MIT
Science, Technology, and
Global Security Working Group

The Proposed US Missile Defense in Europe:
Technological Issues Relevant to Policy

Theodore A. Postol
Professor of Science, Technology, and National Security Policy, Massachusetts Institute of Technology
Voice: 617 253-8077; e-mail: postol@mit.edu

George N. Lewis
Associate Director, Peace Studies Program, Cornell University
Voice: 607 255-8914; e-mail: gnl3@cornell.edu

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Major Questions that Need to Be Addressed

Major Issues

- What Are the Benefits Versus the Costs Associated with the Current Plan to Deploy a Missile Defense in Europe?
- Could This Deployment Cause an Avoidable Major Policy Confrontation with Russia at a Time When Russian-US Cooperation is Critical?
- Will the System Provide the Promised Performance Benefits?
- Are Their Alternative System Configurations that Could “Do the Job” that would Not Be Perceived as a Threat by the Russians?

Summary of the Technological Issues Relevant to Policy (1 of 2)

- Aegis system interceptors are kinematically able to provide intercept coverage for a missile defense of Europe.
- There are as yet unresolved questions about whether the Aegis interceptor Kill Vehicle has adequate acquisition and divert capabilities to reliably find and maneuver to hit Intermediate Range Ballistic Missile (IRBM) warheads.
- However, the Missile Defense Agency has made statements that the Aegis can do the job.
- Two-Stage Ground-Based Interceptors sited in Poland are kinematically able to provide intercept coverage for most, but not all, of Europe.
- The Two-Stage Ground-Based Interceptors are also capable of intercepting Russian ICBMs launched towards targets on the East Coast of the United States.
- Missile Defense Agency claims that such intercepts are not possible are inaccurate.
- There are still many unresolved engineering and technical problems associated with both the two-stage and three-stage Ground-Based Interceptors.
- It is not clear that the unresolved performance uncertainties associated with the Ground-Based Interceptor are less than those that confront Aegis.
- Thus, from the perspective of performance uncertainties, Aegis interceptors appear to be as viable a choice for policy makers as Ground-Based Interceptors.

Summary of the Technological Issues Relevant to Policy (2 of 2)

- The planned radar support for the European missile defense is woefully inadequate.

  X-band radars are fundamentally not suited for the role of acquisition and surveillance. Lower frequency radars operating at VHF, UHF, or L-Band are all far more suitable for this mission.
- The radar acquisition and surveillance problem could probably be solved by using multiple Forward-Based X-Band radars placed strategically between Iran and Europe.

  These radars would probably only be able to acquire and track cone-shaped ballistic missile warheads at ranges less than 1000 km range. They would, however, be able to track the upper rocket stage that deploys the warhead at greater range. This may make it possible for the radar to cue on upper rocket stages as part of a process aimed at acquiring and tracking the warhead.
- The radar acquisition and surveillance problem could also be solved by using the Russian Voronezh Class VHF Early Warning Radar in Armavir, Russia.
- Even if the funding for the Missile Defense Program were expanded to a substantial part of the entire Department of Defense budget, the resulting missile defense system would still be fundamentally unreliable, unless it can be demonstrated that the system can tell the differences between simple decoys and warheads.
- There is overwhelming evidence that exoatmospheric Missile Defenses are fundamentally vulnerable to exoatmospheric decoys. This near-certain vulnerability has far ranging implications for the viability of exoatmospheric missile defenses and the nation’s security. Congress should consider investigating this serious and fundamental vulnerability.

Proposed Elements Of A European Missile Defense

- Up to 10 silo-based long-range interceptors located in Eastern Europe (2011-2013)

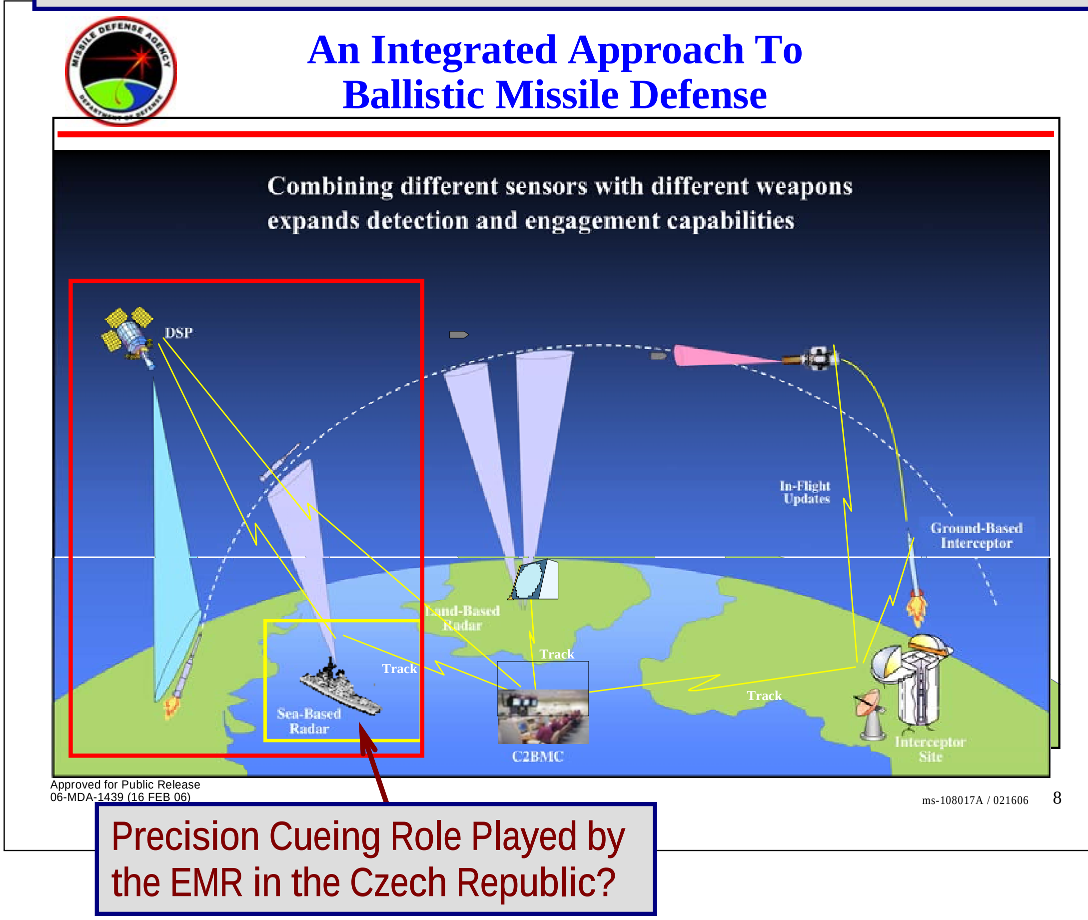
- Re-location of a narrow-beam, midcourse tracking radar currently used in our Pacific test range to central Europe (2011)

- Field an acquisition radar focused on the Iranian threat from a forward position to provide detection, cueing, and tracking information (2010-2011)

Locations of Physical Assets Relevant to an Assessment of the Policy Issues

Ballistic Missile Trajectories from Iran and Tatischevo, Dombarovskiy, and Vypolzovo, Russia to Washington

Precision Cueing Role Played by the EMR in the Czech Republic?



Reported Demonstrations of How Simple Radar Cueing Information Can Substantially Improve a Missile Defense's Theoretical Capabilities

"With cuing from an Aegis ship and three ships with the Block 1A capability, we can in fact defend our ally Japan and the U.S. forces there. Additionally, if we station a ship off the Hawaiian Islands with a ship forward, we can in fact defend Hawaii. Likewise, we can defend Guam by moving the detection ship forward. We have run many of these scenarios."

Rear Admiral Brad A. Hicks
Program Director,
Aegis Ballistic Missile Defense
December 19, 2005 in a talk at the Marshall Institute

Full talk is available at:
http://www.marshall.org/article.php?id=363

Why Cueing from the European Midcourse Radar (EMR) Could be of Concern to Russian Military Analysts

Reported by several publications:

On August 19, 2004, Army Col. Charles Dreissnack, THAAD's program manager, said at a conference that recent tests of the THAAD's radar have shown that THAAD will have a "residual" capability against ICBMs.

He said: "We weren't planning to have the ICBM capability," but the radar is "outperforming what we thought it supposed to do."

He also said that although deployment won't begin until FY 2009, test assets could be ready to defend Hawaii years earlier.

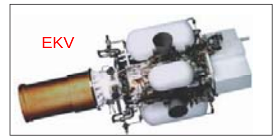
From
Marc Selinger, "THAAD displaying 'residual' capability against ICBMs,"
Aerospace Daily & Defense Report, August 20, 2004.

Note: This description implies that THAAD's NMD capabilities are limited by the radar, not the interceptor. See "Highly Capable Theater Missile Defenses and the ABM Treaty" in *Arms Control Today*, April 1994. Available on the Web at:

http://www.ucsusa.org/global_security/missile_defense/theater-missile-defense-the-abm-treaty.html

Interceptors are Modified Ground-Based Interceptors

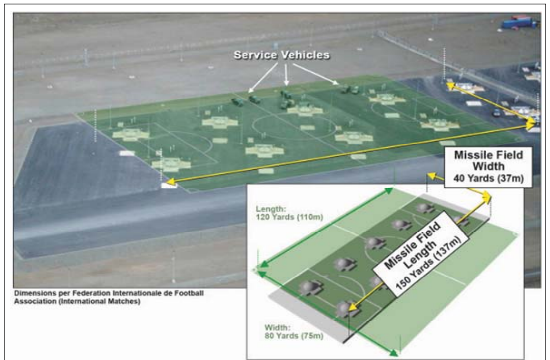
2 Stage Instead of 3 Stage
30,450 lbs versus 31,500 lbs
47 Feet Long versus 51 Feet



The interceptors planned for Poland are nearly identical to the three-stage interceptors based in the U.S. except that they are a two-stage variant that is quicker, lighter, and better suited for the engagement ranges and timelines for Europe. The silos that house the ground-based interceptors have substantially smaller dimensions (e.g., diameter and length) than those used for offensive missiles, such as the U.S. Minuteman III ICBM. Any modification would require extensive, lengthy, and costly changes that would be clearly visible to any observer.

The ground-based interceptors are comprised of a booster vehicle and an exoatmospheric kill vehicle (EKV). Upon launch, the booster flies to a projected intercept point and releases the EKV which then uses on-board sensors (with assistance from ground-based assets) to acquire the target ballistic missile. The EKV performs final discrimination and steers itself to collide with the enemy warhead, destroying it by the sheer kinetic force of impact.

Future European Missile Site – Size Comparison



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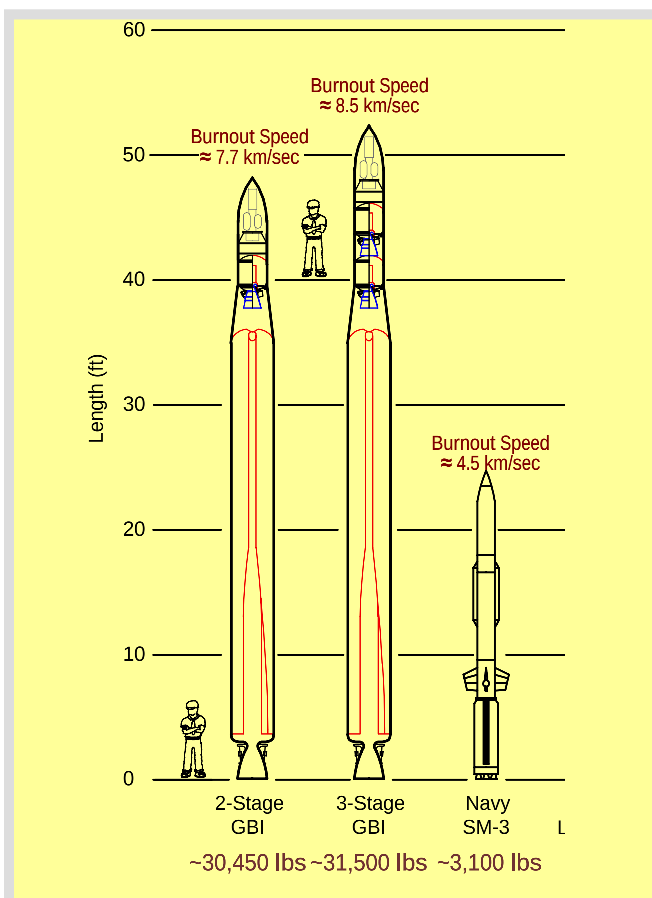
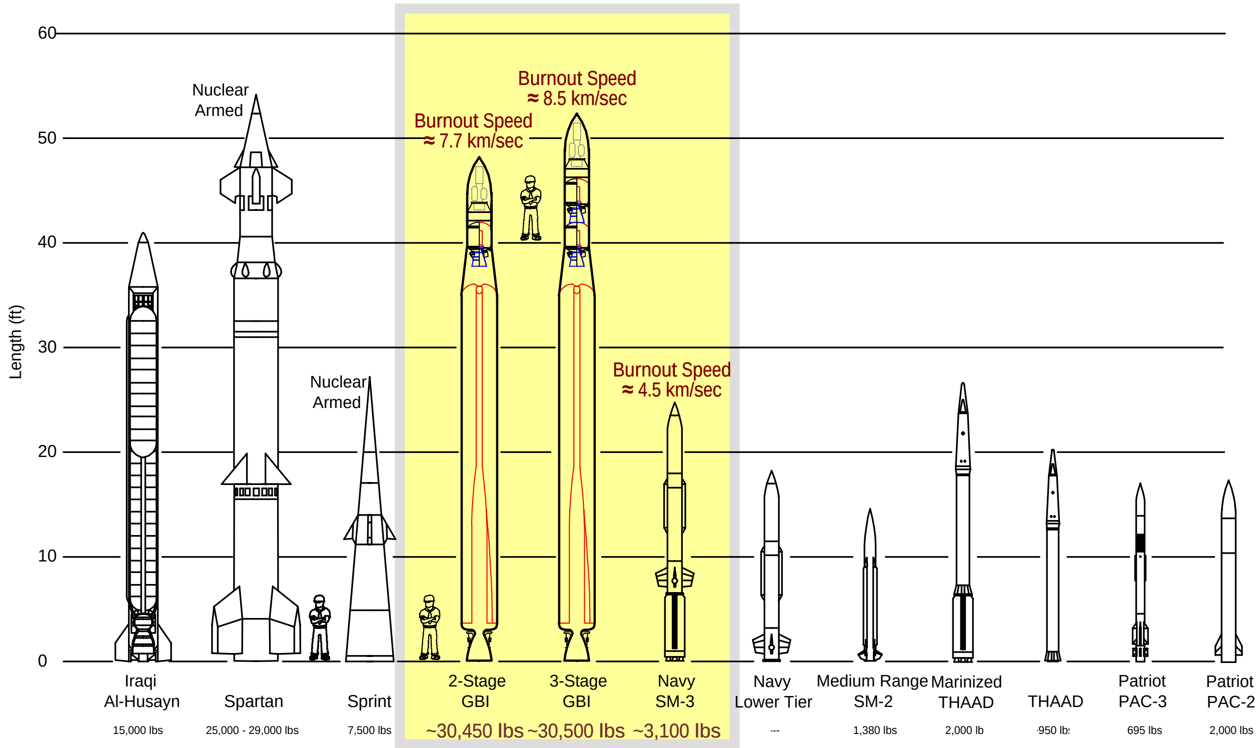
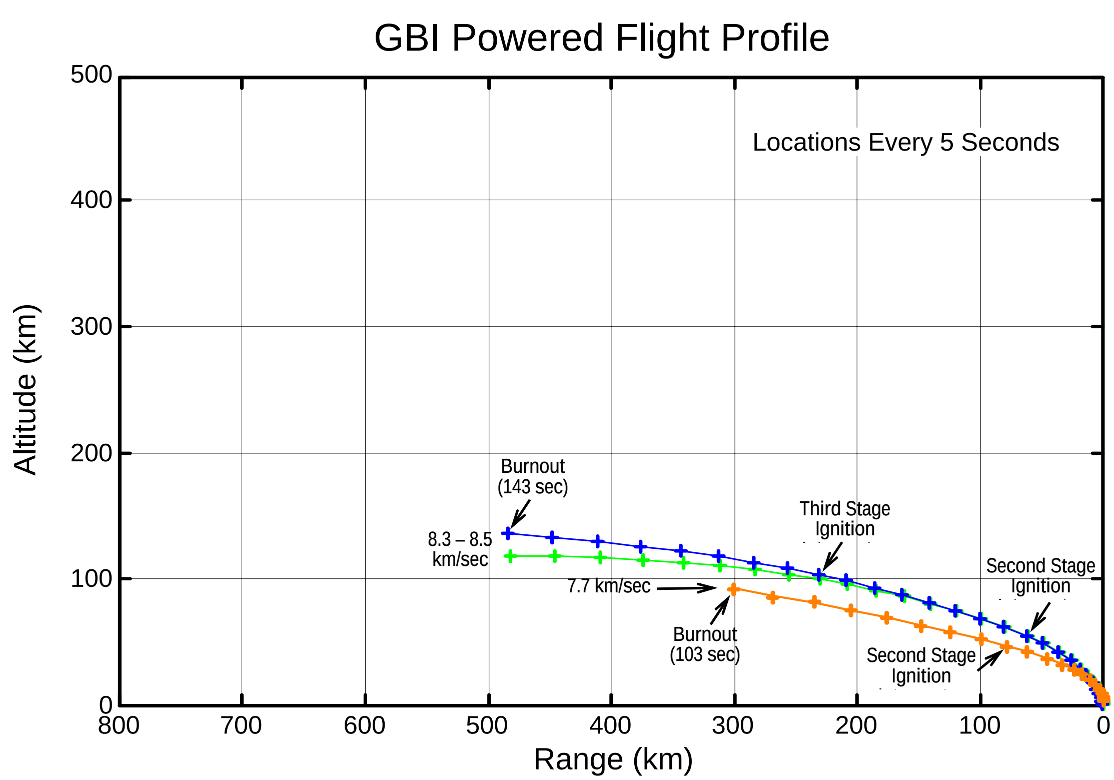
Relative Sizes and Weights of Candidate European Missile Defense Interceptors



