

“Golden Dome” A Scientific and Technical Assessment

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The Context

Background

Even a single nuclear weapon exploded over a city would have horrific consequences—immediately killing millions of people and injuring millions more.

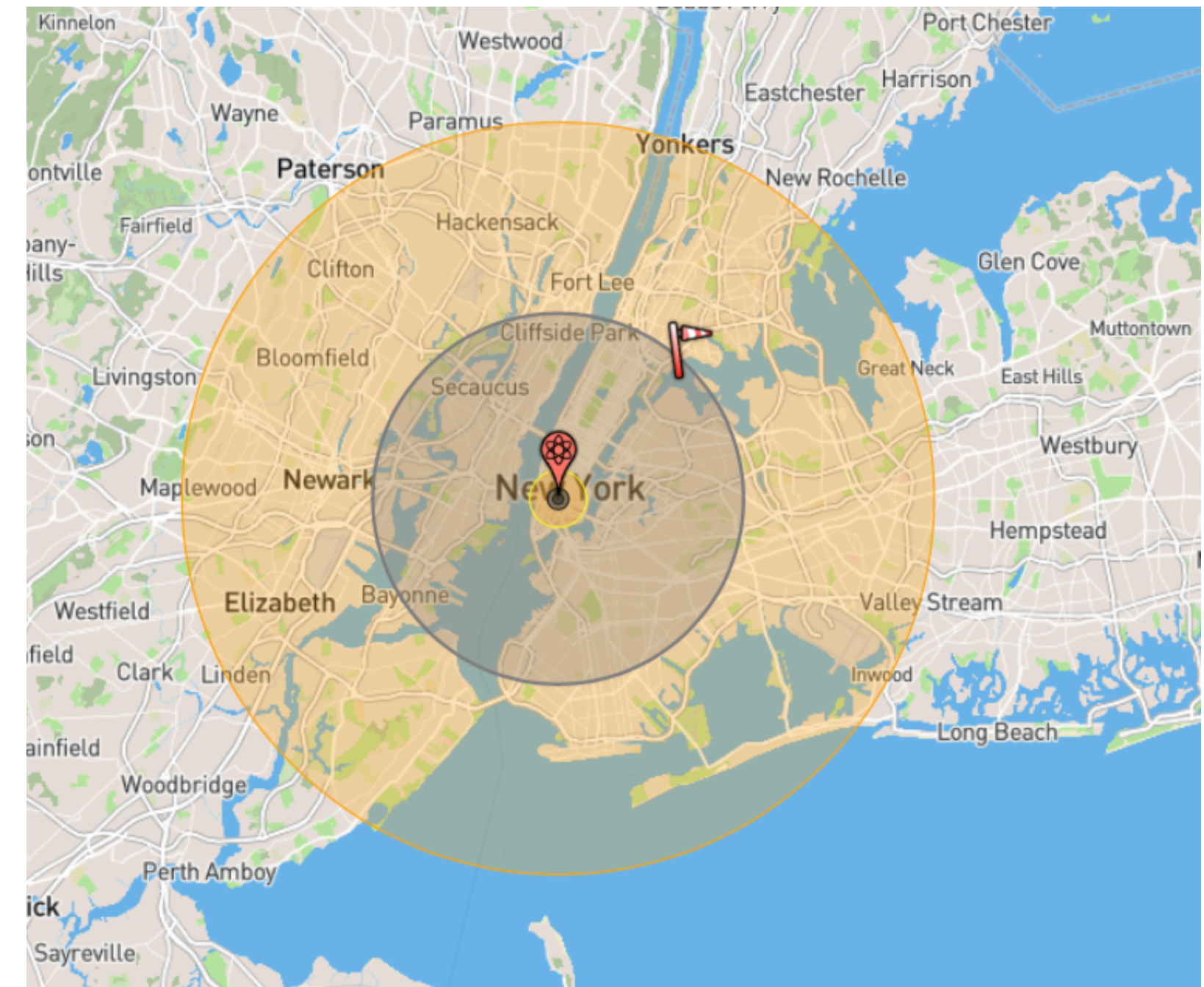
Nuclear-armed intercontinental-range ballistic missiles (ICBMs) make us vulnerable to such an attack suddenly and from far away.

A natural reaction is to seek to intercept these missiles or their warheads, to prevent their them from striking us.

During the past 70 years, the United States has spent over \$500 billion on ballistic missile defense, mostly on systems intended to intercept nuclear-armed ICBMs that might be launched against the United States.

But, as the 2025 APS Report says: “The ability of any of these systems to intercept even a single warhead during a nuclear attack has not been demonstrated.”

Immediate effects of a 5 Mt airburst over New York
Fatalities: 3.2 million Injuries: 4.6 million



Additional fatalities would be caused by firestorms, fallout radiation, injuries, the lack of food and shelter, the failure of medical, social, public health services.

The dream of a technological solution to the threat of nuclear-armed long-range ballistic missiles

Nike-Zeus (1950s)

Nike-X (1960s)

Sentinel (1966–68)

Safeguard (1969–76)*

Terminal Phase



Star Wars (1983–1990)

Global Protection Against Accidental Launches (1991–1997)*

Midcourse Phase



National Missile Defense (NMD) Research (1997–2001)*

Ground-based Midcourse Defense (GMD) (2001–2020)

*Limited by the U.S.-Soviet ABM Treaty

Most of these systems were never fully deployed.

None were shown to be effective in real-world battle situations.

