  - Four interceptor kill probability 97%

Projected cost through FY2019: $41 Billion (source GAO, projection in 2013)

GMD Test Record (from MDA)

http://www.mda.mil/global/documents/pdf/testrecord.pdf

Date	Test Name	Hit
Ground-Based Interceptor (GBI)		
2-Oct-99	IFT-3	✓
19-Jan-00	IFT-4	x
8-Jul-00	IFT-5	x
14-Jul-01	IFT-6	✓
3-Dec-01	IFT-7	✓
15-Mar-02	IFT-8	✓
14-Oct-02	IFT-9	✓

Date	Test Name	Hit
Ground-Based Interceptor (GBI)		
11-Dec-02	IFT-10	x
15-Dec-04	IFT-13c*	x
14-Feb-05	IFT-14	x
1-Sep-06	FTG-02*	✓
25-May-07	FTG-03	N/A
28-Sep-07	FTG-03a	✓
5-Dec-08	FTG-05	✓

Date	Test Name	Hit
Ground-Based Interceptor (GBI)		
31-Jan-10	FTG-06	x
15-Dec-10	FTG-06a	x
05-Jul-13	FTG-07	x
22-Jun-14	FTG-06b	✓
30-May-17	FTG-15	✓

Additional successful test: 3-25-2019

- 10 successful intercepts in 18 attempts since 1999
- Causes of Failures:
  - IFT-4 – Kill vehicle's infrared sensor cooling malfunctioned
  - IFT-5 – Kill vehicle and booster did not separate
  - IFT-10 – Kill vehicle and booster did not separate
  - IFT-13c* – Interceptor failed to launch due to problematic software configuration
  - IFT-14 – Interceptor failed to launch after a silo support arm did not retract, triggering an automatic abort
  - FTG-06 – Kill vehicle and system sensor performance issues
  - FTG-06a – Kill vehicle guidance error in final seconds of flight
  - FTG-07 - Kill vehicle and booster did not separate
- FTG-03 is characterized as a "no-test" – Target malfunctioned after launch, interceptor was not launched

Physics 280: Session 24

Plan for This Session

Questions

News

Module 7: Efforts to Defend Against Nuclear Attacks

Next Week: Nuclear arms control

iClicker Question

Even though the tests have been scripted and have not included realistic decoys or other simple countermeasures, the ground-based midcourse defense (GMD) system has achieved what success rate?

A. 0%

B. 10%

C. 50%

D. 80%

E. 90%

iClicker Answer

Even though the tests have been scripted and have not included realistic decoys or other simple countermeasures, the ground-based midcourse defense (GMD) system has achieved what success rate?