Relative Sizes and Weights of Missile Defense Interceptors



Location of US 2-Stage and 3-Stage Ground-Based Interceptor Variants at 5 Second Intervals During Powered Flight



In March, Director of Missile Defense Agency Tells European Leaders that the Proposed US System Cannot Counter Russian Offensive Missiles

Missile Defense For U.S. Allies And Friends

Distribution Statement A: Approved for public release; distribution is unlimited

March 2007

Lt Gen Trey Obering, USAF
Director
Missile Defense Agency

Approved for Public Release 07-MDA-2332 (9 MAR 07) ms-109395A / 030707

Why Poland And The Czech Republic?

- U.S. missile defense interceptors in Alaska and California do not provide protection for Europe
- Technical analysis shows that Poland and the Czech Republic are the optimal locations for fielding U.S. missile defense assets in Europe
  - Maximizes defensive coverage of Europe from ballistic missiles launched from the Middle East
  - Provides redundant coverage for the U.S. against intercontinental-range ballistic missiles
- Placing the interceptor field in Poland and the radar in the Czech Republic maximizes the defensive coverage of Europe

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U.S. System Cannot Counter Russian Offensive Missiles

- U.S. missile defense system deployments are directed against rogue nation threats, not advanced Russian missiles
- A European interceptor site (up to 10 interceptors) would be no match for Russia's strategic offensive missile force - would be easily overwhelmed
- European interceptor site has no capability to defend U.S. from Russian launches
  - Not geographically situated in European for this purpose
  - Too close Russian launch site to be able to engage intercontinental missiles headed for U.S.
  - Would result in "tail chase" for interceptors launched from a European site
- No plan to expand the number of interceptors in Europe - not in our five year budget
- Standing invitation to the Russians to visit U.S. missile defense sites for transparency purposes

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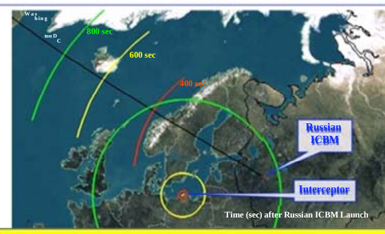
Interceptors Cannot Catch Russian Missiles



U.S. European Interceptor Site Cannot Affect Russian Strategic Capability

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Concerns Expressed by the Russians

Engagement With Russia

- March 17, 2006 (Washington): Bilateral Defense Commission Meeting. Under Secretary of Defense Edelman and General Mazurkevich, Chief of the Main Directorate for International Cooperation
- April 3, 2006 (Moscow): Briefing of Russian officials by U.S. Embassy (Moscow) on DOD decision to resume consultations with Poland regarding the site of U.S. missile defense assets
- November 3, 2006 (Moscow): Dr. Cambone, Lt Gen Obering, DASD Green, Russian Minister of Defense Ivanov, Chief of General Staff Gen-Col Baluevskiy, Gen-Col Mazurkevich
  - Russians did not acknowledge Iran emerging threat as a rationale for deployment of U.S. missile defense assets
  - Believe Russia is real target
  - Russians "portrayed" lack of understanding and confusion on technical aspects of a deployed missile program and proposed architecture. U.S. committed to following-up with technical discussions to Russian counterparts
- January 29, 2007 (Moscow): Strategic Dialogue Meeting. Under Secretaries Joseph and Deputy Foreign Minister Kislyak
  - Ambassador re-committed that U.S. will follow-up with technical briefings/explanations regarding U.S. missile deployment
- February 9, 2007 (Seville): Secretary Gates and Minister of Defense Ivanov during NATO-Russia Council Ministerial meeting

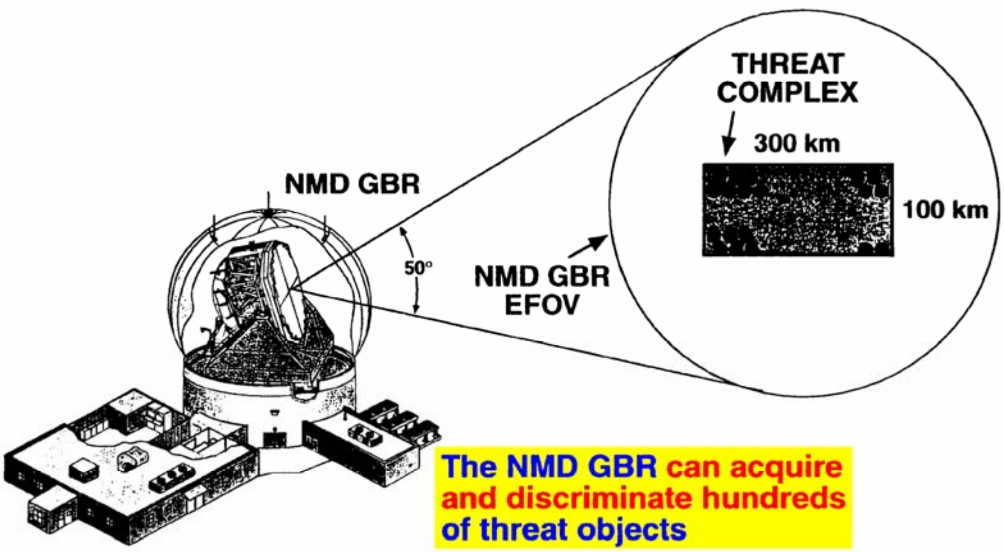
U.S. Has Offered Future Event Establishing Technical Experts Meeting (Spring 2007)

Can the Europe-Based Missile Defense Engage Russian ICBMs and if so Why Does that Matter?

UNCLASSIFIED

NMD GBR (U)

M-960123-14U-B (C) (6039)