The myth of Patriot's success during the First Gulf War

- Reports that the Patriot system was effective were based on deliberately false claims or inexcusable ignorance.
- President H. W. Bush claimed that of 45 attempts to intercept Scud missiles using the Patriot system, 43 were successful. He said “this is proof positive that missile defense works”.
- In fact, there was no clear evidence that even a single Scud missile was successfully intercepted and there were many clear examples of failures.

The “Golden Dome” Proposal

President Trump's "Golden Dome" Executive Order



Credit: Scientific American

- Ground-, sea-, and space-based defenses to protect the United States and its allies and their armed forces against attack by aircraft, ballistic missiles, hypersonic glide vehicles, cruise missiles, and drones fired at any time from anywhere by any adversary, including peer and near-peer adversaries, and
- Theater missile defenses to protect forward-deployed United States troops and allied territories, troops, and populations.

What is Israel's "Iron Dome"?

- Iron Dome was developed to defend against artillery and mortar shells and very short-range, highly inaccurate home-made rockets, primarily launched by Hamas and Hezbollah.
- These rockets travel up to 70 km at speeds of about 1 km/s and have 10 kg warheads.
- Iron Dome engages only about 50% of the rockets like these that are launched against Israeli targets and is able to intercept about 80%–90% of the rockets it engages.
- As a result, Iron Dome is only able to intercept about 40% of rockets like these that are launched against the area it is defending.
- "Iron Dome" is unable to defend against longer-range missiles.

Israeli and U.S. missile defenses would be unable to defend Israel against nuclear-armed ICBMs

- The medium-range missiles Iran used to retaliate against Israel travel $\sim 1,000\text{--}2,000$ km at speeds ~ 3 km/s and carry warheads with an explosive power of ~ 500 kg of TNT.
- Together, Israel and the US were able to intercept about 60%–80% of Iran's medium-range missiles.
- In contrast, a nuclear-armed ICBM can travel 10,000–16,000 km at 7 km/s and carry a warhead with an explosive power millions of times greater.
- Israeli and U.S. missile defenses would fail catastrophically if used to try to intercept nuclear-armed ICBMs.

Even a limited nuclear attack on Israel would have catastrophic consequences

- Even a single “small” 10-kt nuclear weapon exploded at ground level would contaminate 8,000 km² of land, more than 4 times the total area of all of Israel’s cities and towns.
- Nine or ten 10 kt weapons—corresponding to the number of Iranian missiles that penetrated the combined Israeli and U.S. defenses during both the April and October 2024 Iranian counterattacks—could kill or injure half the Israeli population and render the country uninhabitable for years, if not decades.
- Systems like those used by Israel, which has a populated area about the size of Delaware, i.e., 1,400 times smaller than the U.S., would be completely unable to defend the United States.

The time windows for interception—and their challenges

Boost phase (~ 3 min)

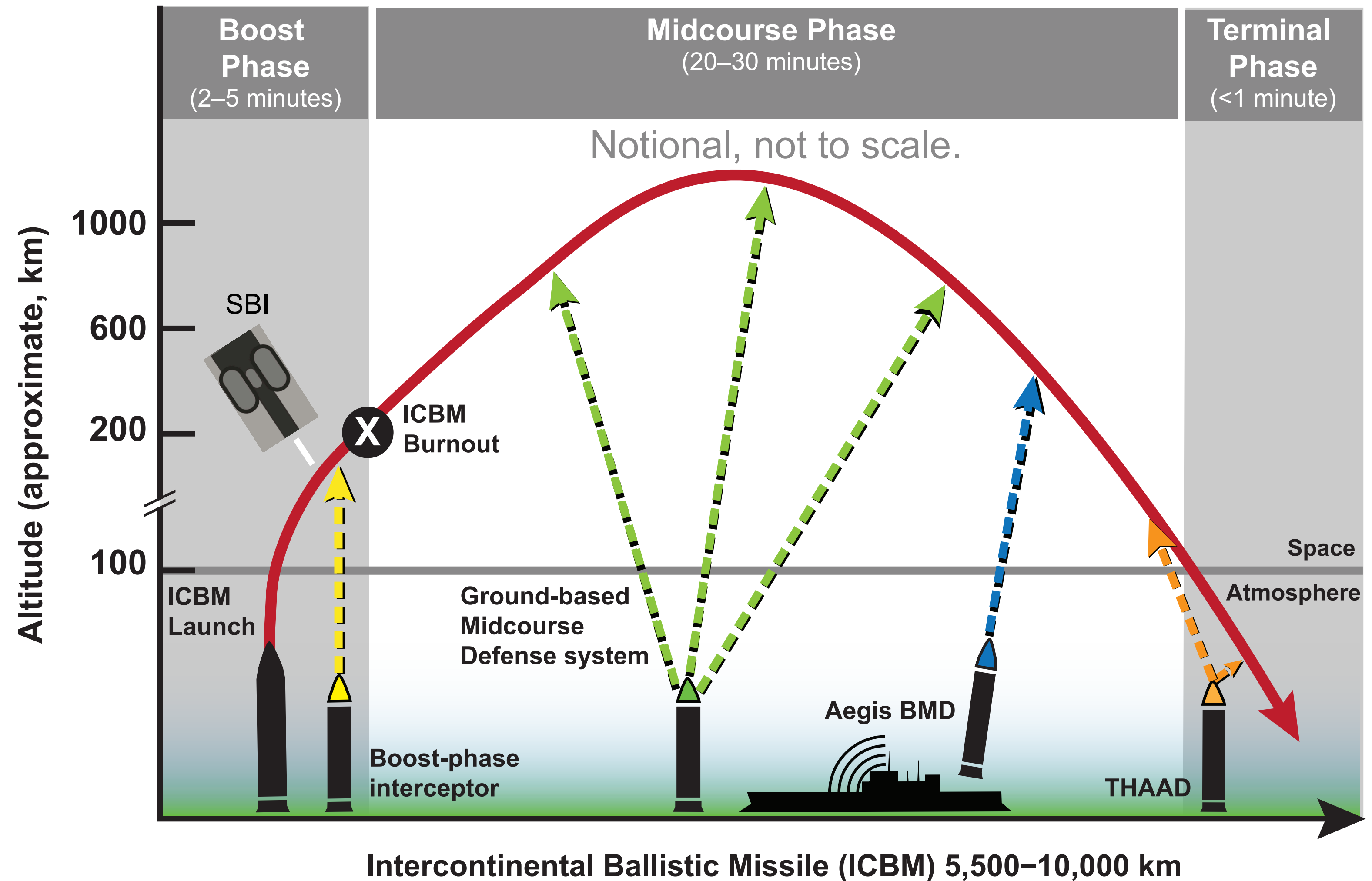
*Target: missile in flight
(warhead not yet deployed)
Missile motors are burning
Accelerating and climbing*