A. 0%

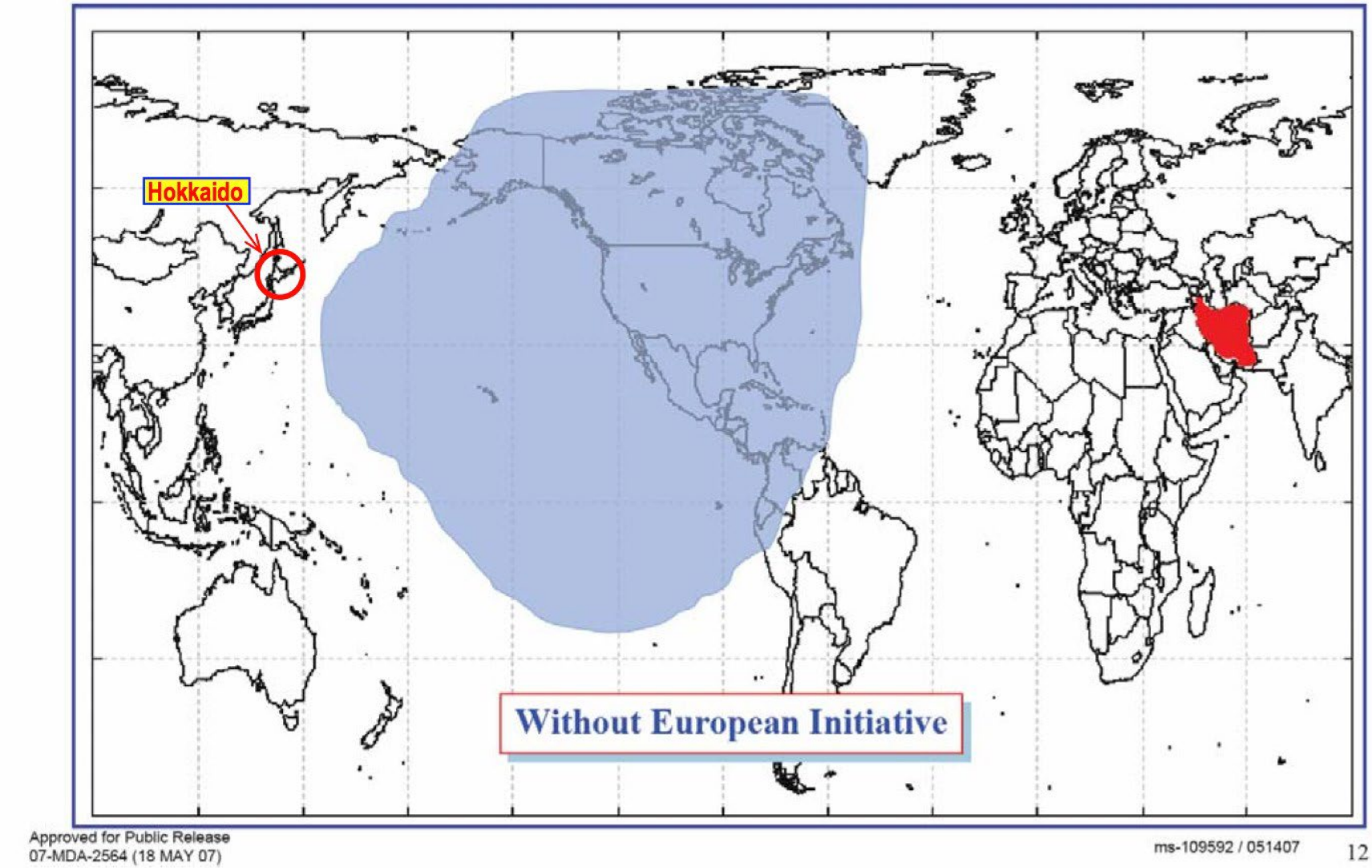
B. 10%

C. 50%

D. 80%

E. 90%

Claimed Theoretical Effectiveness of U.S. GMD Against Iranian Ballistic Missiles

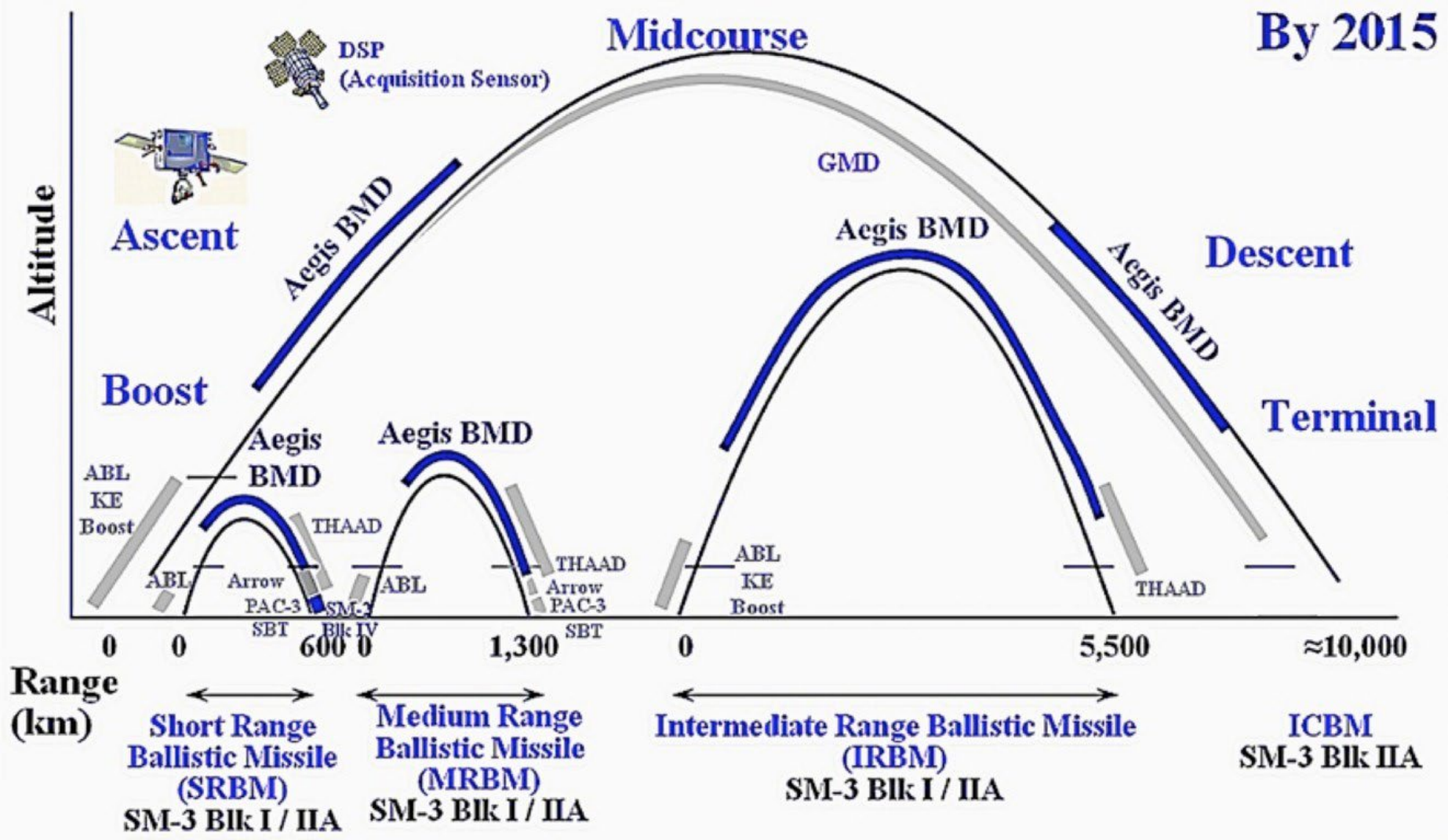


Module 7: Efforts to Defend Against Attacks

European Missile Defense System

(as adapted by the Obama Administration giving up missile defense launch sites in Eastern Europe in favor of sea launched missiles)

Obama Administration: Phased Adaptive Approach to EMD



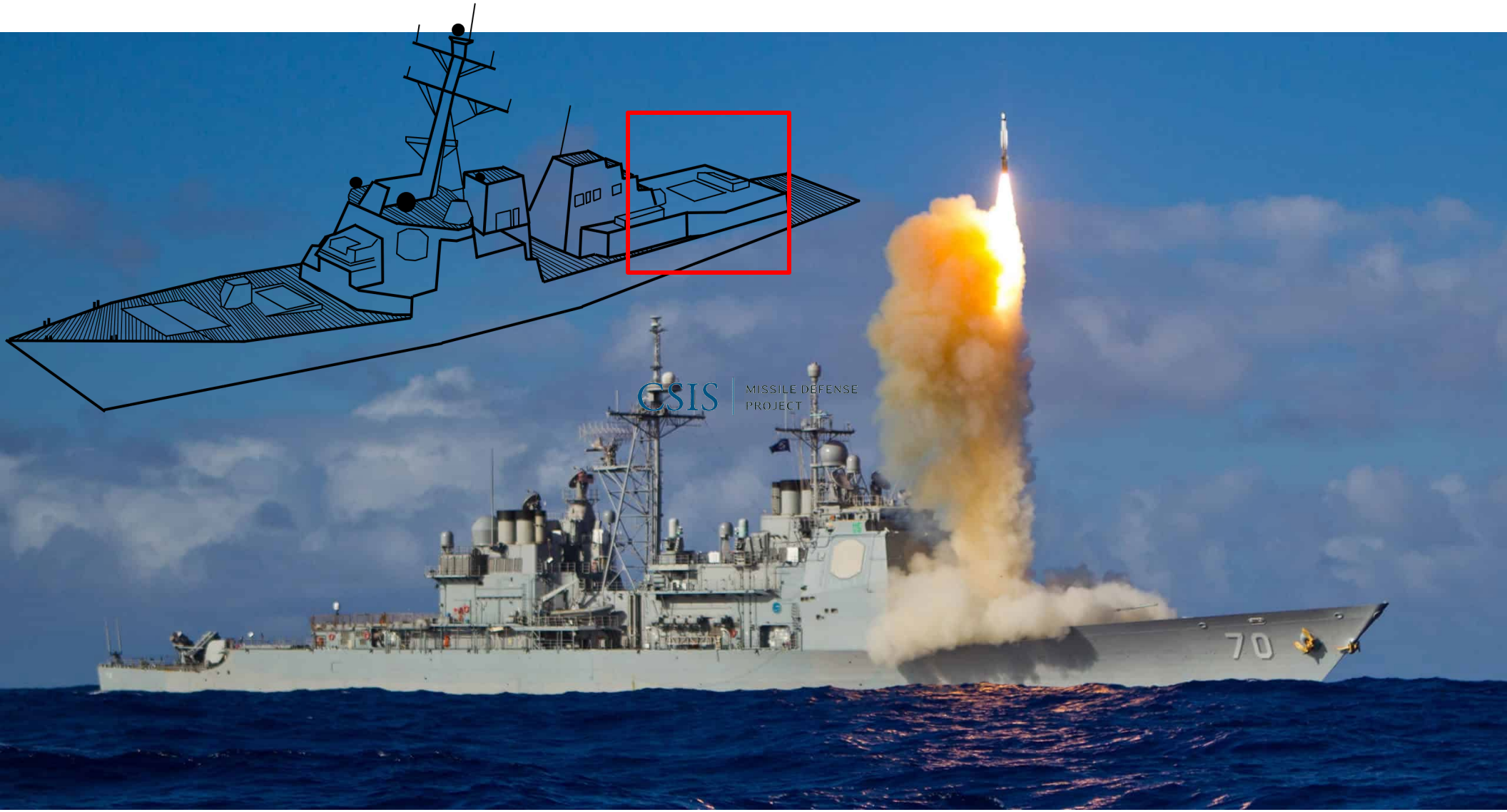
Phased Adaptive Approach to EMD

The European Phased Adaptive Approach (PAA) was presented as a more flexible alternative to Bush's proposed European-based GMD system.