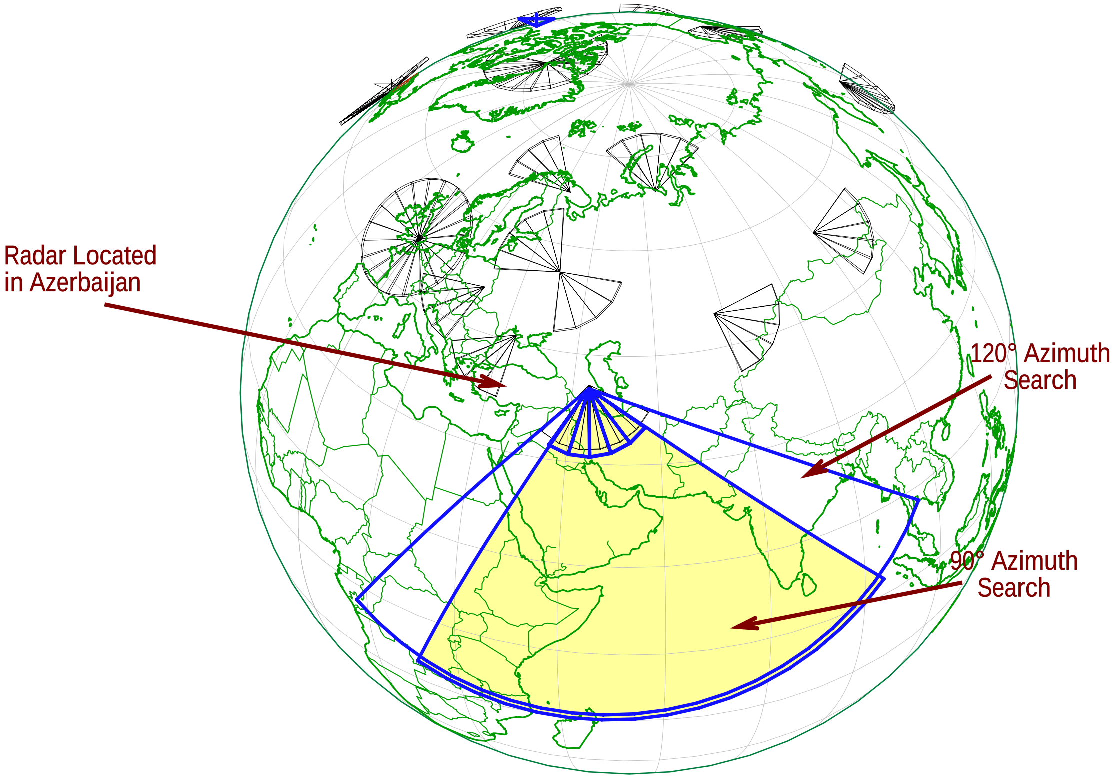


The NMD GBR can acquire and discriminate hundreds of threat objects

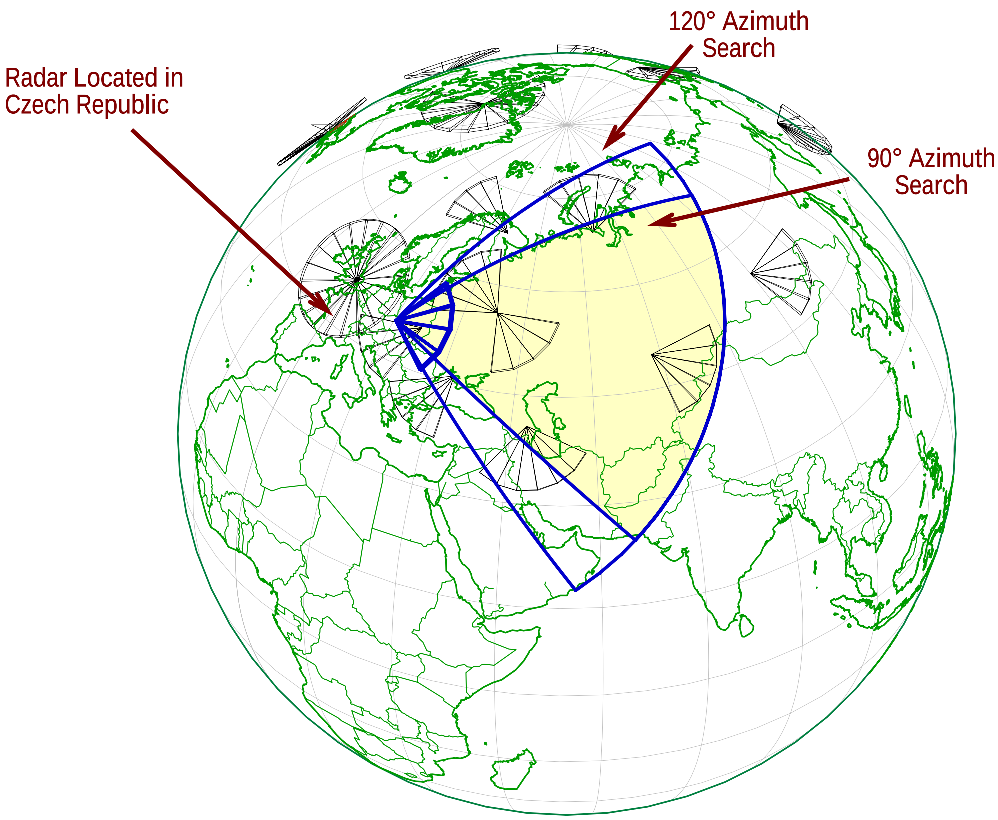
GBR - Full Threat Capability

UNCLASSIFIED

Search Coverage of the X-Band Radar Using Electronic Scanning

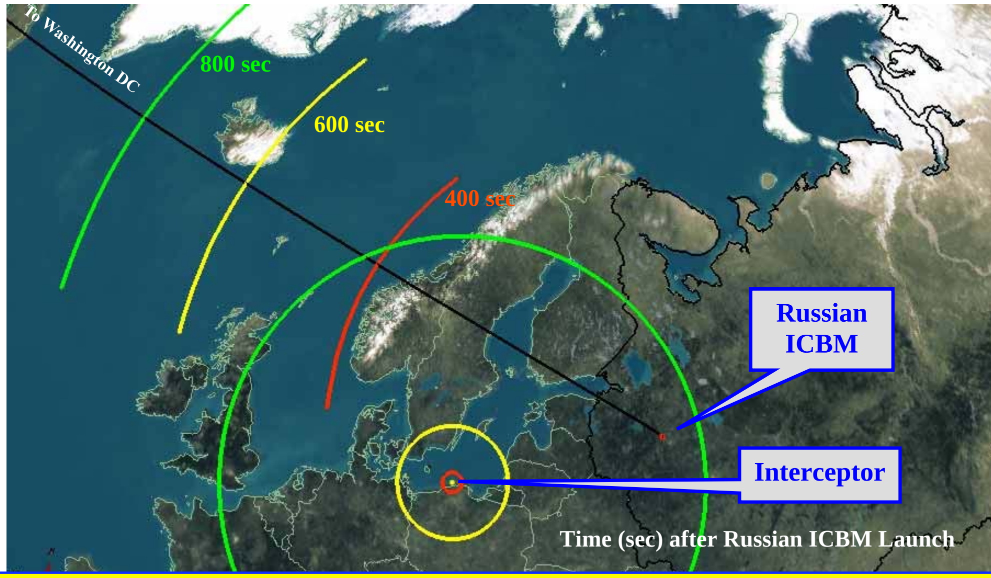


Search Coverage of the X-Band Radar Using Electronic Scanning



General Obering's Original Slide

Interceptors Cannot Catch Russian Missiles



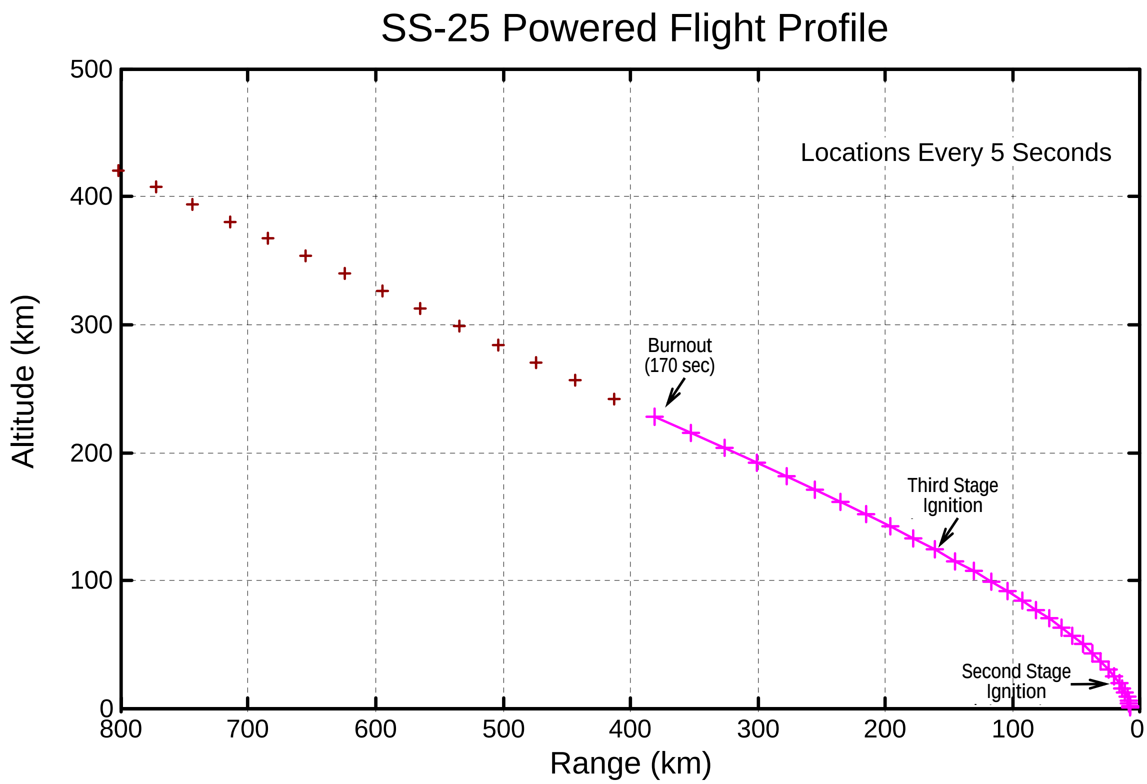
U.S. European Interceptor Site Cannot Affect Russian Strategic Capability

Obering's Slide With MDA Labels Removed

Interceptors Cannot Catch Russian Missiles

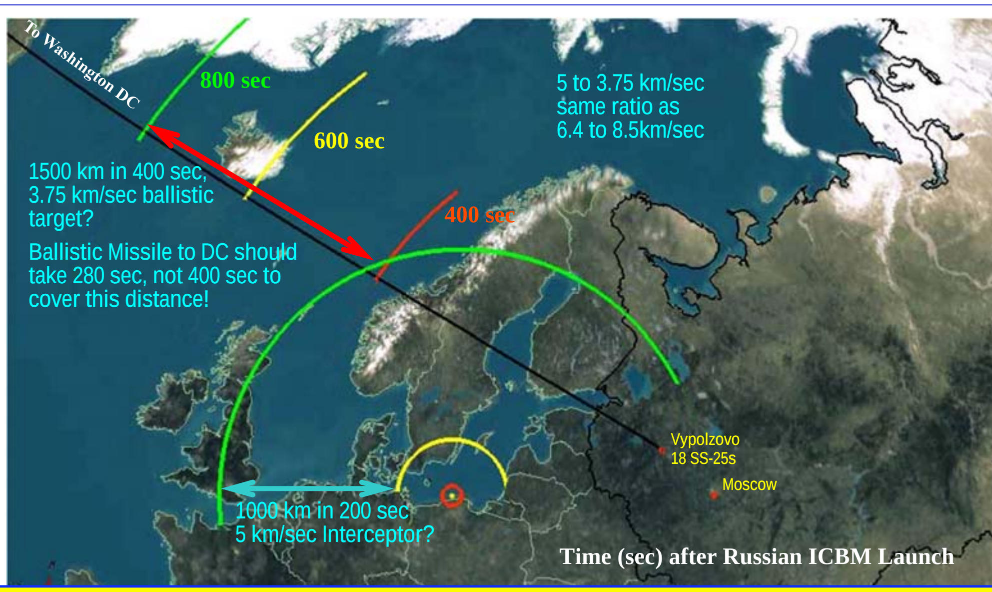
U.S. European Interceptor Site Cannot Affect Russian Strategic Capability

Location of SS-25 Russian ICBM at 5 Second Intervals During Powered Flight



Obering's Slide – Distances and Speeds Wrong

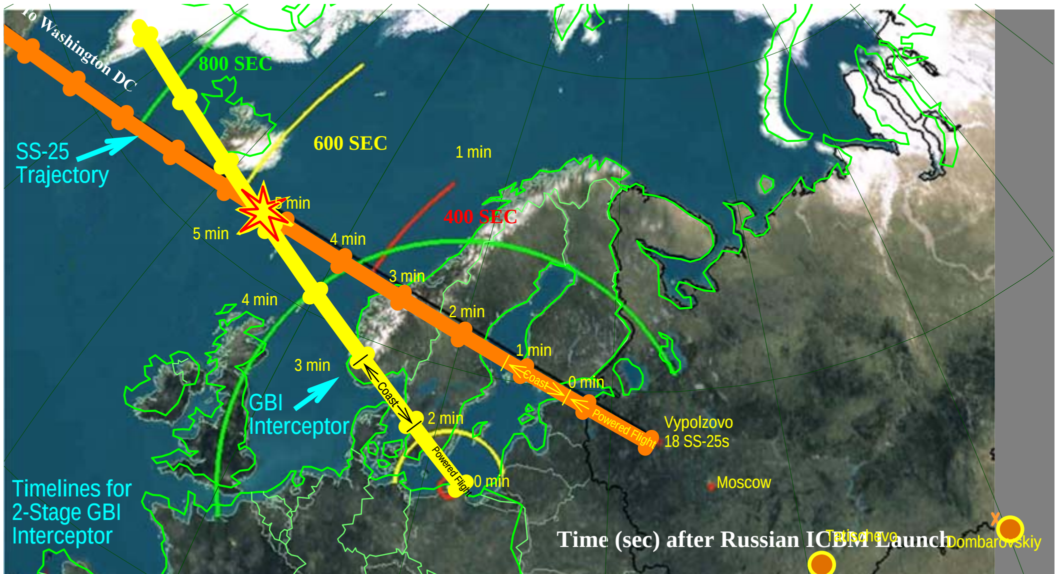
Interceptors Cannot Catch Russian Missiles



U.S. European Interceptor Site Cannot Affect Russian Strategic Capability

Actual Timelines for an Engagement

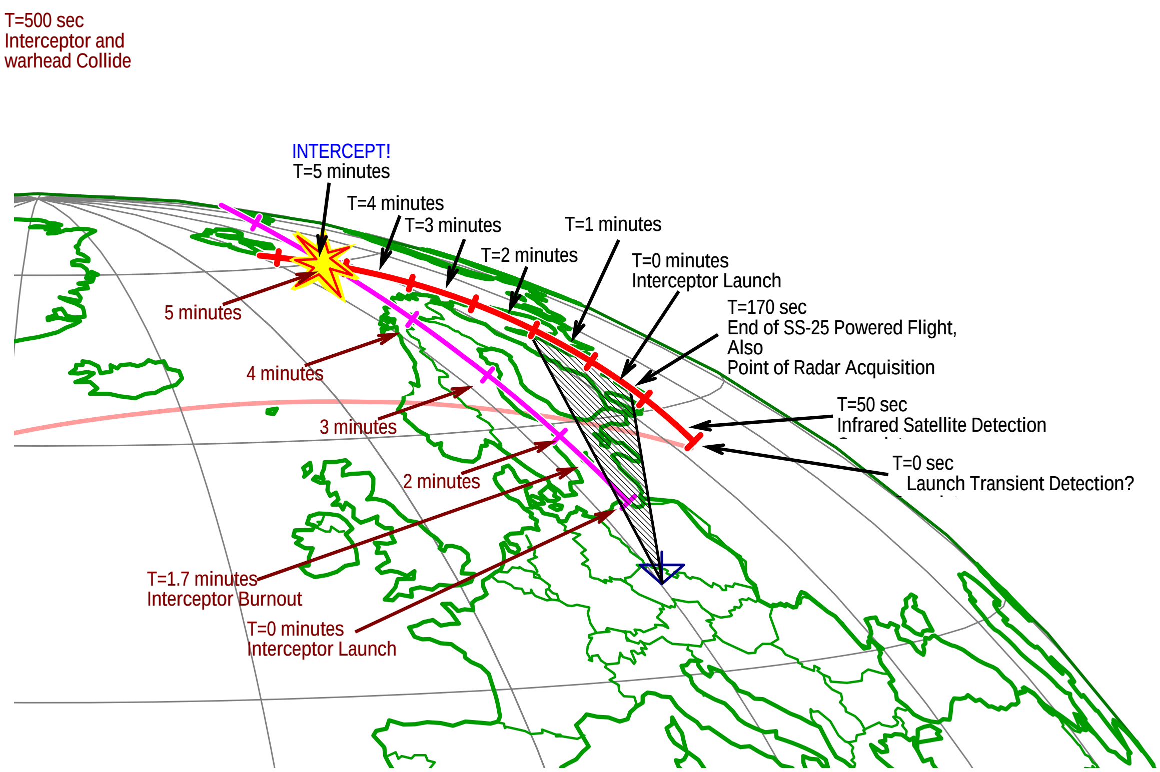
Interceptors Cannot Catch Russian Missiles



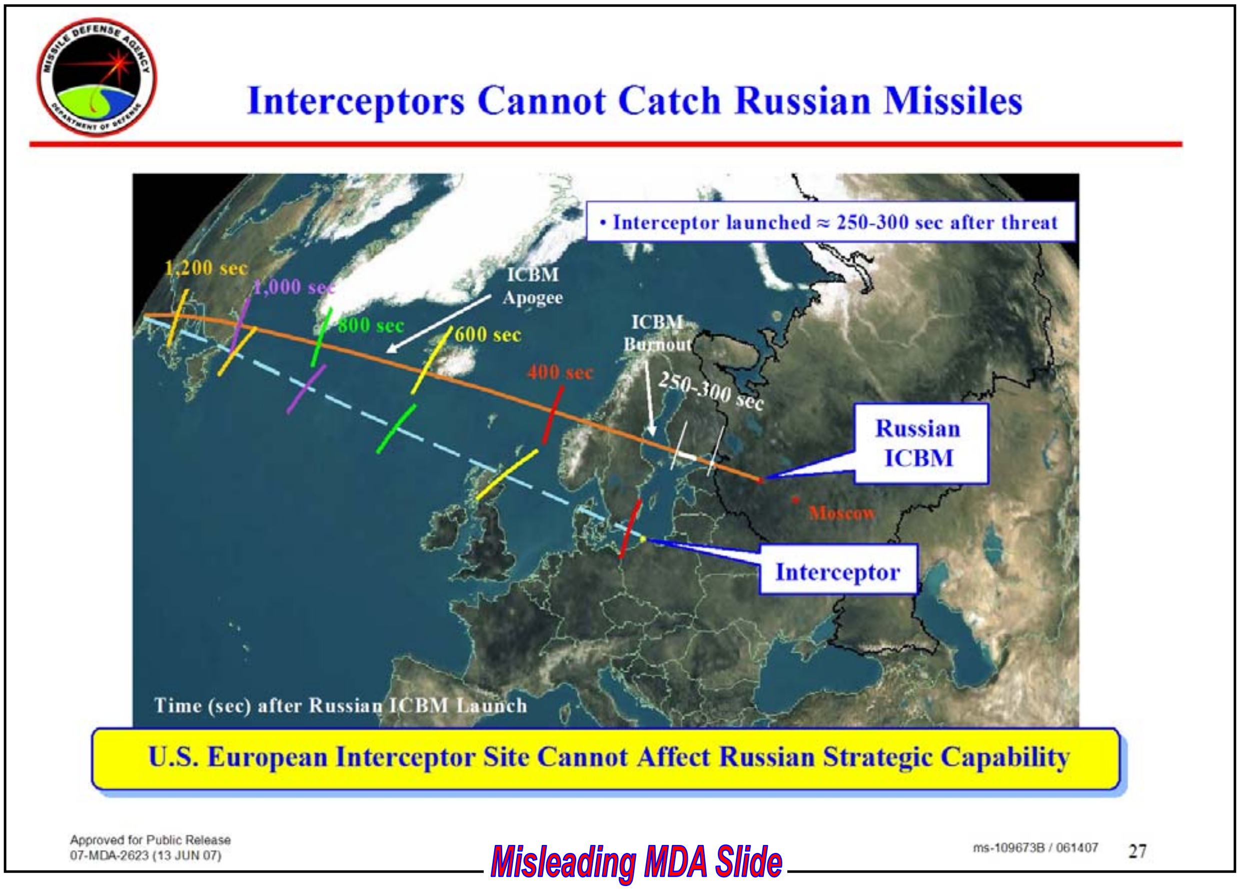
U.S. European Interceptor Site Cannot Affect Russian Strategic Capability