Midcourse (~ 20–30 min)

*Target: warhead only
Follows a ballistic trajectory
In space (no air drag)
Current system: GMD*

Terminal phase (~ 30 sec)

*Target: warhead only
Warhead descends, reenters
Atmospheric drag increases
Current system: THAAD*



Credit: *Strategic Ballistic Missile Defense, APS 2025*

Midcourse Intercept

The challenge of discrimination

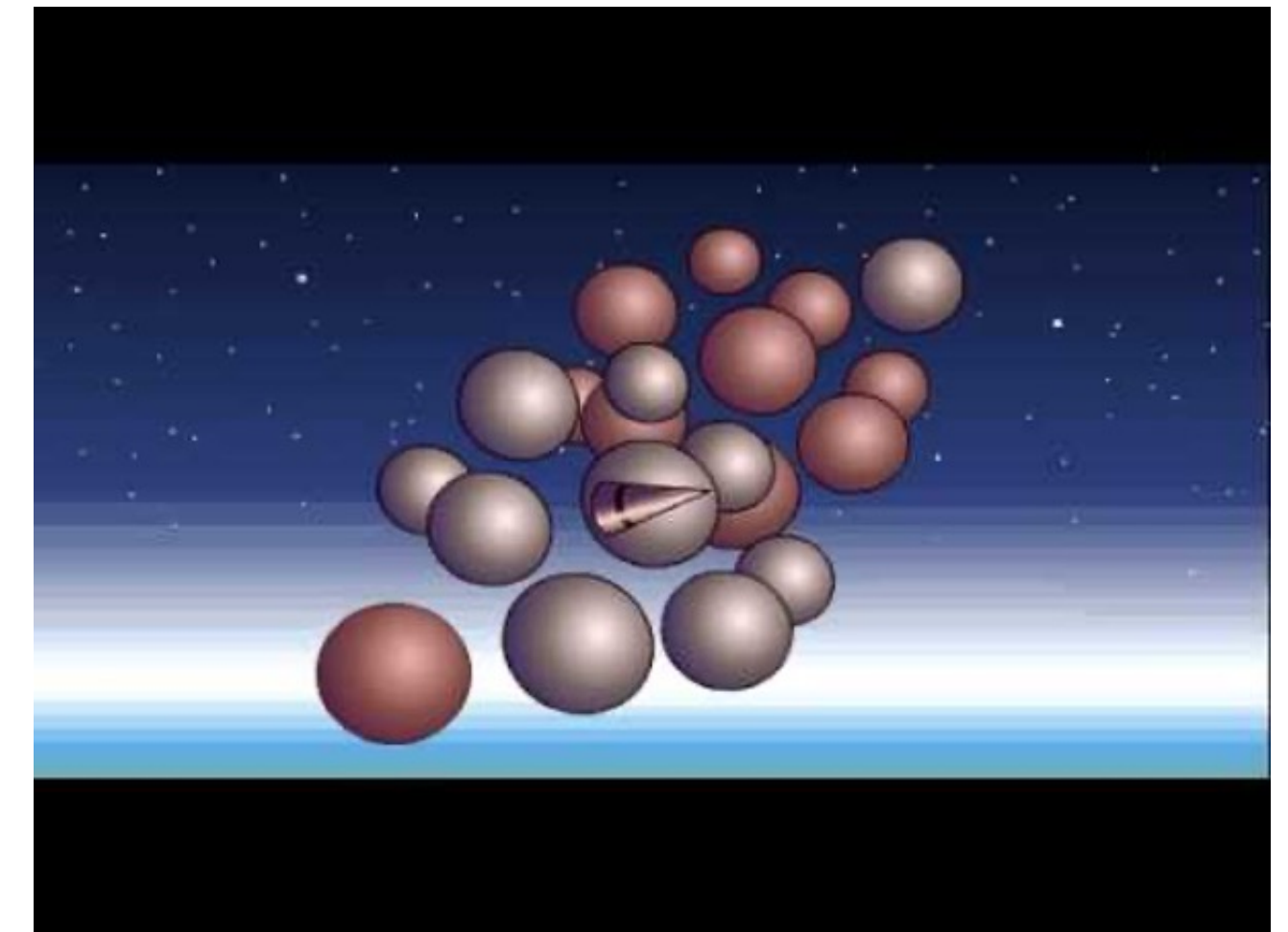
The midcourse discrimination challenge: offensive countermeasures