It uses SM-3 interceptors, which are roughly 10X smaller than the 20-ton interceptors of the proposed European-based GMD system and will evolve continuously with increasing capability.

A system using these smaller and lighter interceptors would be incrementally tailored to the perceived threat over the coming decade.

Phased Adaptive Approach to EMD



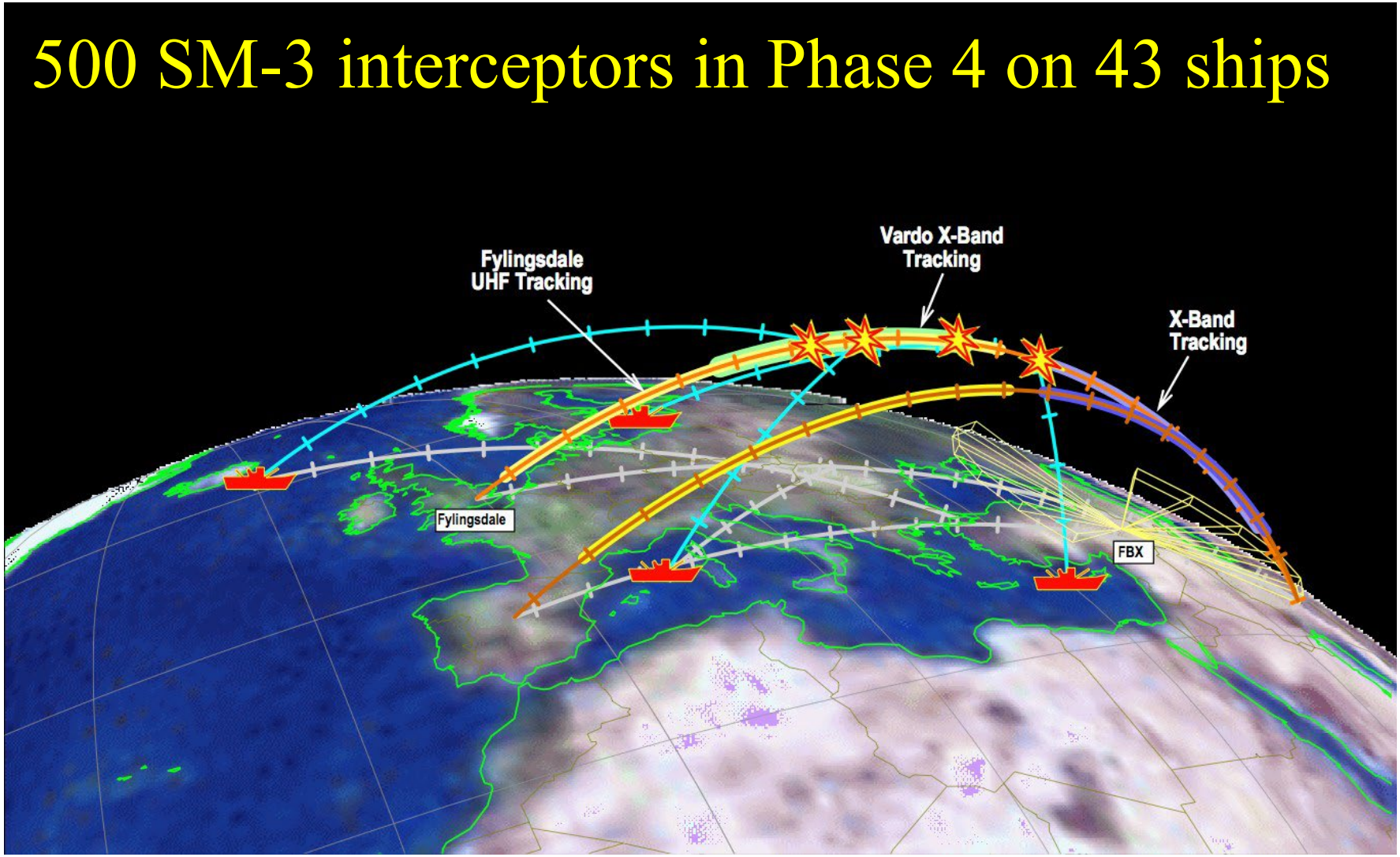
https://missilethreat.csis.org/system/aegis/

Phased Adaptive Approach to EMD

U.S. Navy photo

A Standard Missile-3 is launched from the guided-missile destroyer USS *Paul Hamilton* in the Pacific Ocean on November 1, 2008.

Phased Adaptive Approach to EMD



Phased Adaptive Approach to EMD

- The PAA plan called for more than 500 SM-3 interceptors to be based on 43 ships by 2021.
- The PAA plan called for SM-3s with increasing capability to be stationed in Romania (in 2015) and in Poland (in 2021).
- The plan is to deploy SM-3 IIB interceptors by 2021. They are advertised as having some capability against longer-range missiles.
- In a study presented on January 29th , 2013 the GAO concludes that the final phase of PAA in its present configuration may be ineffective in defending the US from ICBMs from Iran. The Obama administration canceled the final phase IV of PAA.

Navy/MDA Plans for Deployment of BMD-Capable Aegis Ships and SM-3 Interceptors

Table 1. Numbers of BMD-Capable Aegis Ships and SM-3 Missiles

	FY15	FY16	FY17 (req.)	FY18 (proj.)	FY19 (proj.)	FY20 proj.)	FY21 (proj.)
BMD-capable Aegis ships							
3.6 version	22	19	17	14	11	7	6
4.X version	8	10	10	12	15	19	20
5.0 CU version	3	4	7	11	9	4	2
5.1 version	0	0	0	0	5	13	21
Total	**33**	**33**	**34**	**37**	**40**	**43**	**49**
Aegis Ashore sites	**0**	**1**	**1**	**1**	**2**	**2**	**2**
SM-3 missile cumulative deliveries / inventory (including RDT&E purchases)							
Block I/IA	150/119	150/101	150/85	150/60	150/49	150/37	150/35
Block IB	59/49	107/92	146/128	185/166	221/202	256/236	295/271
Block IIA	0/0	0/0	0/0	4/2	15/11	17/12	20/14
Total	**209/168**	**257193**	**296/213**	**339/228**	**386/262**	**423/285**	**465/320**

Source: For numbers of BMD-capable Aegis ships and Aegis Ashore sites: Table prepared by CRS based on MDA briefing slide provided to CRS on March 25, 2016. For SM-3 cumulative deliveries/inventory: FY2017 MDA budget submission.