This statement is wrong

Engagement Event Timeline for Engagement of SS-25 from Vypolzovo with 2-Stage Missile Defense Interceptor



Misleading MDA Slide Indicating Interceptors Cannot Engage Russian ICBMs



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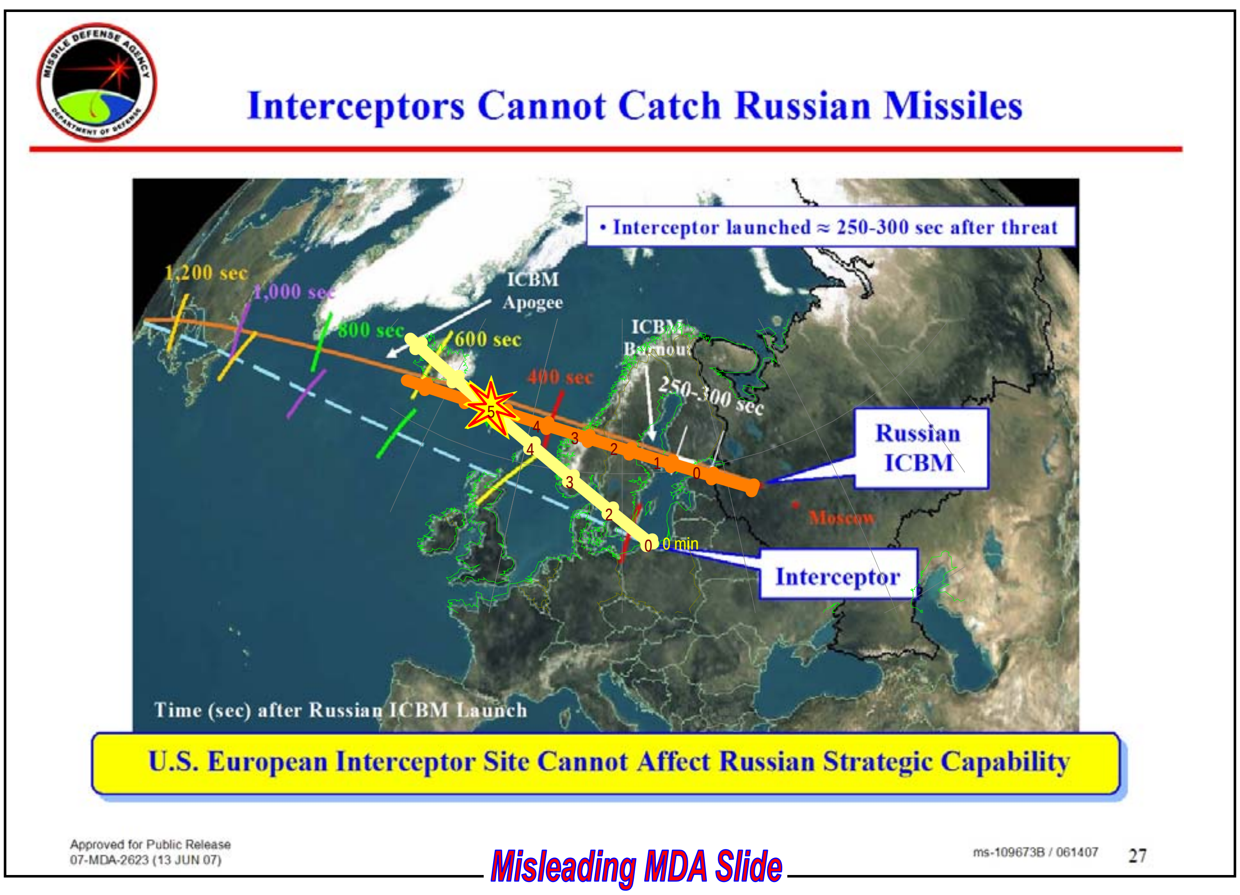
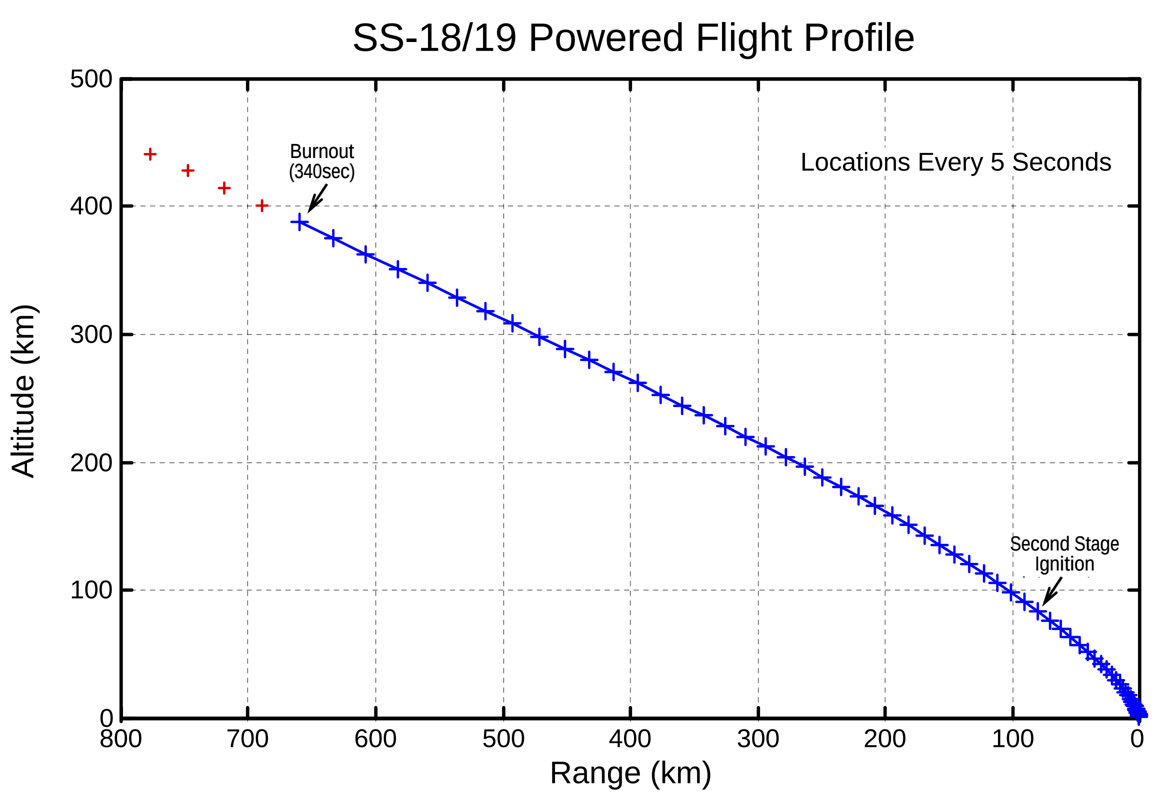
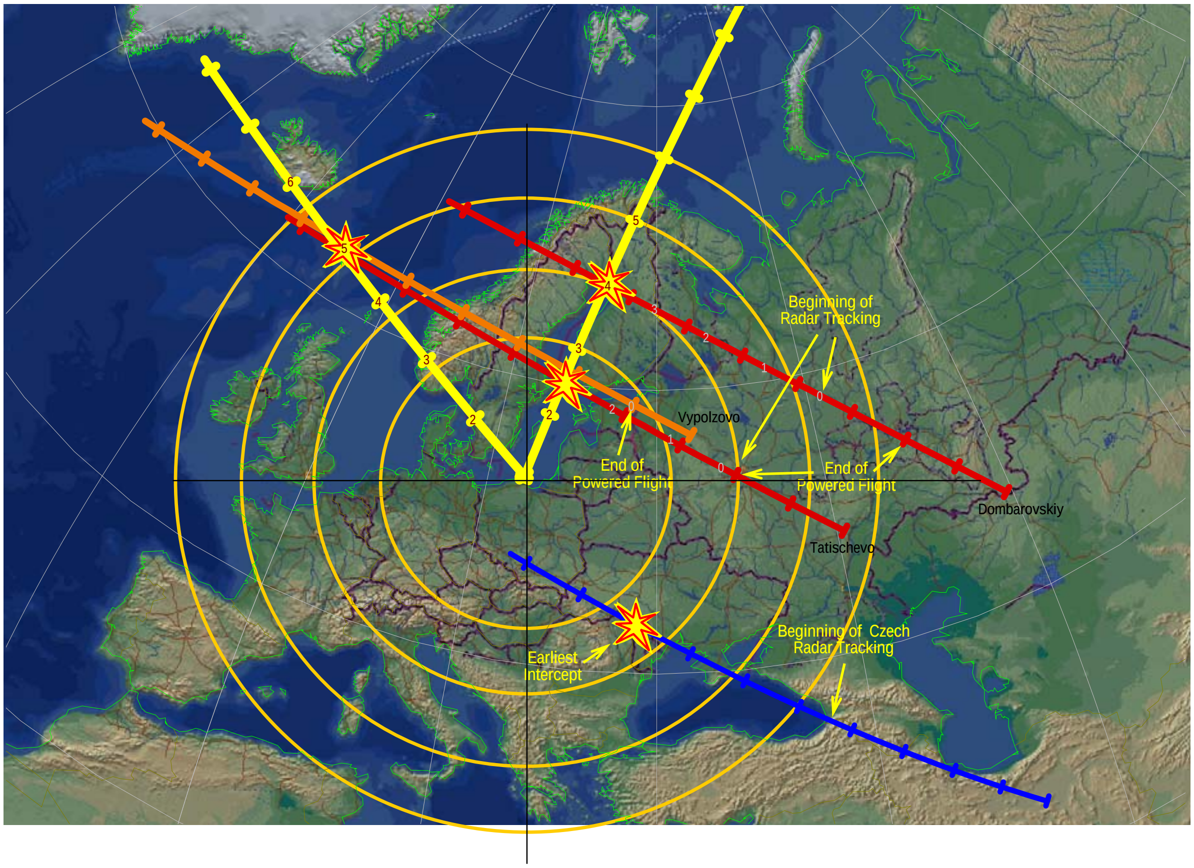


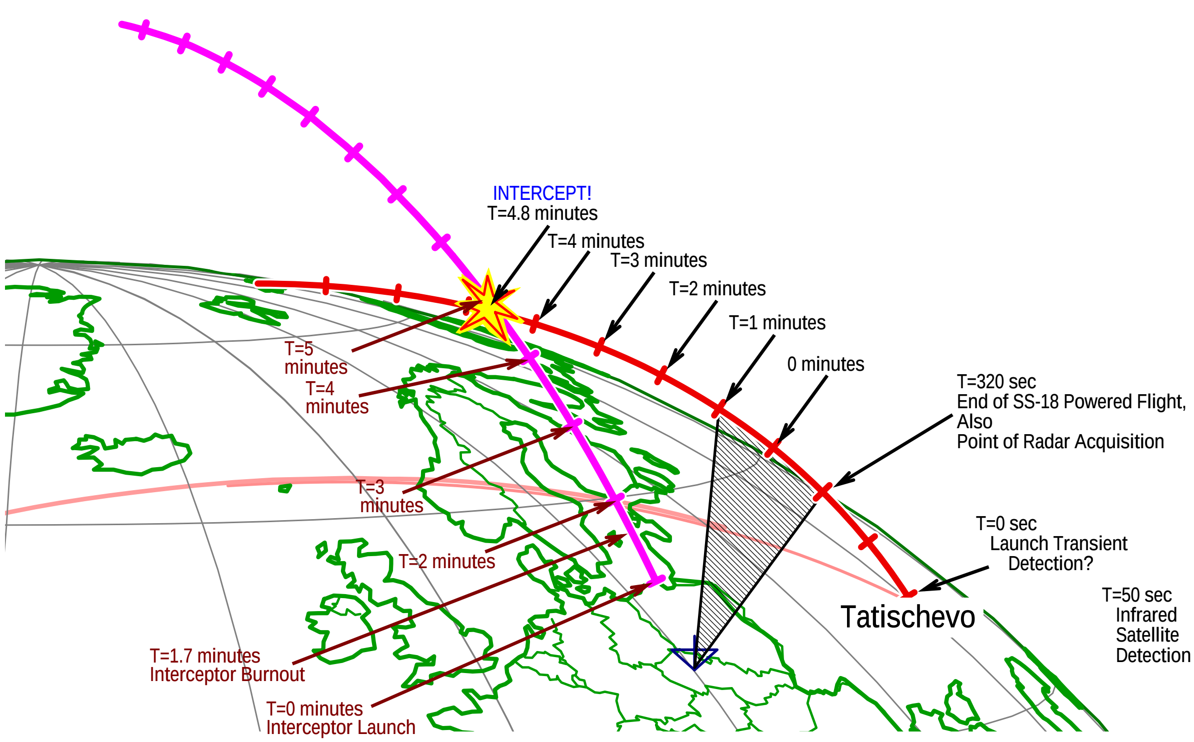
Location of SS-18/19 Russian ICBM at 5 Second Intervals During Powered Flight