Passive countermeasures

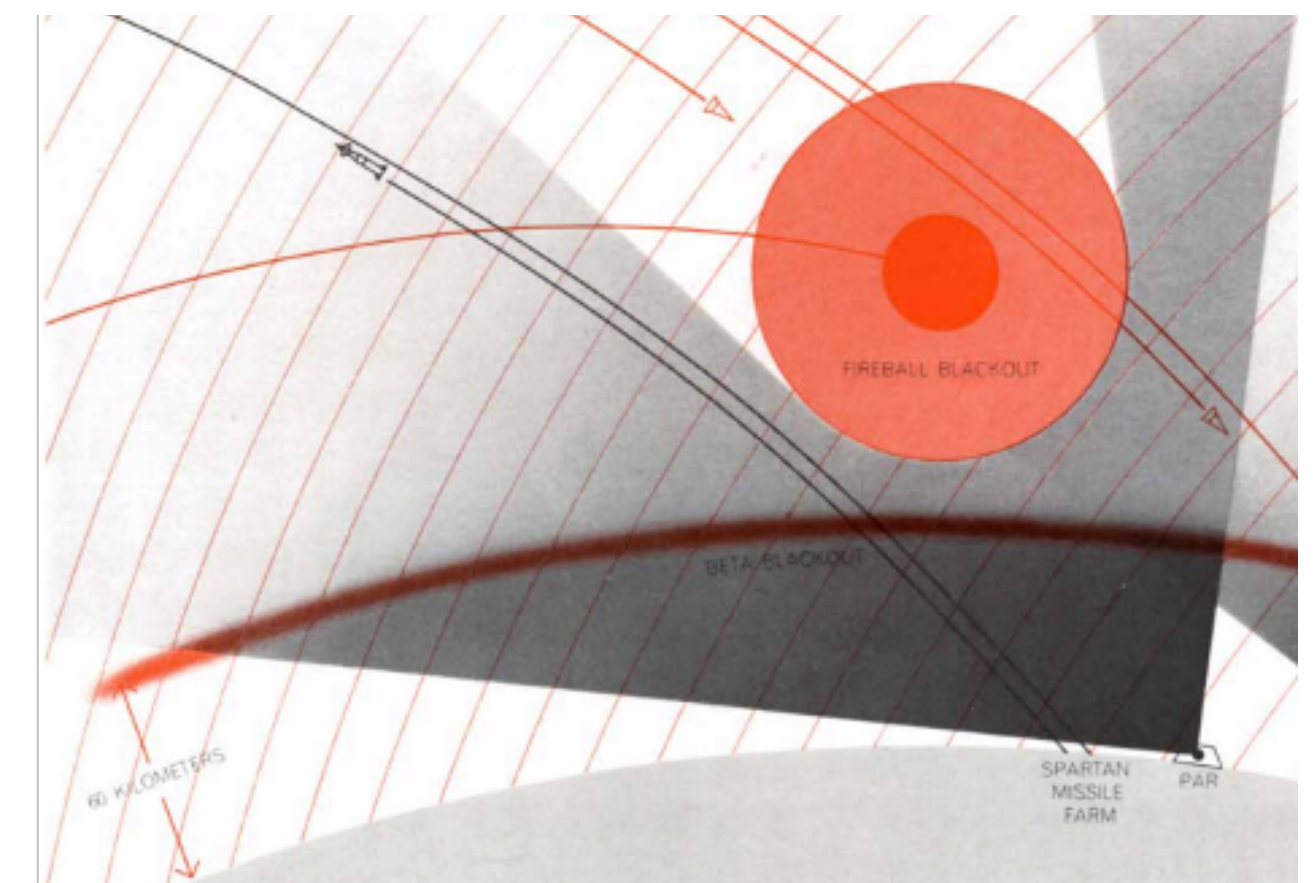
- Radar-absorbing materials, booster fragments & chaff, radar jammers
- Simulation, such as releasing decoys that look like warheads, perhaps dozens accompanying each warhead
- Anti-simulation, such as releasing many objects with many different appearances, or enclosing the warhead in a balloon

Active countermeasures

- Destroying or disabling sensors, including forward-based radars and space-based infrared sensors
- A high-altitude nuclear detonation, making radar tracking & discrimination and infrared detection essentially impossible



Anti-simulation: A warhead in a balloon.
Countermeasures, Sessler et al. 2000



Attack on sensors: Radar blackout.
Scientific American, Garwin & Bethe 1968

The results of ground-based midcourse-defense intercept tests

The Pentagon has consistently rated the GMD tests as low in operational realism. Even so, the system has failed as often as it has succeeded.

- all the successful intercept tests used similar lighting conditions/time of day
- There were no tests against salvos of simulated warheads
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 - no tests against salvos of simulated warheads
- Tests appear to have never included complex countermeasures, e.g., use of target dynamics and penetration aids
 - slow pace of tests, 20 in 24 years.
- The pace of testing has been very slow, with only 20 tests in 24 years

Test	Date	Designation	Kill vehicle
1	10/2/99	IFT-3	prototype
2	1/19/2000	IFT-4	prototype
3	7/8/2000	IFT-5	prototype
4	7/1/2001	IFT-6	prototype
5	12/1/2001	IFT-7	prototype
6	3/2/2002	IFT-8	prototype
7	10/14/2002	IFT-9	prototype
8	12/11/2002	IFT-10	prototype
9	12/15/2004	IFT-13c	prototype
10	2/14/2005	IFT-14	prototype
11	9/1/2006	FTG-02	CE-I
12	9/28/2007	FTG-03	CE-I
13	12/5/2008	FTG-05	CE-I
14	1/31/2010	FTG-06	CE-II
15	12/15/2010	FTG-06a	CE-II
16	7/5/2013	FTG-07	CE-I
17	7/22/2014	FTG-06b	CE-II
18	5/30/2017	FTG-15	CE-II Block 1
19	3/25/2019	FTG-11	CE-II, CE-II Block 1
20	12/11/2023	FTG-12	CE-II Block 1