Current MDA Funding Request and Projections for Aegis BMD Program

Table 2. MDA Funding for Aegis BMD Efforts, FY2016-FY2021

(In millions of dollars, rounded to nearest tenth; totals may not add due to rounding)

	FY16	FY17 (req.)	FY18 (proj.)	FY19 (proj.)	FY20 (proj.)	FY21 (proj.)
Procurement funding						
Aegis BMD (line 24)	566.7	463.8	727.3	962.4	1,079.9	1,221.1
Aegis Ashore Phase III (line 28)	30.6	57.5	69.9	0	0	0
Aegis BMD hardware and software (line 30)	145.3	50.1	139.5	93.2	122.0	86.0
SUBTOTAL Procurement	**742.6**	**571.4**	**936.7**	**1,055.6**	**1,201.9**	**1,307.1**
Aegis BMD (PE 0603892C) (line 79)	830.6	959.1	841.7	700.6	592.9	528.7
Aegis BMD Test (PE 0604878C) (line 107)	78.5	95.0	127.7	91.5	88.2	98.5
Land-based SM-3 (PE 0604880C) (line 109)	35.0	43.3	29.0	19.3	21.3	21.6
Aegis SM-3 IIA (PE 0604881C) (line 110)	172.6	106.0	0	0	0	0
SUBTOTAL RDT&E	**1,116.7**	**1,203.4**	**998.4**	**811.4**	**702.4**	**648.8**
TOTAL	**1,859.3**	**1,774.8**	**1,935.1**	**1,867.0**	**1,904.3**	**1,955.9**

Source: Table prepared by CRS based on FY2017 MDA budget submission.

Aegis/SM-3 in Tests and Combat

Congressional Research Service
Informing the legislative debate since 1914

Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress

Updated January 12, 2026

[CRS Source]

Table A-1. Reported Aegis BMD Flight Tests From January 2002 to the Present

Date	Country	Name of flight test of exercise	Ballistic Missile Target	Reported as successful?
Exo-atmospheric (using SM-3 missile)				
1/25/02	US	FM-2	Unitary short-range (TTV)	Yes
6/13/02	US	FM-3	Unitary short-range (TTV)	Yes
11/21/02	US	FM-4	Unitary short-range (TTV)	Yes
6/18/03	US	FM-5	Unitary short-range (TTV)	**No**
12/11/03	US	FM-6	Unitary short-range (TTV)	Yes
2/24/05	US	FTM 04-1 (FM-7)	Unitary short-range (TTV)	Yes
11/17/05	US	FTM 04-2 (FM-8)	Separating short-range (MRT)	Yes
6/22/06	US	FTM 10	Separating short-range (TTV)	Yes
12/7/06	US	FTM 11	Unitary short-range (TTV)	**No**
4/26/07	US	FTM 11 Event 4	Unitary short-range (ARAV-A)	Yes
6/22/07	US	FTM 12	Separating short-range (MRT)	Yes
8/31/07	US	FTM-11a	Classified	Yes
11/6/07	US	FTM 13	Unitary short-range (ARAV-A)	Yes
			Unitary short-range (ARAV-A)	Yes
12/17/07	Japan	JFTM-1	Separating short-range (MRT)	Yes
11/1/08	US	Pacific Blitz	Unitary short-range (ARAV-A)	Yes
			Unitary short-range (ARAV-A)	**No**
11/19/08	Japan	JFTM-2	Separating short-range (MRT)	**No**
7/30/09	US	FTM-17	Unitary short-range (ARAV-A)	Yes
10/27/09	Japan	JFTM-3	Separating short-range (MRT)	Yes
10/28/10	Japan	JFTM-4	Separating short-range (MRT)	Yes
4/14/11	US	FTM-15	Separating intermediate range (LV-2)	Yes
9/1/11	US	FTM-16 E2	Separating short-range (ARAV-B)	**No**
5/9/12	US	FTM-16 E2a	Unitary short-range (ARAV-A)	Yes
6/26/12	US	FTM-18	Separating short-range (MRT)	Yes
10/25/12	US	FTI-01	Separating short-range (ARAV-B)	**No**
2/12/13	US	FTM-20	Separating medium-range (MRBM-T3)	Yes
5/15/13	US	FTM-19	Separating short-range (ARAV-C)	Yes
9/10/13	US	FTO-01	Separating medium-range (eMRBM-T1)	Yes
9/18/13	US	FTM-21	Separating short-range (ARAV-C++)	Yes
10/3/13	US	FTM-22	Separating medium-range (ARAV-TTO-E)	Yes
11/6/14	US	FTM-25	Separating short-range (ARAV-B)	Yes
6/25/15	US	FTO-02 E1	Separating medium-range (IRBM T1)	n/a[a]
10/4/15	US	FTO-02 E2	Separating medium-range (eMRBM)	n/a[b]
10/20/15	US	ASD-15 E2	Separating short-range (Terrier Orion)	Yes
11/1/15	US	FTO-02 E2a	Separating medium-range (eMRBM)	**No**
12/10/15	US (Aegis Ashore)	FTO02 E1a	Separating medium-range (IRBM T1)	Yes
2/3/17	US-Japan	SFTM-01	Separating medium-range (MRT)	Yes
6/21/17	US-Japan	SFTM-02	Medium-range target	**No**
10/15/17	US	FS17	Medium-range target	Yes
1/31/18	US (Aegis Ashore)	FTM-29	Intermediate-range target	**No**
9/11/18	Japan	JFTM-05	Simple separating target	Yes
10/26/18	US	FTM-45	Medium range target	Yes
12/10/18	US (Aegis Ashore)	FTI-03	Intermediate-range target	Yes
11/16/20	US	FTM-44	ICBM target	Yes
5/26 and 30/2021	US-Netherlands	ASD/FS21[c]	Non-separating MRBM target	Yes[c]
4/9/22[f]	US	FEM-01	Medium range target	Outcome not reported
8/9/22	US	Part of Pacific Dragon exercise	ARAV-B SRBM target	Yes
11/16/22[e]	US-Japan	JFTM-07	Medium-range T4-E target	Yes
11/18 or 19/22[e]	US-Japan	JFTM-07	Short-range target	Yes
10/25/23	US	Vigilant Wyvern/ FTM-48	Two short-range targets	Yes
2/8/24	US	FTX-23	Medium Range Ballistic Missile (MRBM) target	Yes
Endo-atmospheric (using SM-2 missile Block IV missile and [for MMW E1 and subsequent] SM-6 Dual I missile)				
5/24/06	US	Pacific Phoenix	Unitary short-range target (Lance)	Yes
6/5/08	US	FTM-14	Unitary short-range target (FMA)	Yes
3/26/09	US	Stellar Daggers	Unitary short-range target (Lance)	Yes
7/28/15	US	MMW E1	Unitary short-range target (Lance)	Yes
7/29/15	US	MMW E2	Unitary short-range target (Lance)	Yes
12/14/16	US	FTM-27	Unitary short-range target (Lance)	Yes
8/29/17	US	FTM-27 E2	Medium-range target (MRBM)	Yes
5/29/21	US	FTM-31	Medium-range target (MRBM)	**No**
7/24/21	US	FTM-33	Two SRBM targets	Yes and **unconfirmed**[d]
3/30/23	US	FTM-31 E1a	Medium-Range target (MRBM)	Yes (2-missile salvo)
3/28/24	US	Stellar Laelaps/ FTM-32	Advanced Medium Range Ballistic Missile (MRBM) target	Yes