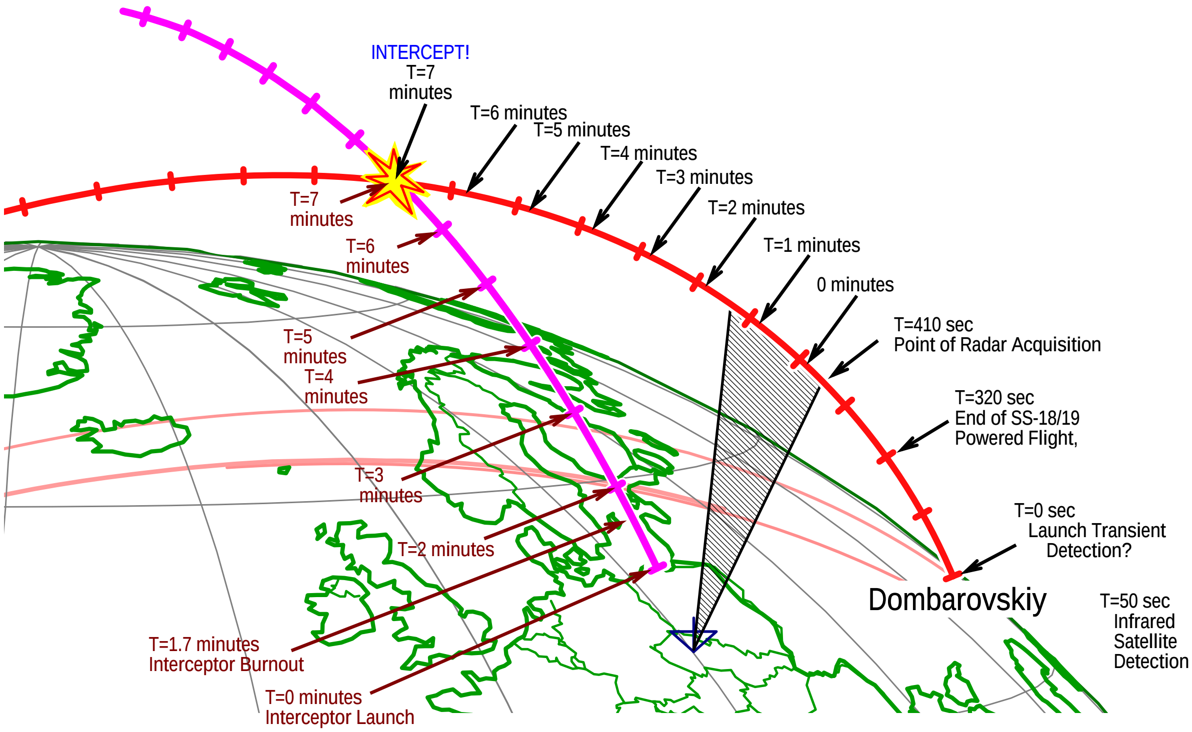
Timelines and Events for Intercepts with Two-Stage Variant of the GBI



Engagement Event Timeline for Engagement of SS-18/19 from Tatischevo with 2-Stage Missile Defense Interceptor



Engagement Event Timeline for Engagement of SS-18/19 from Dombarovskiy with 2-Stage Missile Defense Interceptor



Presidential National Security Directive 23 (PNSD-23)

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Signed by President Bush on December 6, 2002.

- PNSD-23 reaffirmed the policy of the Bush administration "to develop and deploy, at the earliest possible date, ballistic missile defenses drawing on the <u>best</u> technologies available."
- The Directive also states that the United States would begin to deploy missile defenses in 2004 "as a starting point for fielding *improved and expanded missile defenses later [emphasis added]*."
- And that the ultimate goal was missile defenses "not only capable of protecting the United States and our deployed forces, but also friends and allies."
- PNSD-23 was preceded in January 2002 by a memorandum from then Secretary of Defense Donald Rumsfeld. The Rumsfeld memo directs the Missile Defense Agency to develop defense systems by first using whatever technology is "available," even if the capabilities produced are limited relative to what the defense must ultimately be able to do.

Observation

PNSD-23 Appears to be a Mandate for *Continued* and *Unbounded* Expansion and Modernization of the Missile Defense System in Europe and Elsewhere.

If this is True, PNSD-23 Would Indicate to the Russians that the Current Defense Deployment in Europe is only the *Leading Edge* of a Much Larger and More Capable Future Deployment.

Major Question that Needs to Be Addressed

Major Foreign Policy Issue

US May Need to Explain to the Russians Why US Interceptors Cannot Engage Russian ICBMs

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U.S. Has Offered Future Event Establishing Technical Experts Meeting (Spring 2007)

Major Question

Major Issue

Is There Another Option to Base Interceptors so they Do Not Pose a Perceived Threat to Russian ICBMs?

An alternative way of asking this question is:

Could the Aegis System "Do the Job"?

Emergency Engagement Capability

First SM-3 Block I's
"Ready For Fleet Issue" – November 2004
11 Rounds Delivered By August 2006

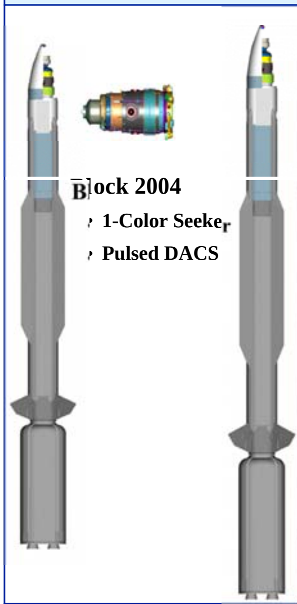
First SM-3 Block IA Encanned
2 Rounds Delivered By 31 AUG 06

Intercept

FTM-10

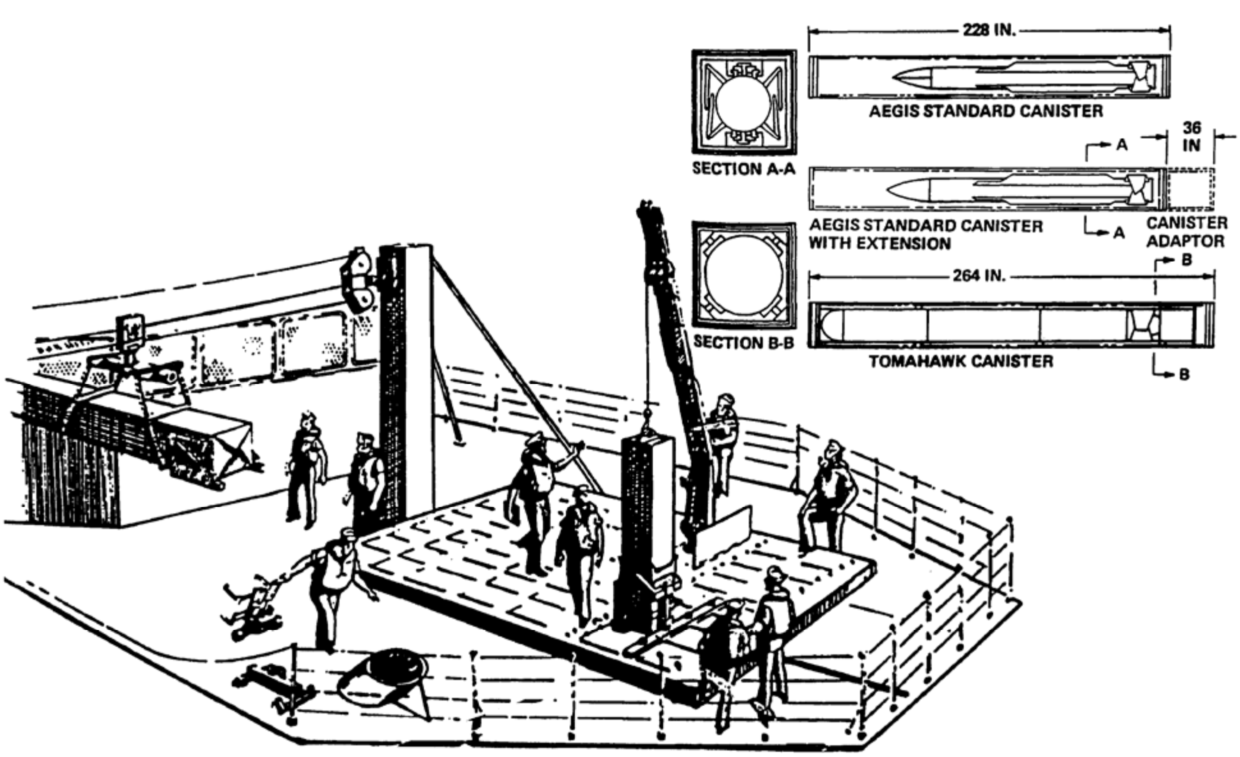
If Directed, Capability Available

Aegis BMD SM-3 Evolution Plan

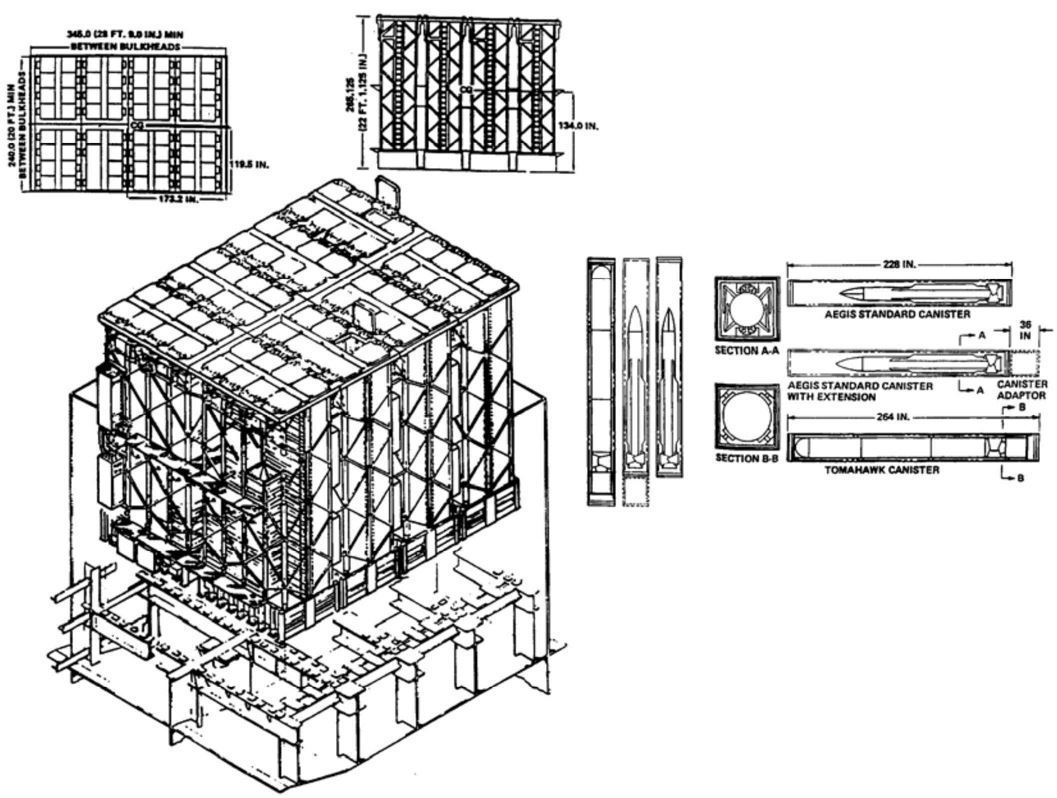
Block IA	Block IB	Block II	Block IIA
 Block 2004 • 1-Color Seeker • Pulsed DACS	 • 2- Color Seeker - Increased IR Acquisition - Improved Discrimination • TDACS - Increased Divert - Lowers AUR Cost • All-Reflective Optics (ARO) • Advanced Signal Processor (ASP)	High Velocity Variant  • Block IB Seeker • 21" Propulsion - 2nd & 3rd Stage - Increased Missile Vbo = xx • 21" Nosecone • MK 41 VLS Compatible  	High Divert Variant  • Large Diameter KW - Advanced Discrimination Seeker - High Divert DACS • 21" Propulsion - 2nd & 3rd Stage - Increased Missile Vbo = yy • 21" Nosecone • MK 41 VLS Compatible  
Block 2004	Block 2008	Block 2010 / 2012	Block 2012 / 2014