Source: L.Gregory 2025

Boost-Phase Intercept

The tyranny of time

The tyranny of time: what a boost-phase intercept (BPI) defense must achieve *before the attacking missile's motor stops burning*

- Detect the launch of a missile.
- Compute the missile's initial trajectory.
- Determine whether it is an SRBM, MRBM, ICBM, SLBM, or a space launch vehicle.
- If it is an ICBM or SLBM, determine whether it is a test launch or a missile on an attack trajectory.
- If it is on an attack trajectory, the defense must fire its interceptors.
- The defense's interceptors must be able to accelerate fast enough and be able to steer to reach the accelerating and maneuvering attacking missile and collide with it *before its motor shuts down*.

The tyranny of time: the burn times required for a North Korean ICBM to strike U.S. cities

North Korea's Hwasong-18 solid-propellant ICBM —

- The full burn time = 170 sec
- The burn time needed to strike Seattle = 158 sec
- The burn time needed to strike Fairbanks = 137 sec



Credit: Wikipedia

Maximum range \approx 13,000 km

Significant countermeasures
+ defense penetration aids

The tyranny of time: the burn times required for a Russian ICBM to strike U.S. cities

Russian RS-24 Mod 2 Yars ICBM —

- The full burn time = 160 sec (?)
- The burn time needed to strike Seattle = 150 sec
- The burn time needed to strike Fairbanks = 145 sec



Credit: The War Zone

Maximum range \approx 12,000 km

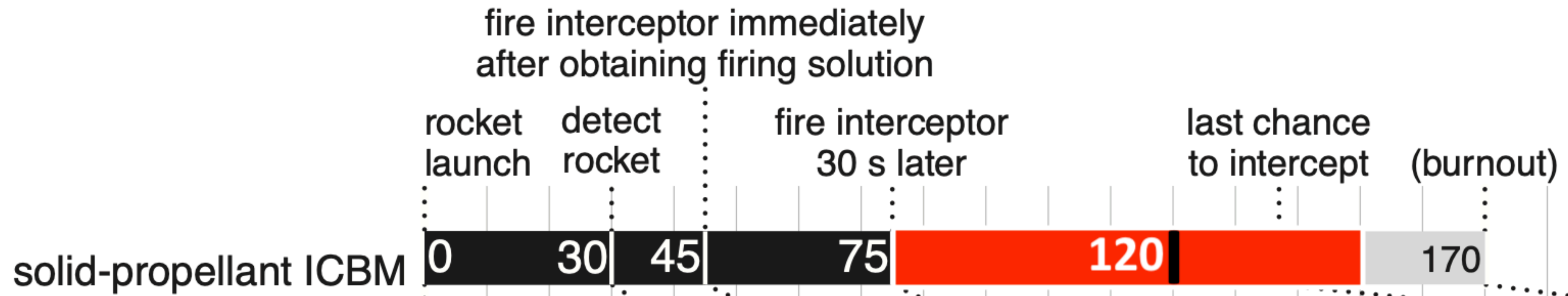
Significant countermeasures
+ defense penetration aids

The tyranny of time: the interval within which a BPI system must achieve each intercept step in order to be successful

- **30 sec** to detect the launch of a missile
- **15 sec** to compute its initial trajectory
- **30 sec** to determine whether the missile is an SRBM, MRBM, ICBM, SLBM, or a space launch vehicle, and if it is an ICBM or SLBM, whether it is only a test or is on an attack trajectory
- If it is on an attack trajectory, fire interceptors
- **45–75 sec** for the interceptors to reach the accelerating and maneuvering missile and collide with it

Credit: *Boost-Phase Missile Defense*, APS 2003

The tyranny of time: the time line for a successful boost-phase intercept



Credit: *Boost-Phase Missile Defense*, APS 2003

Compressing decision times to 10s of seconds would require significant automation, increasing the risk of serious mistakes in a crisis and accidental escalation to nuclear war.

For this reason alone, a system like this would be very dangerous.