[CRS Source]

These systems have seen use in the Israel-Iran conflict since early 2024

CRS Report:

“By the end of FY 2026, there will be 63 total BMD capable ships requiring maintenance support.”

BUSINESS INSIDER

DOW +0.57% NASDAQ +1.04% S&P 500 +0.78% OIL -2.21% AAPL -0.44% NVDA +2.05% MSFT +1.94% TSLA +2.74% AMZN

MILITARY & DEFENSE

US Navy warships shot down Iranian missiles with a weapon they've never used in combat before

By Jake Epstein

The guided-missile destroyer USS Fitzgerald launched a Standard Missile-3 during a joint ballistic-missile defense exercise in the Pacific Ocean in 2012. US Navy photo

March 2026… still seeing use and having some success, this time in Turkish airspace

BUSINESS INSIDER Follow

US Navy destroyers are firing top interceptors to bring down Iranian missiles flying into NATO airspace

Jake Epstein
Fri, March 13, 2026 at 10:22 AM CDT
3 min read

Add Yahoo on Google 467

Aegis Ashore

- Aegis Ashore is the land-based component of the Aegis BMD system. The deckhouse and launchers – designed to be nearly identical to the version installed aboard U.S. Navy destroyers and cruisers – are equipped with the Aegis BMD weapon system and the SM-3.

2018	Planned deployment of Aegis SM-3 Interceptors in Poland
15 December 2023	Naval Support Facility Redzikowo transitioned from Missile Defense Agency to US Navy
10 July 2024	Official transfer to NATO announced; site declared operational
13 November 2024	**Base officially opened**
21 November 2024	Russia warned the base is a “priority target for potential neutralization”

Recent Funding of Missile Defense Agency

Missile defense, budget —

FY10, $7.9B. (before 9/11 about ~$3.5B/year)

FY11, $8.5B.

FY12, $8.4B.

FY13, $8.3B

FY14, $7.6B

FY15, $7.8B

FY16, $8.3B

FY17, $8.1B

FY18 – FY23, $8.9B – $9.9B

FY 26, $10.2B + $3B supplemental

Table 1. FY2026 MDA Procurement and R&D Funding Line Items for Aegis BMD Efforts

(In millions of dollars, rounded to nearest tenth; totals may not add due to rounding)

	FY26 Request
Procurement line items	
Aegis BMD (line 46)	0
(SM-3 Block IB missile quantity)	*(0)*
SM-3 Block IIA (line 49)	444.8
(SM-3 Block IIA missile quantity)	*(12)*
Aegis Ashore Phase III (line 53)	0
Aegis BMD hardware and software (line 58)	17.2
SUBTOTAL Procurement line items above	**462.0**
Research and development (RDT&E) line items	
Aegis BMD (PE 0603892C) (line 90)	994.4
Aegis BMD Test (PE 0604878C) (line 125)	153.6
Land-based SM-3 (PE 0604880C) (line 127)	24.6
SUBTOTAL RDT&E line items above	**1,172.6**
TOTAL Procurement and RDT&E line items above	**1,634.6**

26p280 Defenses, p. 117

Total MDA spending 1985 to 2022: ~ 235 B

Possible Russian Concerns About the Phased Adaptive Approach to EMD

- The main concern of cautious Russian military planners would be the capability of missile defense interceptors to simply reach, or “engage”, Russian strategic warheads, rather than whether any particular engagement results in an actual interception, or “kill.”
- Interceptors with a kinematic capability to reach Russian ICBM warheads would be sufficient to raise concerns in Russian national security circles — regardless of the possibility that Russian decoys and other countermeasures might defeat the system in actual engagements.
- Hence even a missile defense system that could be rendered ineffective could still create serious concerns for cautious Russian military planners.

Possible Russian Concerns About the Phased Adaptive Approach to EMD

- The last two phases of the PAA – when the higher burnout velocity "Block II" SM-3 interceptors go on-line – could create legitimate concerns for Russian military analysts.
- These interceptors could in principle be used to create an integrated continental U.S. missile defense system that could engage Russian ICBM warheads, either in combination with, or independent of, the Ground-Based Midcourse (GMD) system now deployed in Alaska and California.
- This fact introduces the possibility that Russian ICBMs could face many hundreds, or eventually thousands, of SM-3 interceptors, in addition to the 30 or so GMD interceptors already deployed.
- Such large numbers of interceptors, which might in reality have little capability in combat, could be expected to create fears among Russian political and military leaders that the PAA could cause some attrition of Russian warheads.