■ Funded Since PB06 ■ Capability Change From Previous Block

Basic Characteristics of the Vertical Launch System Components

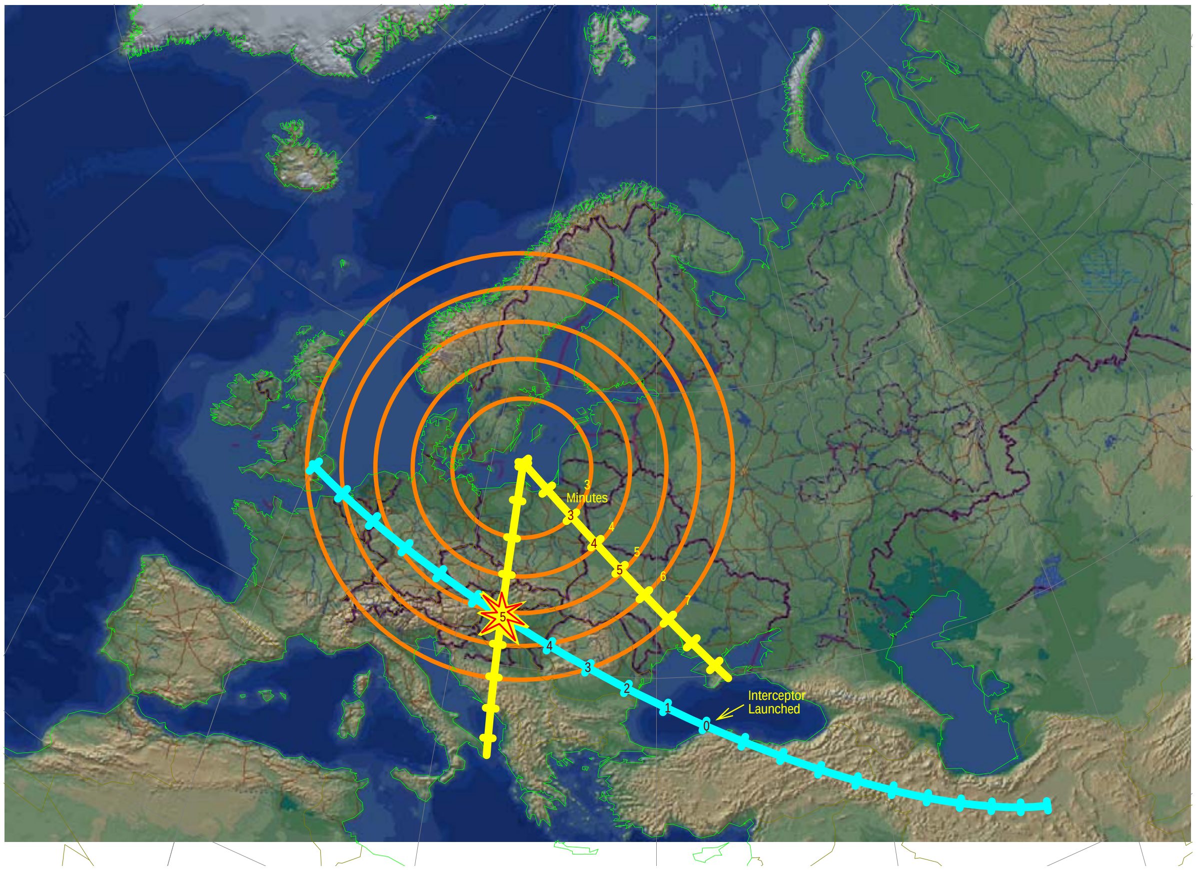


Basic Characteristics of the Vertical Launch System Components

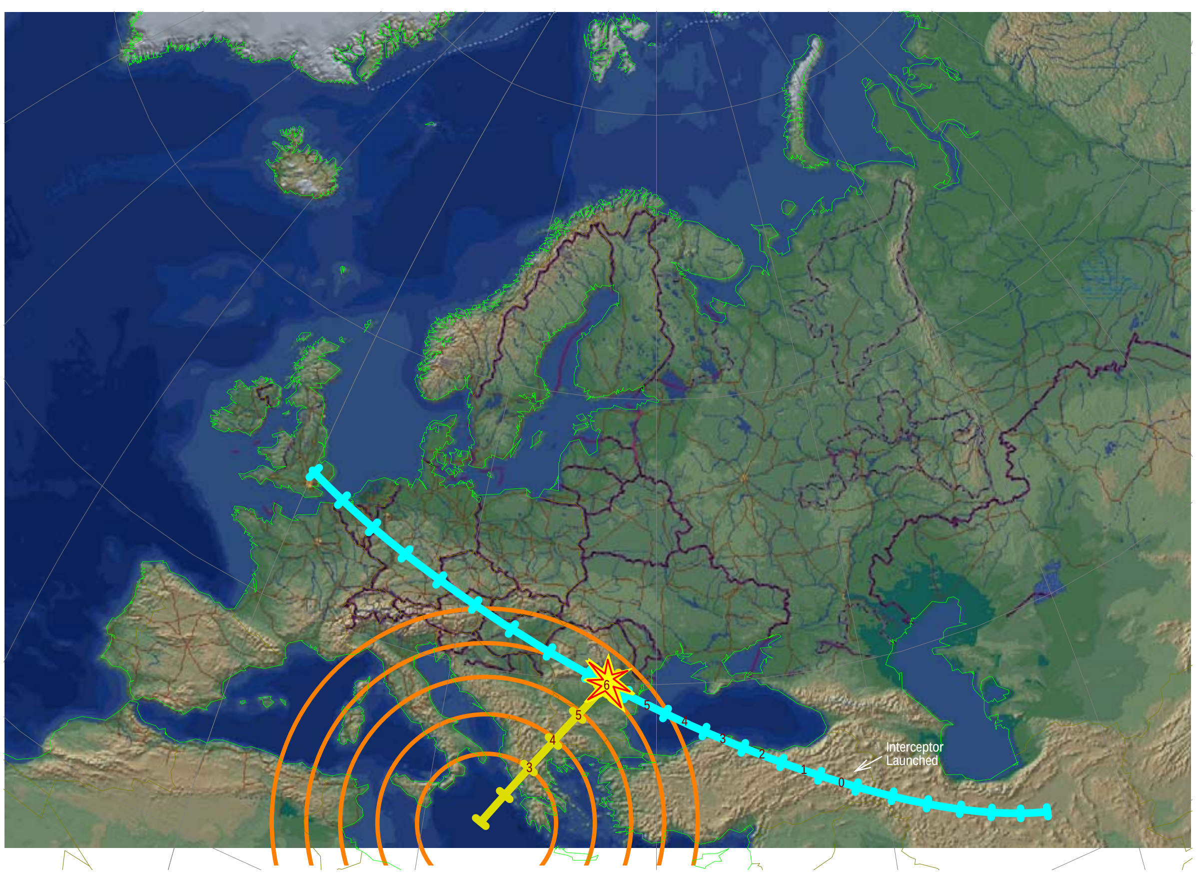


61-Missile Magazine

Aegis Engagement Timelines for Defense of UK from the Baltic Sea



Aegis Engagement Timelines for Defense of UK from the Mediterranean Sea



Conclusions with Regard to Interceptor Capabilities

Assuming systems work as MDA claims:

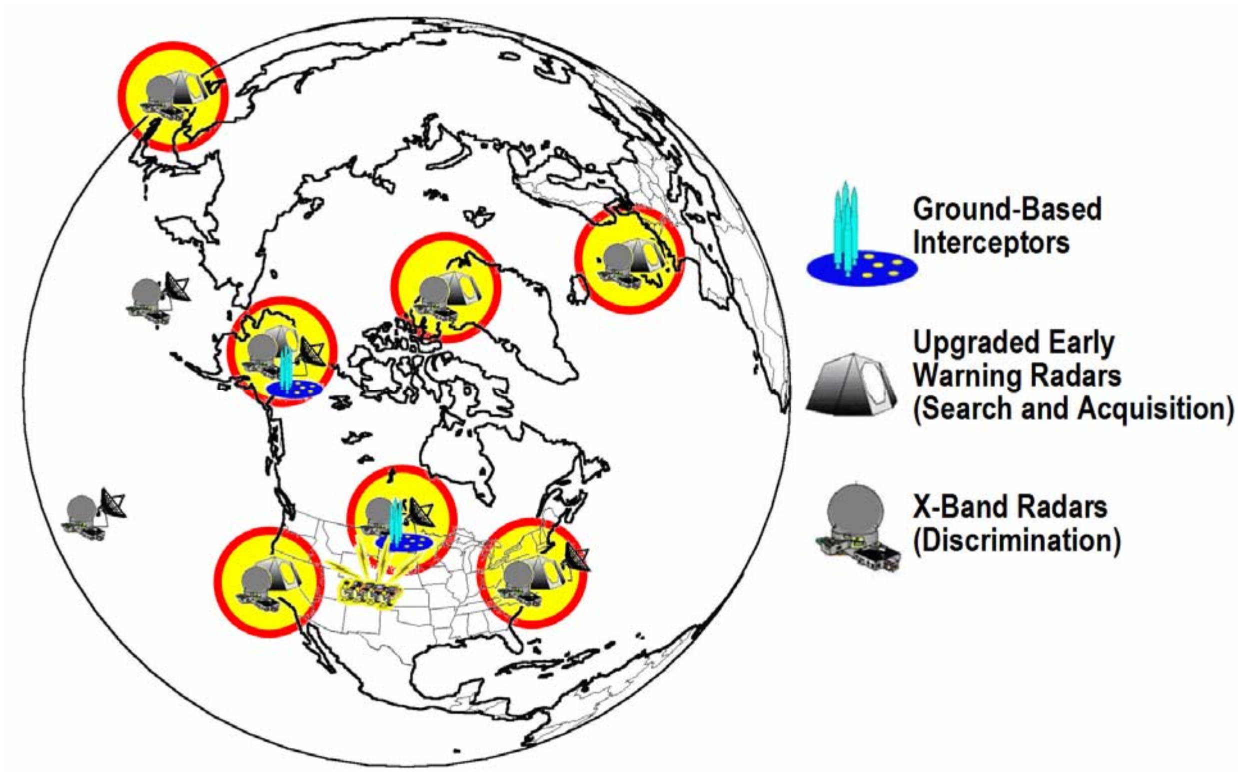
- The current proposed system could engage Russian ICBMs.
- Russian ICBMs will be observable by the EMR in the Czech Republic during their bussing operations, allowing for warheads and decoys to be tracked as they are deployed and providing potentially very valuable cueing information to missile defense units in the continental United States.
- There are many other alternative deployments that could easily meet the US stated objective of defending against postulated Iranian ICBMs.
- Aegis system interceptors are kinematically able to provide intercept coverage for a missile defense of Europe.
- Two-Stage Ground-Based Interceptors sited in Poland are kinematically able to provide intercept coverage for most, but not all, of Europe.
- The Missile Defense Agency has made statements that the Aegis can do the job, but there are as yet unresolved questions about whether the Aegis interceptor Kill Vehicle has adequate acquisition and divert capabilities to reliably find and maneuver to hit Intermediate Range Ballistic Missile (IRBM) warheads.
- There are also many unresolved engineering and technical issues associated with the Two and Three Stage Ground-Based Interceptors *and* the EKV.
- Thus, from the perspective of performance uncertainties, Aegis interceptors appear to be as viable a choice for policy makers as Ground-Based Interceptors.

Can the System “Do the Job”?

The Complementary Role of Acquisition and Tracking Radars in the Europeand Missile Defense

What Has Happened to the Acquisition Radars the US Missile Defense Program?

Original System Plans Required that the UEWRs be Used for Acquisition
and X-Band Radars be Used for Discrimination!



Basic Physics Determining Radar Capabilities

Capability of Radar Determined by Average Power Radiated from Antenna

Size of the Antenna

Radar Cross Section (RCS) of Targets to be Engaged

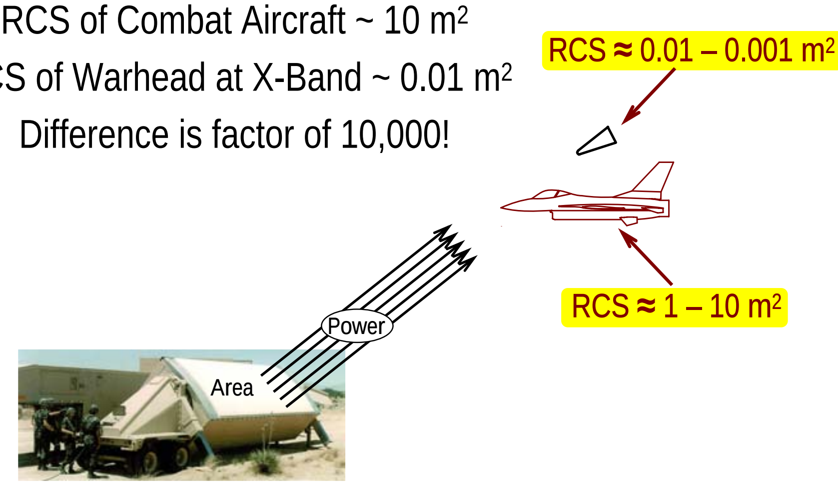
Radar Cross section Reduction

This is why Stealth can be effective against previously capable radars

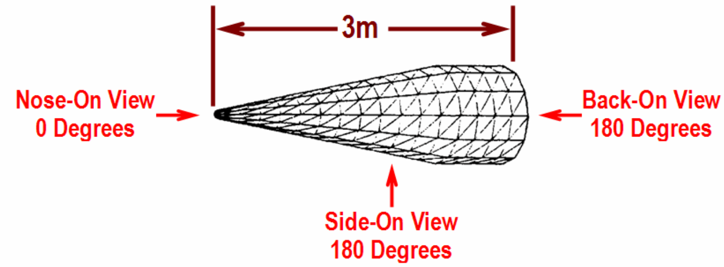
RCS of Combat Aircraft ~ 10 m^2

RCS of Warhead at X-Band ~ 0.01 m^2

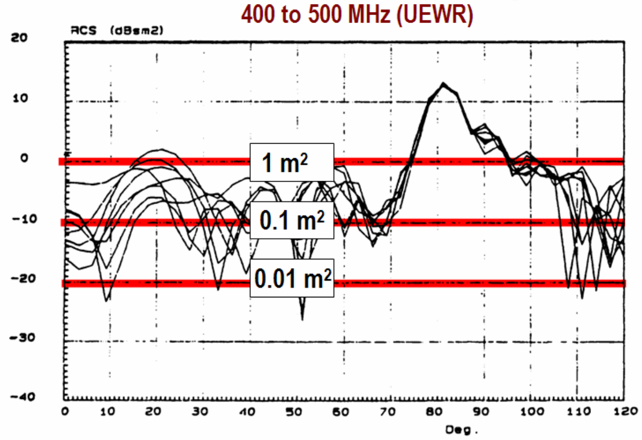
Difference is factor of 10,000!



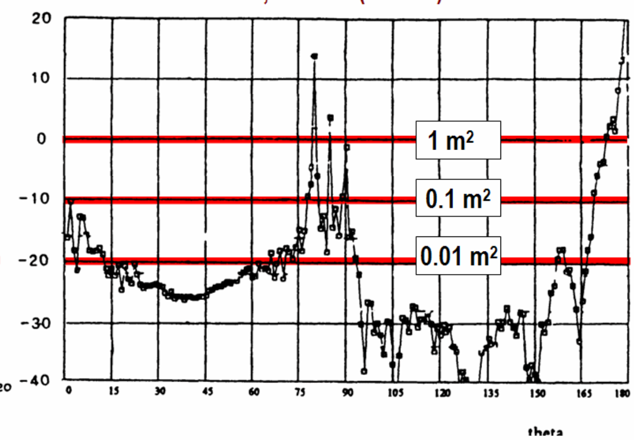
Radar Cross Section of Large Round-Nose Warhead



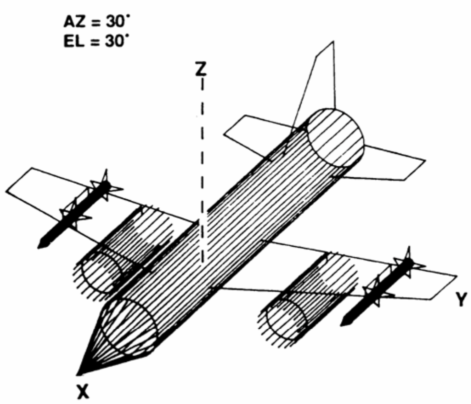
UHF Radar Cross versus Look Angle
400 to 500 MHz (UEWR)



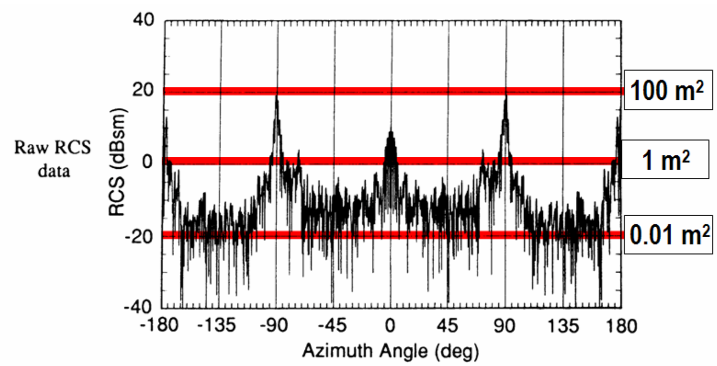
X-Band Radar Cross versus Look Angle
10,000 MHz (10 GHz)