But the tyranny of time is likely be even more brutal

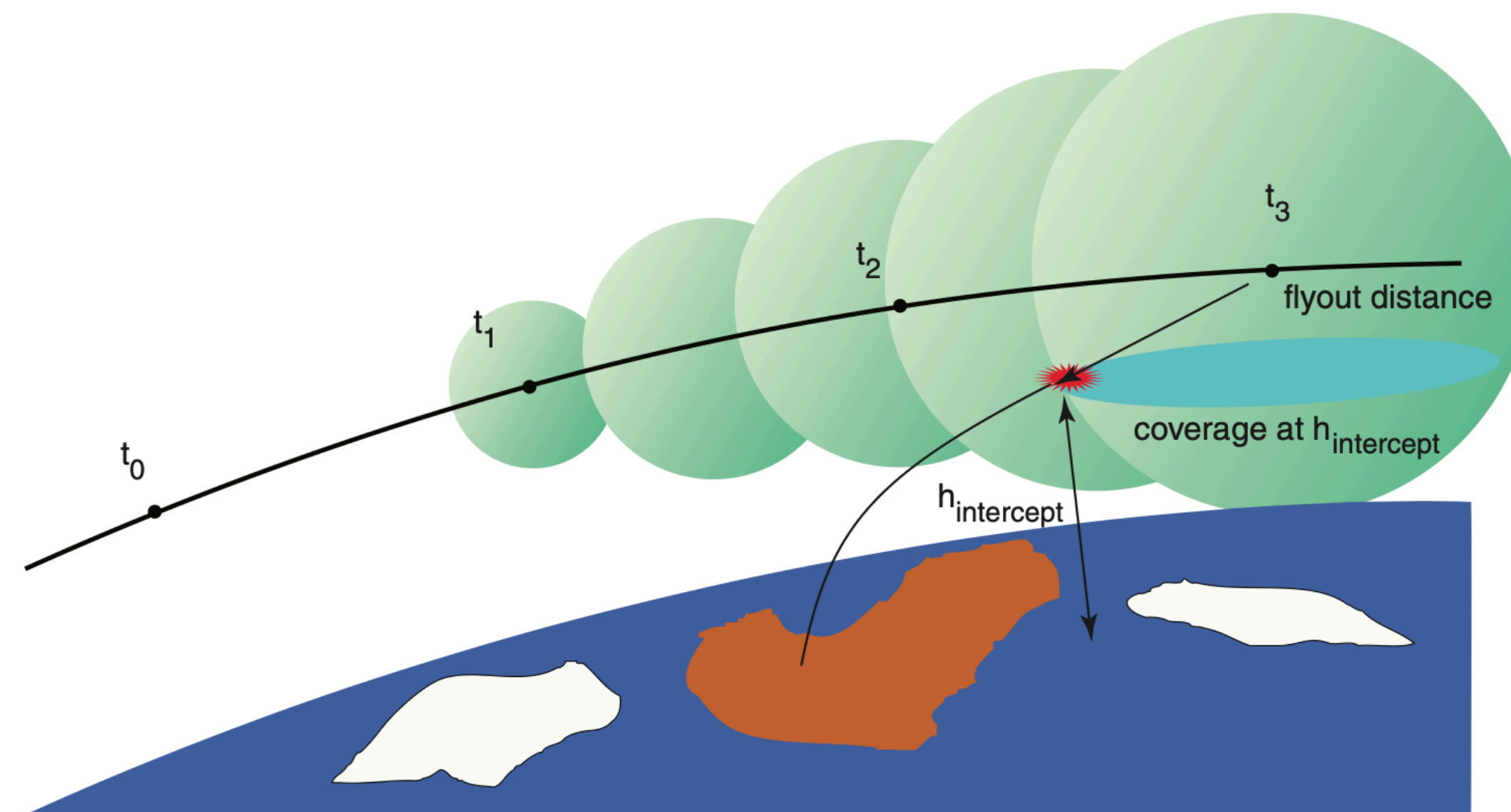
- Even today, an SLBM launched from Arctic, Atlantic, or Pacific waters could strike a U.S. city after burning for only 100 seconds. In this case, interceptors would have only 25 seconds of flyout time to reach the missile while its motors are still burning, a practical impossibility.
- In response to U.S. deployment of a BPI system adversaries could develop and deploy fast-burn ICBMs and SLBMs with *much shorter burn times*, to defeat the system —
 - The 2012 NRC Report used as a reference ICBMs with full burn times of 150 sec.
 - The 2003 APS Study listed a detailed ICBM model with a full burn time of 130 sec.
 - The 1985 OTA Report listed the Midgetman ICBM as having a full burn time of 60 sec.
 - The 1985 OTA Report described an MX-like ICBM design with a full burn time < 60 sec.

Why a boost-phase defense from space would require tens of thousands of space-based interceptors (SBIs)

- Each SBI moves rapidly around Earth on its orbit.
- And as Earth rotates, any given launch site rotates under the SBI's orbit.

As a result, any given SBI will usually not be able to reach the threatening ICBM or SLBM before the missile deploys its warhead(s).

This is called the “absentee” problem.



Credit: *Boost-Phase
Missile Defense*
(APS 2003)