FKL,Dep.of Physics

Possible Russian Concerns About the Phased Adaptive Approach to EMD

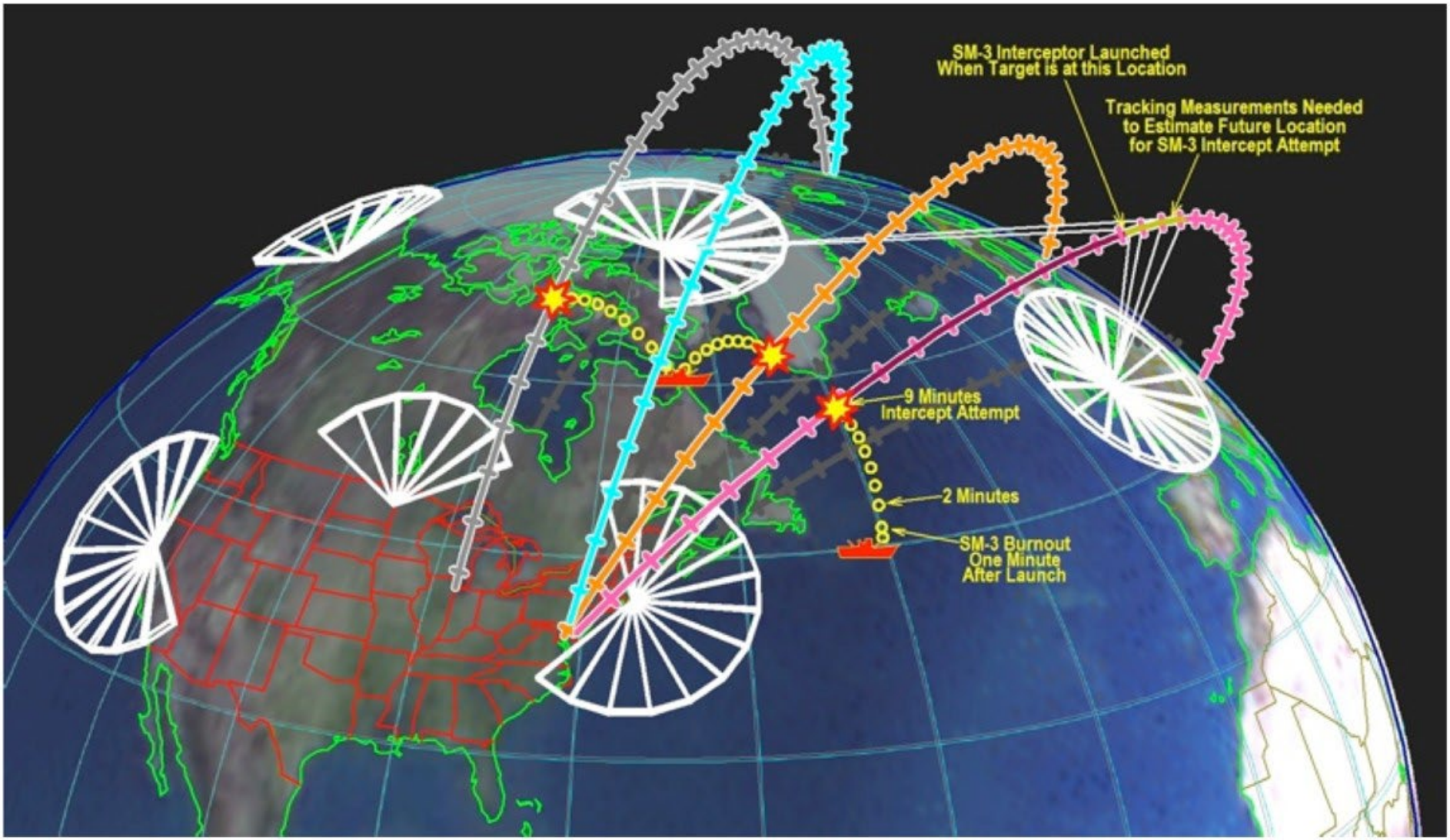
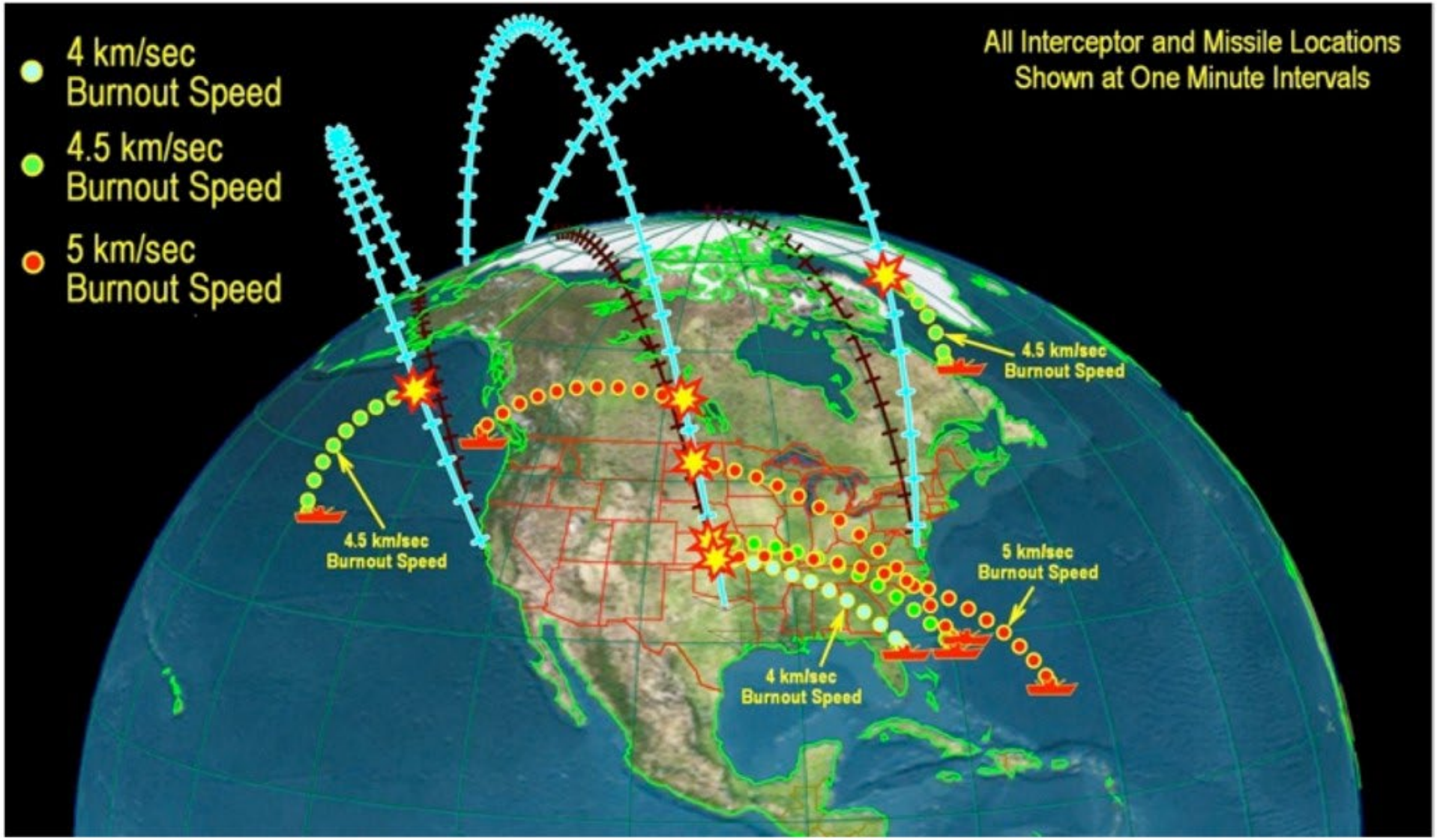


Figure 3: Northwest Atlantic-based SM3 Block II interceptors (with a conservative assumed burnout speed of 4 km/sec) engaging Russian ICBM warheads: each tick on the trajectories marks one minute.