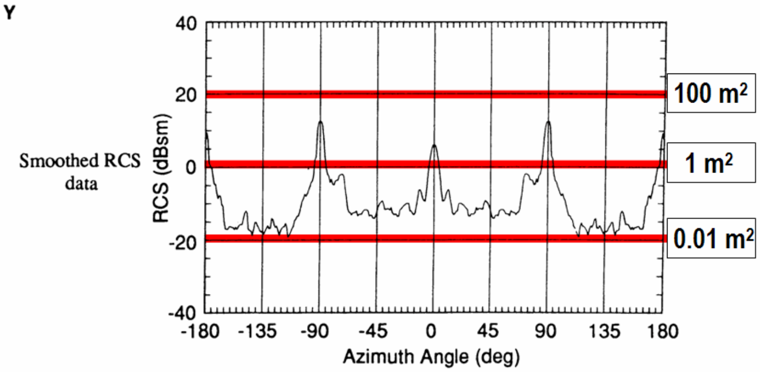


Radar Cross Section of Generic Aircraft



Generic aircraft model

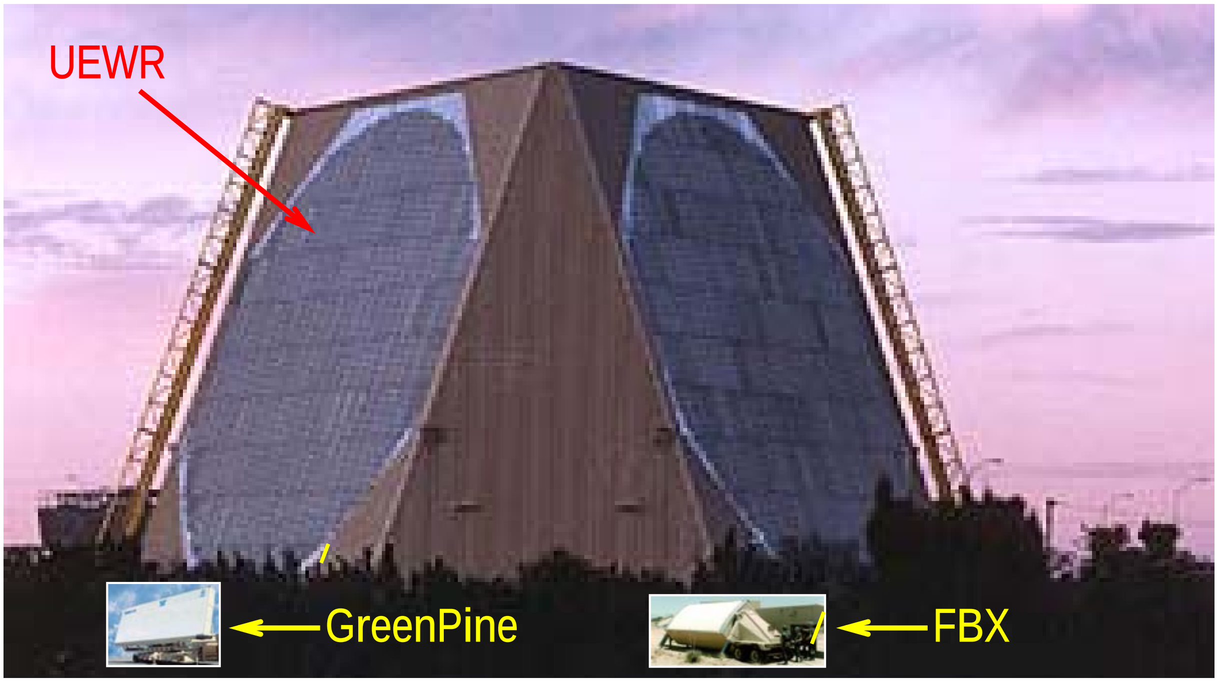




Computed raw and smoothed RCS data for generic aircraft model at 10 GHz. Smoothed data is the median within each 5° window with 2° slide.

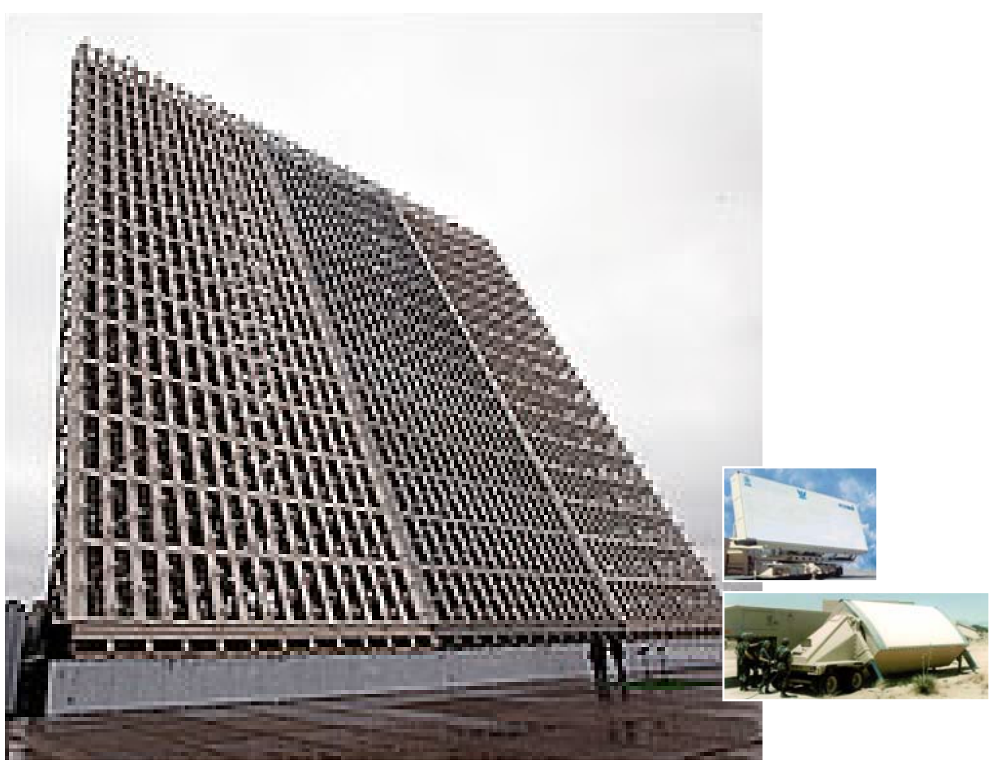
Phased Array Warning System (PAVE PAWS)
UHF Radar Being Used in National Missile Defense System

The size of the FBX and its limited average power make it considerably less capably than large lower frequencies radars like the US UEWR and the Russian Voronezh VHF radars for acquiring and and tracking naturally stealthy ballistic missile warheads at long-range.

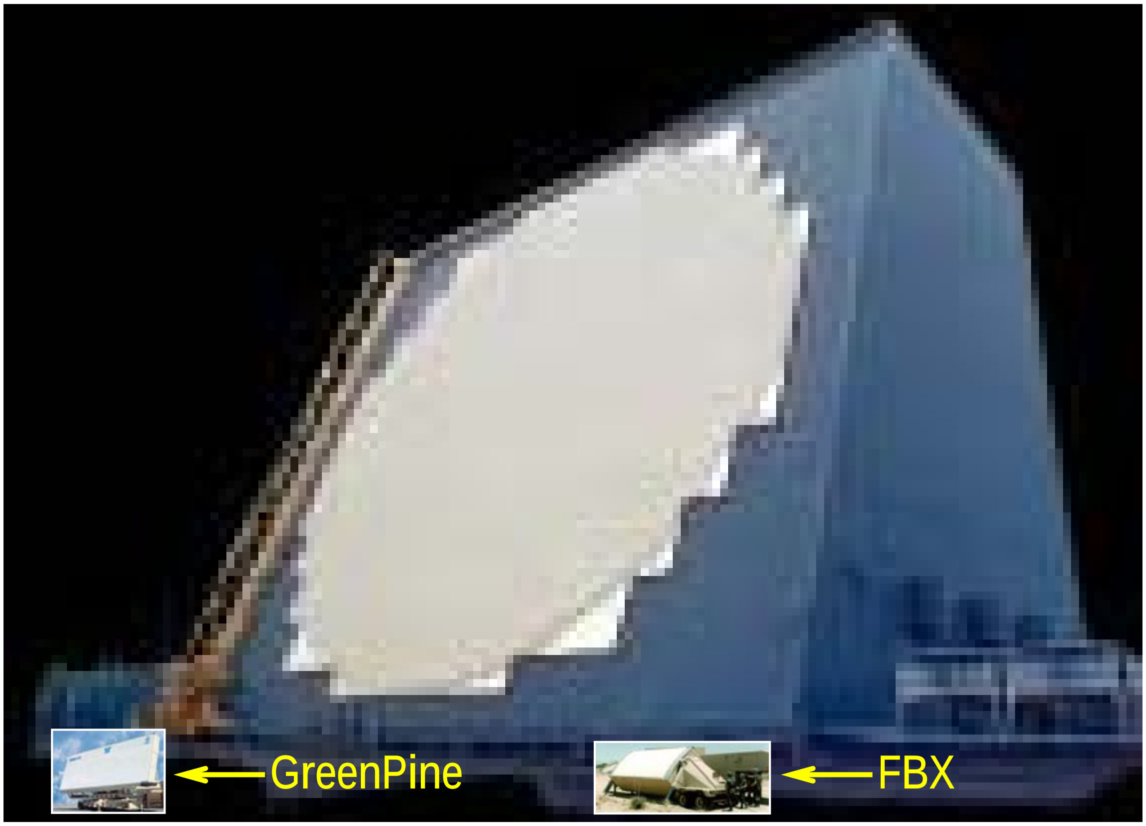


Russian Voronezh Class Third Generation Upgraded VHF Early Warning Radar
that is Potentially Usable in "Light" National Missile Defense System

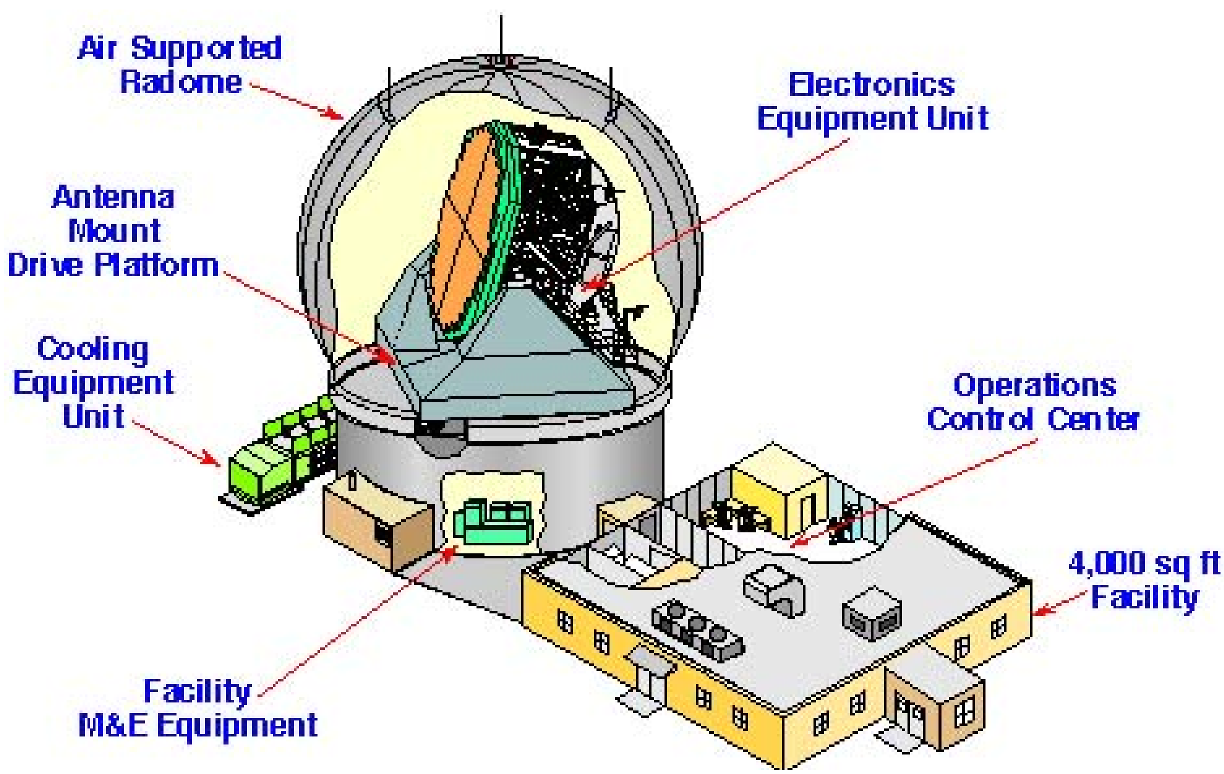
The size of the FBX and its limited average power make it considerably less capably than large lower frequencies radars like the US UEWR and the Russian Voronezh VHF radars for acquiring and and tracking naturally stealthy ballistic missile warheads at long-range.