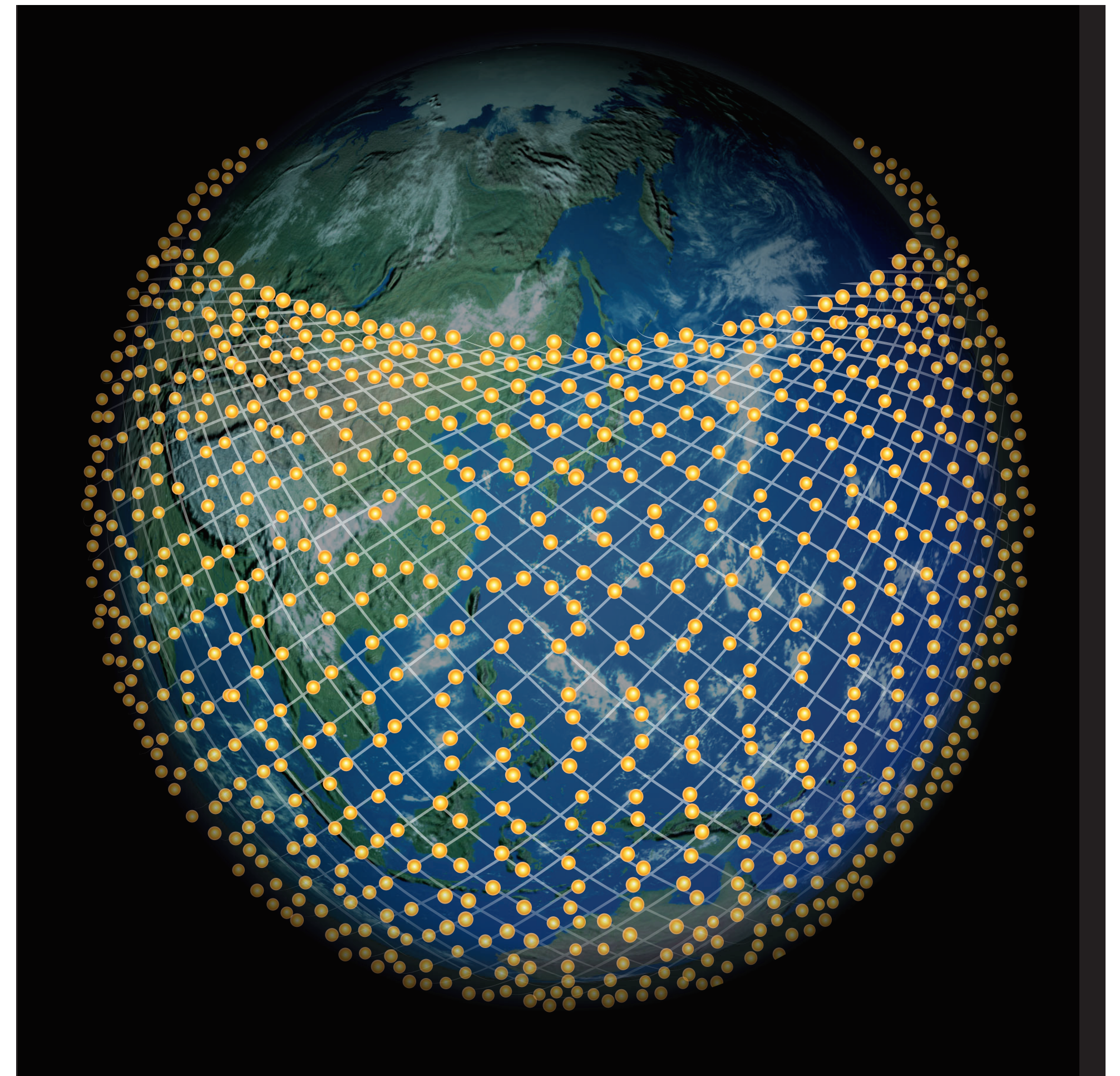
A space-based BPI system would require many thousands of SBIs

As one example, a constellation of $\sim 6,000$ 5 km/s SBIs would be needed to assure that at least one is in position to attempt to defend cities in the lower 48 states against a single solid-propellant ICBM or SLBM launched from anywhere and prevent spoofing of the defensive system, *assuming that every SBI works perfectly and would actually hit and disable or destroy the target missile.*

To attempt to defend only U.S. cities in the lower 48 states from a salvo of 10 solid-propellant ICBMs launched within ~ 200 sec from about the same area would require about 60,000 SBIs.

Many times this number of SBIs would be required to attempt to defend cities in Alaska as well.

What a constellation of only 1,600 space-based interceptors would look like:



Credit: *Strategic Ballistic Missile Defense*, APS 2025

How many SBIs would a system need to be reliable?

For an SBI system to be reliable, it would have to have many more interceptors than I've been talking about.

Even ground-based interceptors stored in protective silos—where they can be maintained—have had serious reliability issues.

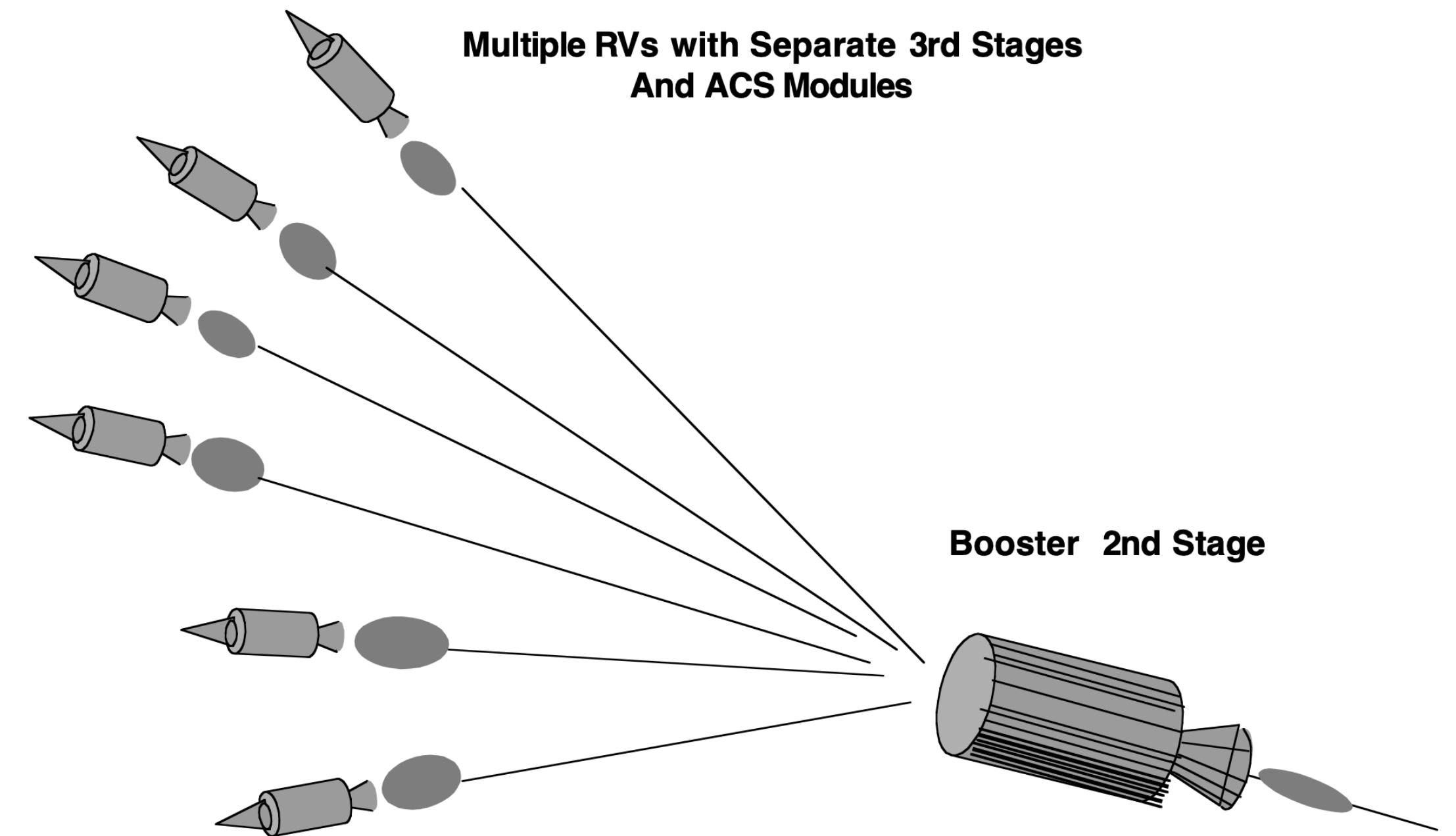
Expecting SBIs to work perfectly after being exposed to the harsh environment of space for many years, without servicing, would invite failure.