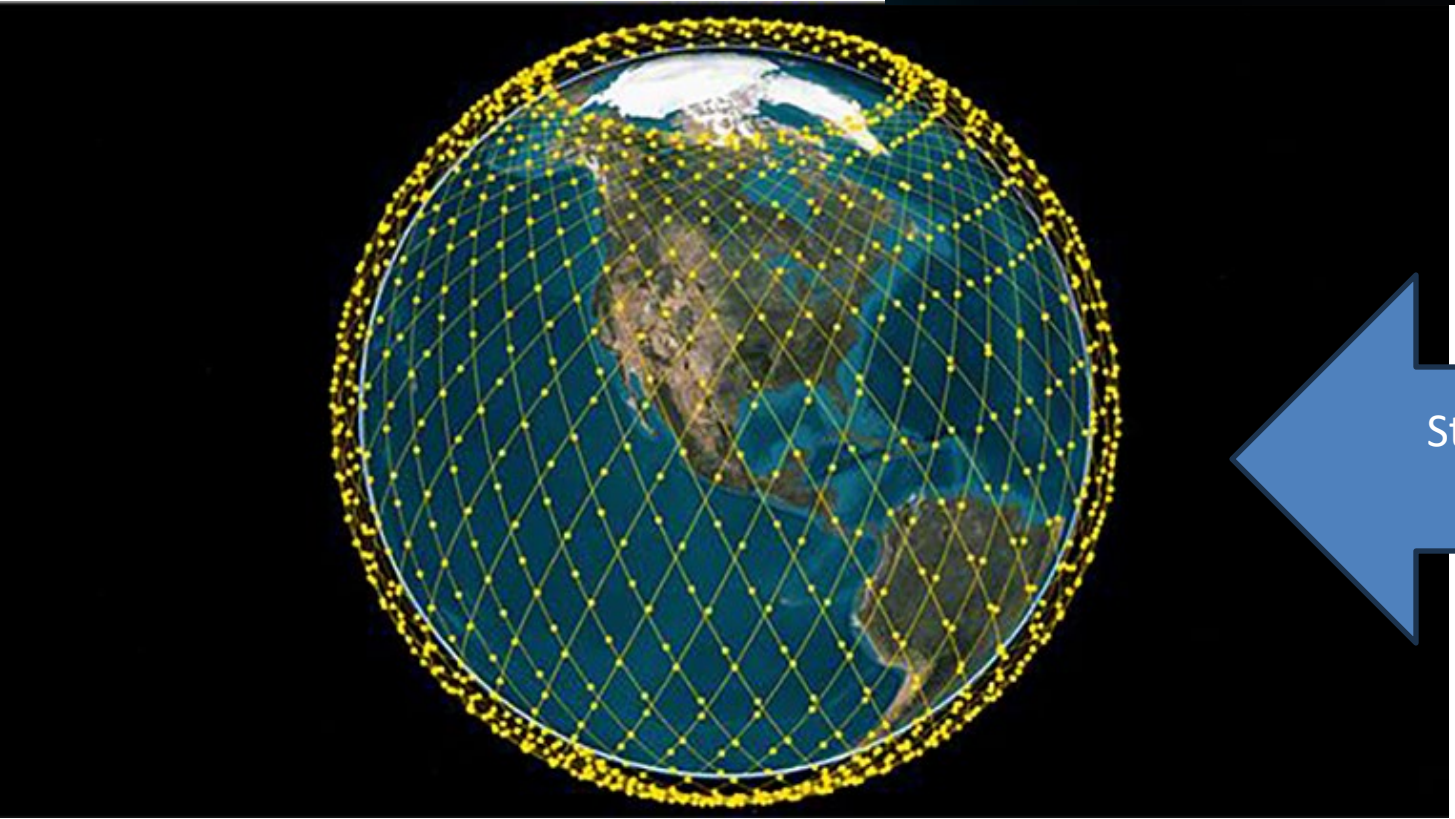
Possible Russian Concerns About the Phased Adaptive Approach to EMD



Defenses Against Long-Range Nuclear-Armed Ballistic Missiles

GOLDEN DOME

Stupid. Wrong.
Image made by Idiot or AI.



Still stupid, but image
not made by idiot.

GOLDEN DOME

By the authority vested in me as President by the Constitution and the laws of the United States of America, including my authority as Commander in Chief of the Armed Forces of the United States, it is hereby ordered:

Section 1. *Purpose*. The threat of attack by ballistic, hypersonic, and cruise missiles, and other advanced aerial attacks, remains the most catastrophic threat facing the United States.

FULL TEXT LINK

GOLDEN DOME – Executive Order

Sec. 2. *Policy*. To further the goal of peace through strength, it is the policy of the United States that:

(a) The United States will provide for the common defense of its citizens and the Nation by deploying and maintaining a next-generation missile defense shield;

(b) The United States will deter—and defend its citizens and critical infrastructure against—any foreign aerial attack on the Homeland; and

(c) The United States will guarantee its secure second-strike capability.

GOLDEN DOME – Executive Order

Sec. 3. ***Implementation*. Within 60 days of the date of this order, the Secretary of Defense shall:**

(a) Submit to the President a reference architecture, capabilities-based requirements, and an implementation plan for the next-generation missile defense shield. The architecture shall include, at a minimum, plans for:

(i) Defense of the United States against ballistic, hypersonic, advanced cruise missiles, and other next-generation aerial attacks from peer, near-peer, and rogue adversaries;

(ii) Acceleration of the deployment of the Hypersonic and Ballistic Tracking Space Sensor layer;

(iii) Development and deployment of proliferated space-based interceptors capable of boost-phase intercept;

(iv) Deployment of underlayer and terminal-phase intercept capabilities postured to defeat a countervalue attack;

(v) Development and deployment of a custody layer of the Proliferated Warfighter Space Architecture;

(vi) Development and deployment of capabilities to defeat missile attacks prior to launch and in the boost phase;

(vii) Development and deployment of a secure supply chain for all components with next-generation security and resilience features; and

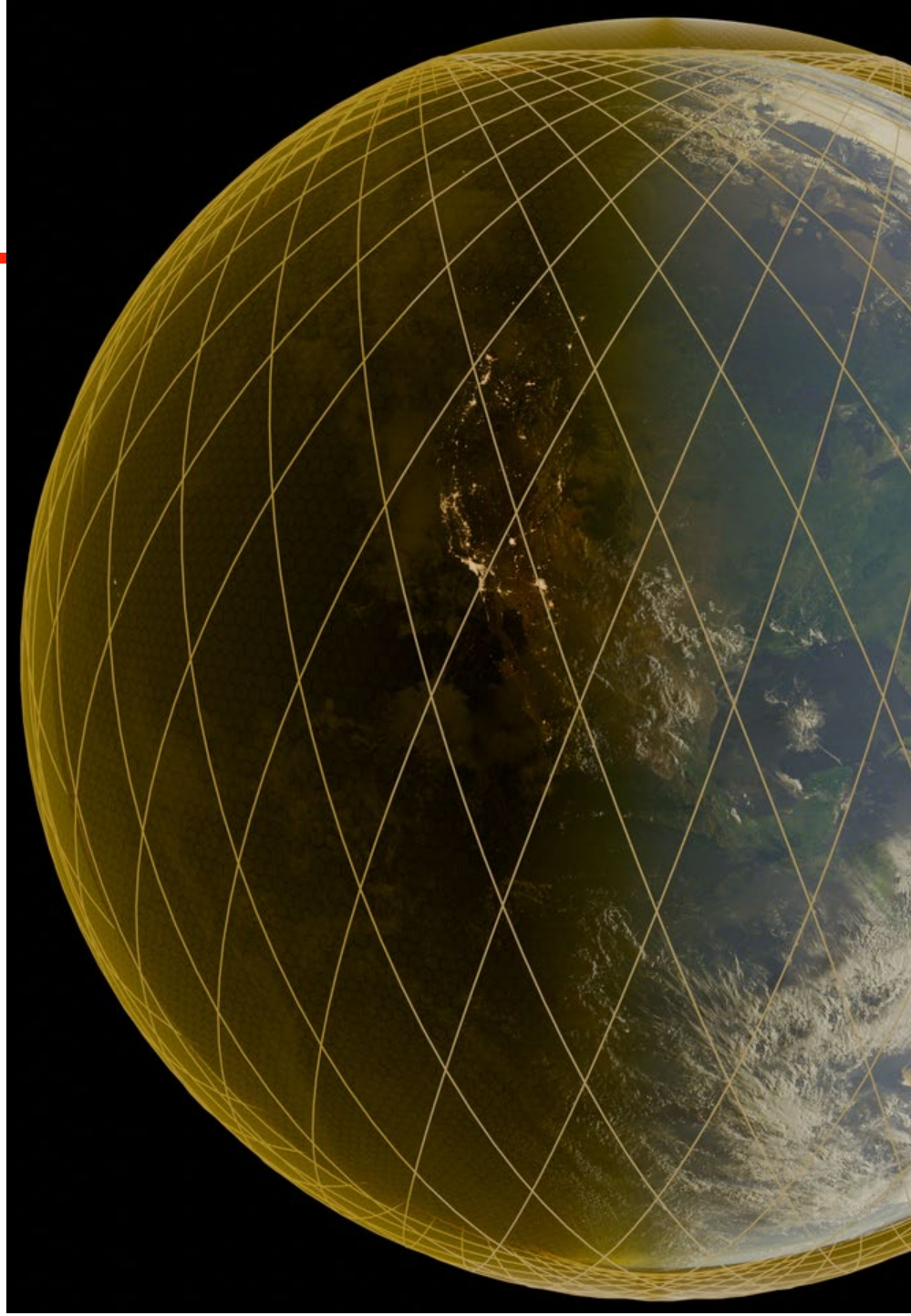
(viii) Development and deployment of non-kinetic capabilities to augment the kinetic defeat of ballistic, hypersonic, advanced cruise missiles, and other next-generation aerial attacks;

GOLDEN DOME

Proposed satellite constellation to detect and destroy ballistic missiles in flight
Cost grows with number of units and estimates continue

Heavily criticized:

- Cost
- Feasibility
- Short lifespan in LEO
- Drives arms race
  (e.g. anti-satellite weapons and weaponization of space)



GOLDEN DOME COST

COST ESTIMATES:

- $175 Billion – White House
- $831 Billion – CBO [link]
- $3+ TRILLION – American Enterprise Institute [link]

Why such variation?

- No real design exists yet
- Launch costs may go down, but also scales with number of interceptors
- Also, construction costs scale with number of interceptors.

"Over the years, analysts have studied the cost of various space-based interceptor, or SBI, options. CBO used a report of its own published in 2004 and a National Research Council study from 2012 as a baseline for its memo to Senate lawmakers. Those studies included cost estimates ranging from $264 billion for a constellation of 1,300 interceptors to $831 billion for 2,000." [Defense News]

GOLDEN DOME – Executive Order

Sec. 4. Allied and Theater Missile Defense Review. The United States continues to cooperate on missile defense with its allies and partners to aid in the defense of ally populations and troops and of forward-deployed United States troops. Following the submission to the President of the next-generation missile defense reference architecture under section 3(a) of this order, the Secretary of Defense shall direct a review of theater missile defense posture and initiatives to identify ways in which the United States and its allies and partners can:

(a) Increase bilateral and multilateral cooperation on missile defense technology development, capabilities, and operations;

(b) Improve theater missile defenses of forward-deployed United States troops and allied territories, troops, and populations; and

(c) Increase and accelerate the provision of United States missile defense capabilities to allies and partners.

GOLDEN DOME - TEST

Trump EO demands a test within 3 years.

Pentagon has scheduled at test called FTI-X for November 2028.

From CNN, a memo signed by Sec Def Hegseth for Maj. Gen Guetlein (USSF) requesting an architecture and implementation plan:

> The memo also states that Golden Dome will be exempt from traditional Pentagon oversight processes for the military's most expensive weapons programs, because this "complex, highly technical effort requires a non-traditional acquisition approach and full support from all DoD components from inception."

Summary and Conclusions

Status of the U.S. Missile Defense Program

The technical performance of the current GMD ABM system is unclear due to insufficient testing under realistic conditions.

As of 2026, the Aegis (ship-based) system is now seeing some use (success?) in the current US-Israel-Iran conflict.

The Phased Adaptive Approach for European Missile Defense may not be effective in defending against ICBMs and requires review. The Obama administration decided to cancel Phase IV.

Difficult to find solution that will create ABM effective against threats from the DPRK and from Iran and at the same time be not seen as threatening the nuclear deterrent of Russia and China.

FKL,Dep.of Physics

Status of the Golden Dome

An executive order cannot magically materialize a trillion dollar defense system. Nor can a trillion dollars guarantee a system works.

Instead, the E.O. uses the President's bully pulpit, his informal power to shape public opinion and pressure Congress from his visibility as head of state, as well as his formal powers to direct the Sec Def and other officials to do exploratory work. The point is to rally political support in Congress/military/defense contractors and influence budget priorities, and set the agenda for future legislative action."

Funding approved by Congress is currently at the fews tens of billions level for 2026 and 2027. [Federal News Network April 2026]

Some Missile Defense Questions

The material presented in this module shows that the political actions in this area by the U.S. and Russia are not consistent with the scientific-technical realities. What is the reason for this failure?

- Is it insufficient scientific-technical advice reaching the highest levels of governments?
- Is it deliberate disregard of such advice by national leaders and the inherent conservatism of governments in their inability to change past erroneous decisions?
- Is it the skillful exploitation of valid public concerns for security by groups and institutions benefitting from large expenditure on missile defense?

GOLDEN DOME

Policy Punchline: An executive order cannot magically materialize a trillion dollar defense system.

Instead, it uses the President's bully pulpit, his informal power from his visibility as head of state to shape public opinion and pressure Congress, as well as his formal powers to direct the Sec Def and other officials to do exploratory work. The point is to rally political support in Congress/military/defense contractors and influence budget priorities- i.e. to set the agenda for future legislative action.

Funding approved by Congress is currently at the fews tens of billions level for 2026 and 2027. [Federal News Network April 2026]