And if even one SBI were to fail to intercept an attacking ICBM, the result would be a catastrophe.

To have 3 SBIs available per target ICBM would require a constellation of 180,000 SBIs in the previous example.

Countermeasures can make a boost-phase defense fail

- Salvo launch ICBMs or SLBMs.
- Launch decoy rockets to confuse the defense and deplete the defense's interceptor stock.
- Deploy the warhead(s) before the final stage has stopped burning.
- Deploy rocket-propelled decoys, flares, and jammers during the flight of the ICBM's upper stages.
- Program the ICBM's upper stages to fly evasive maneuvers, possibly in conjunction with releasing decoys.



Deploy multiple RVs, each with a separate 3rd stage and guidance system

Credit: *Boost-Phase Missile Defense*, APS 2003

An SBI defense can't "win" the cost competition with the offense

President Trump's original claims

- \$175 billion for the entire Golden Dome.
- It will be nearly 100 percent effective and capable of intercepting virtually all aerial threats to the homeland.
- It will be completed within 3 years.
(1 year has already passed)

The March 2025 APS BMD Report

To counter 1 additional ICBM using SBIs, the United States would have to spend ~ 1,000 times the cost of that ICBM.

The construction and initial launch cost of 40,000 SBIs could be ~ \$1 trillion.

The May 2025 Congressional Budget Office Estimate

The estimated 20-year [current year] cost of a system of 2,000 SBIs would be about \$540 billion.

The 2026 American Enterprise Institute Estimate (Todd Harrison)

A robust but still not impenetrable defense has been estimated to cost trillions of dollars over 20 years.

Deploying a system of space-based interceptors would create enormous problems

Attempting to create a BPI system to defend the United States against ICBMs and SLBMs is very unlikely to succeed but it would be enormously costly and would increase the danger the United States faces.

- It is technically infeasible for the foreseeable future.
- It would be enormously expensive.
- It would make the United States less safe by fueling a new arms race.
- It would also make the United States much less safe by reducing the decision time in a crisis to a few 10s of seconds.
- Just testing space-based interceptors, even without deploying them, will be provocative and dangerous.

Midcourse intercept—from the ground or from space—is not a solution

Given the enormously difficult challenge of intercepting an ICBM or SLBM from space during its boost phase, there has been increasing discussion of instead using SBIs to intercept:

- (a) the bodies of long-range missiles while they are still within the atmosphere, earlier than has previously been considered. This would require the interceptor to be even faster and carry endoatmospheric sensors, making it heavier. Preliminary analyses indicate that this is not a solution to the problem.
- (b) the warheads of long-range missiles after they have been deployed. This is just midcourse intercept, once again. It brings with it all the so-far fatal discrimination problems that led to interest in BPI in the first place. Firing interceptors from space instead of from the ground solves nothing—it just makes the system more expensive.

Conclusions

Conclusions

Strategic missile defenses, such as the one proposed as part of the Golden Dome initiative, are often marketed as a humane alternative to deterrence by replacing the threat of retaliation by an effective defense.

But the reality is that there is no prospect of an effective strategic missile defense for the foreseeable future.

An effort to build such a defense would be ineffective, exorbitantly costly, and dangerous—even if it was built with the best intentions, using the best available engineering.

Why dangerous? Because it is likely to provoke adversaries to build additional offensive nuclear weapons, making the threat it is meant to address even larger and more severe.

And it could fail in a uniquely catastrophic way: by creating unwarranted confidence in the ability to defend against a nuclear attack and by turning crises into faster, more automated, more mistake-prone events that are more likely to end in nuclear war.

Arms control agreements have been the only historically successful approach to reducing the nuclear threat