Cobra Dane L-Band Phased Array Intelligence Radar Being Used in National Missile Defense System



National Missile Defense Ground-Based Radar Prototype (NMD-GBR-P) X-Band Radar to be Used in National Missile Defense System



The Forward-Based X-Band Radar (FMX) Has Limited Acquisition Abilities Against 0.01 m^2 Cone-Shaped Warheads at Ranges Greater Than 1000 km

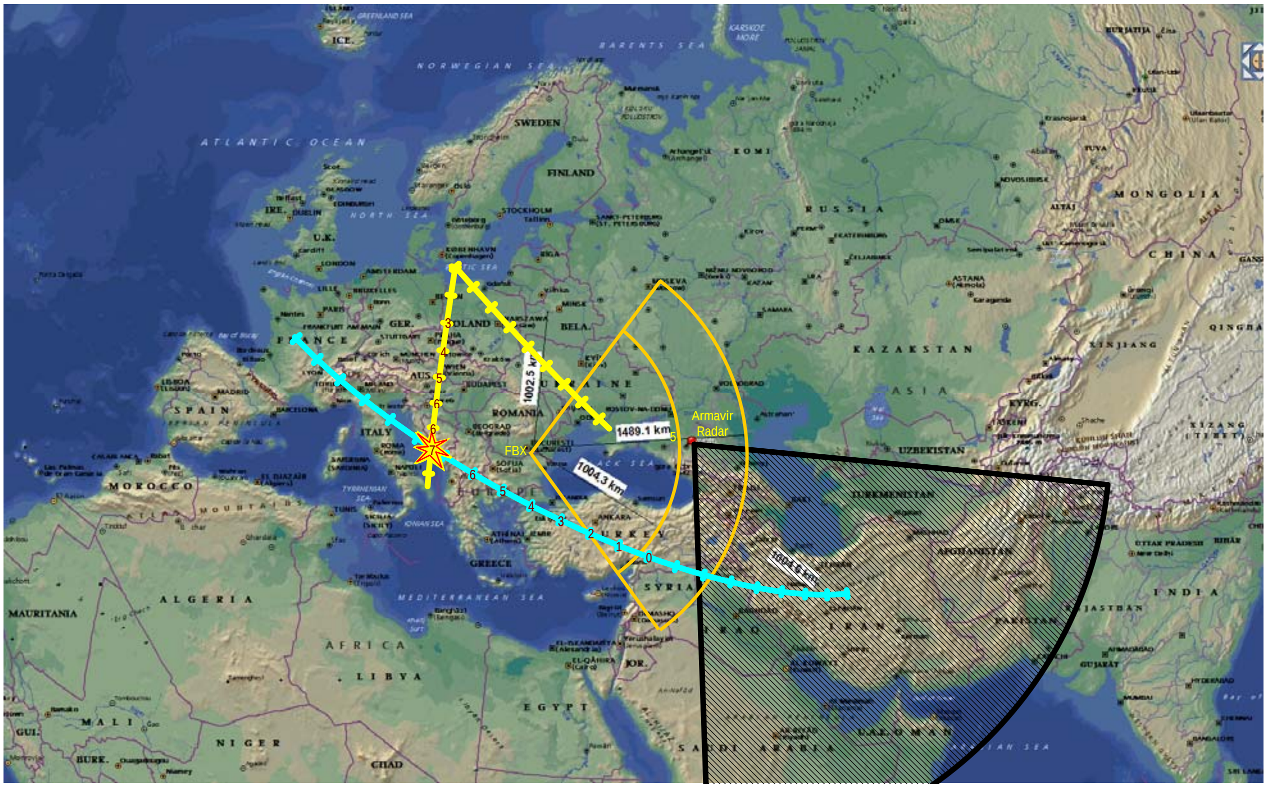
1000 km Range – Dwell Time =0.05 sec; Radar Cross Section = 0.01 m^2, S/N = 20, Area Searched at Distance = 4.3 km x 10.3 km
1500 km Range – Dwell Time =0.25 sec; Radar Cross Section = 0.01 m^2, S/N = 20, Area Searched at Distance = 6.5 km x 15.5 km

The Israeli Green Pine L-Band Missile Defense Radar (1 – 2 GHz) can Acquire and Track a 2 m^2 Target at 500 km and a 0.02 m^2 Target at 50 km

Practical Ranges at Which the FBX Radar can Acquire and Track a 0.01 m² Cone-Shaped Warhead

Practical Ranges at Which the FBX Radar can Acquire and Track a 0.01 m² Cone-Shaped Warhead

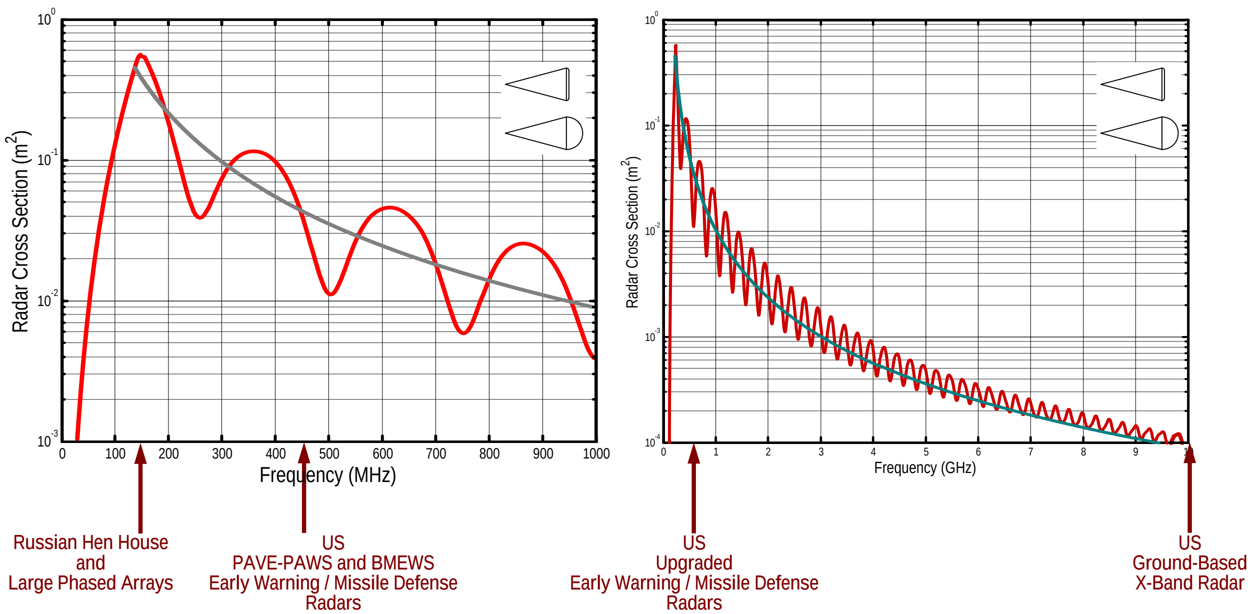
Armavir Acquisition Capability for an FBX Radar in Romania Against a Cone-Shaped Warhead with a 0.01 m² Radar Cross Section at X-Band



Operating Frequencies of Early Warning and Missile Defense Radars

Radar Cross Section of Rounded-Back Cones

The operating frequency of Russia's Early Warning Radars was chosen so that the radar reflectivity of warheads approaching Russia would be as large as possible, thereby making it easier for the radars to detect the approaching warheads at very long range. However, a serious drawback associated with radars operating at these frequencies is that they highly vulnerable to blackout effects from high-altitude nuclear explosions.



Findings of the Technical Analysis (1 of 2)

Assuming systems work as MDA claims:

- The current proposed system could engage Russian ICBMs.
- Russian ICBMs will be observed during their bussing operations, allowing for warheads and decoys to be tracked as they are deployed.
- There are many other alternative deployments that could easily meet the US stated objective of defending against postulated Iranian ICBMs.
- The Russian proposal to instead use radars (Russian and US) in Azerbaijan would allow the US to meet its stated objective of defending against postulated Iranian ICBMs without posing a threat to Russian ICBM forces.
- A system of equal or greater capability than the one currently being proposed by the US could use radars in Azerbaijan and/or Turkey, with interceptors placed in Albania, Bulgaria, Greece, or Turkey

Findings of the Technical Analysis (2 of 2)

The Radar Support Requirements for the System are Woefully Inadequate

- The planned radar support for the European missile defense is woefully inadequate.

  X-band radars are fundamentally not suited for the role of acquisition and surveillance. Lower frequency radars operating at VHF, UHF, or L-Band are all far more suitable for this mission.
- The radar acquisition and surveillance problem could probably be solved by using multiple Forward-Based X-Band radars placed strategically between Iran and Europe.

  These radars would probably only be able to acquire and track cone-shaped ballistic missile warheads at ranges less than 1000 km range. They would, however, be able to track the upper rocket stage that deploys the warhead at greater range. This may make it possible for the radar to cue on upper rocket stages as part of a process aimed at acquiring and tracking the warhead.
- The radar acquisition and surveillance problem could also be solved by using the Russian Voronezh Class VHF Early Warning Radar in Armavir, Russia.

Fundamental Issues that Needs to be Addressed

Fundamental Issue that Needs to Be Addressed

- Even if the funding for the Missile Defense Program were expanded to a substantial part of the entire Department of Defense budget, the resulting missile defense system would still be fundamentally unreliable, unless it can be demonstrated that the system can tell the differences between simple decoys and warheads.
- There is overwhelming evidence that exoatmospheric Missile Defenses are fundamentally vulnerable to exoatmospheric decoys. This near-certain vulnerability has far ranging implications for the viability of exoatmospheric missile defenses and the nation's security. Congress should consider investigating this serious and fundamental vulnerability.

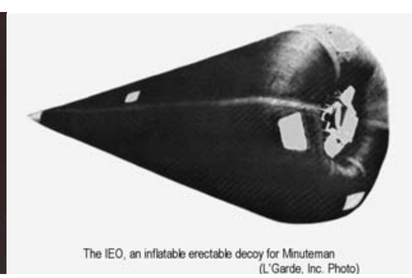
Some Photos of Objects that Could Appear Like Warheads

Large Balloon
With Reflecting Coating

2.2 Meter Diameter Balloon
With Black Coating

Balloon With White Coating

Light Rigid Replica Decoy



Minuteman Inflatable Decoy

Minuteman Warhead

Conclusions

From a Purely Technical Perspective:

- There appears to be no credible *technical* reason that the stated US objective to defend against postulated future Iranian ICBMs could not be fulfilled by other types of deployment configurations.
- Recent statements made by the MDA, and numerous past technically misleading and inaccurate statements made by the MDA, would likely cause skepticism and suspicion among Russian military analysts who advise their political leadership.
- It is therefore understandable that Russian military analysts might suspect that US motivations are different from those that have been stated.

Soviet Capabilities for Strategic Nuclear Conflict, 1983-93 (NIE 11-3/8-83)

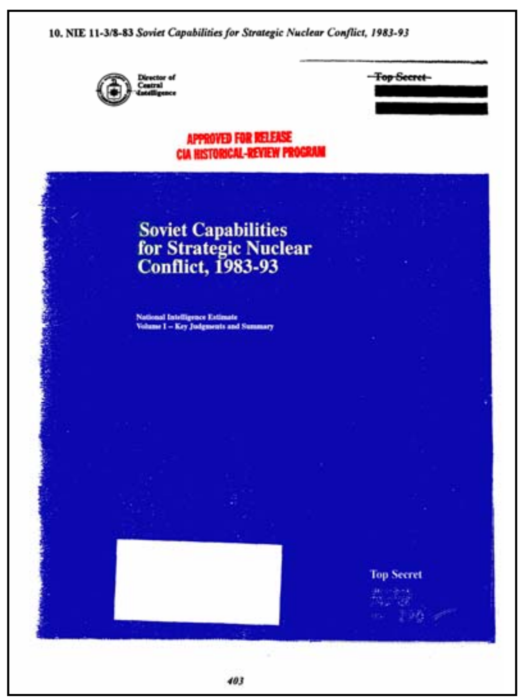
Soviet Capabilities for Strategic Nuclear Conflict, 1983-93 (NIE 11-3/8-83)
Formerly Top Secret

Key Judgments of US Intelligence Community in 1983

We have major uncertainties about how well a Soviet ABM system would function, and the degree of protection that future ABM deployments would afford the USSR. Despite our uncertainties about its potential effectiveness, such a deployment would have an important effect on the perceptions, and perhaps the reality, of the US-Soviet strategic nuclear relationship.

•••

widespread Soviet defenses, even if US evaluations indicated they could be overcome by an attacking force, would complicate US attack planning and create major uncertainties about the potential effectiveness of a US strike.


10. NIE 11-3/8-83 *Soviet Capabilities for Strategic Nuclear Conflict, 1983-93*

Director of Central Intelligence

~~Top Secret~~
[redacted]

APPROVED FOR RELEASE
CIA HISTORICAL-REVIEW PROGRAM

Soviet Capabilities for Strategic Nuclear Conflict, 1983-93

National Intelligence Estimate
Volume I – Key Judgments and Summary

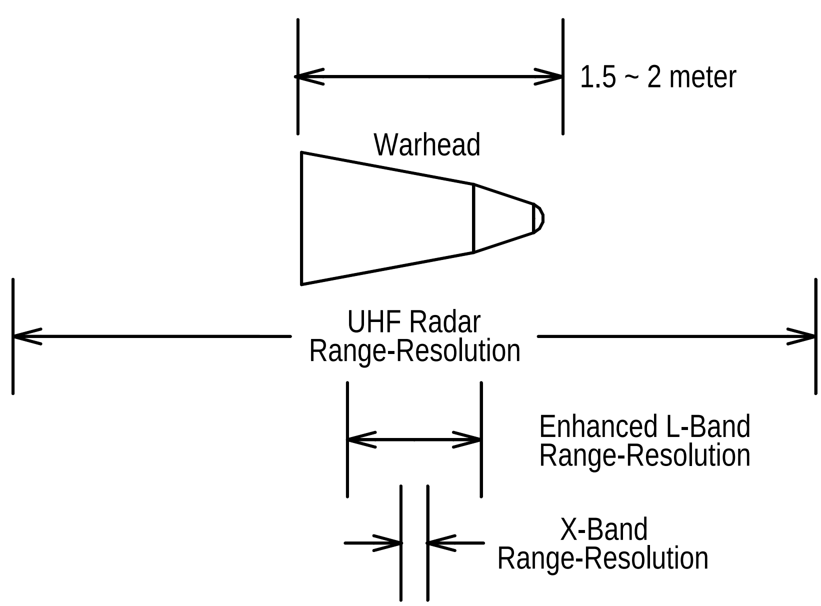
Top Secret

403

Appendix A

Radar Range Resolution
Capabilities of Different Radars that Might Be Used in Missile Defense Systems

Radar Range-Resolution of the Different Missile-Defense Radars



Radars Used for Ballistic Missile Defense

Radar Type	Designation	Frequency	Wavelength	Bandwidth	Range Resolution
Russian Early Warning Radar	VHF	150	2.0 meters	~10 MHz	~10 – 15 meters
US Upgraded Early Warnings	UHF	430 MHz	0.66 meters	~30 MHz	~4 - 5 meters
Cobra Dane	L-Band	1,000 MHz	0.30 meters	~200 MHz	~0.75 meters
Ground-Based Radar	X-Band	10,000 MHz	0.03 meters	~1,000 MHz	~0.15 meters

$$\text{Number of Elements per Unit Area} \sim \frac{1}{\lambda^2}$$

Power per Unit Area ~ 5000 W/m^2

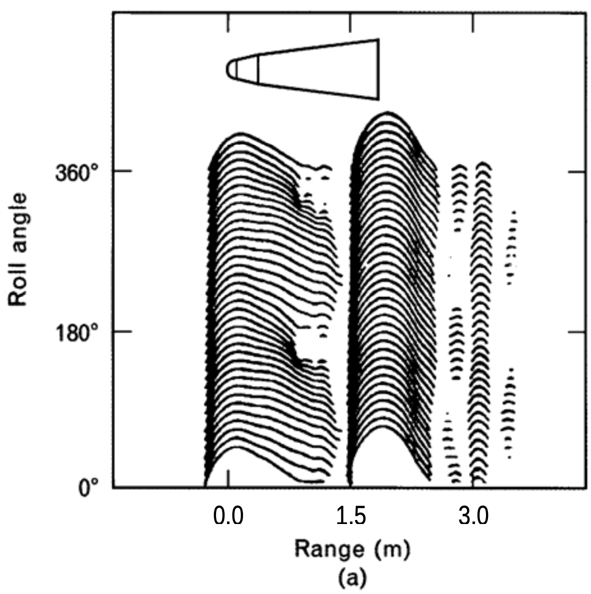
$$\text{Radar Cross Section} \sim \frac{1}{\lambda^2}$$

$$\text{Radar with Comparable Search Capability} \sim \frac{1}{\lambda^4}$$

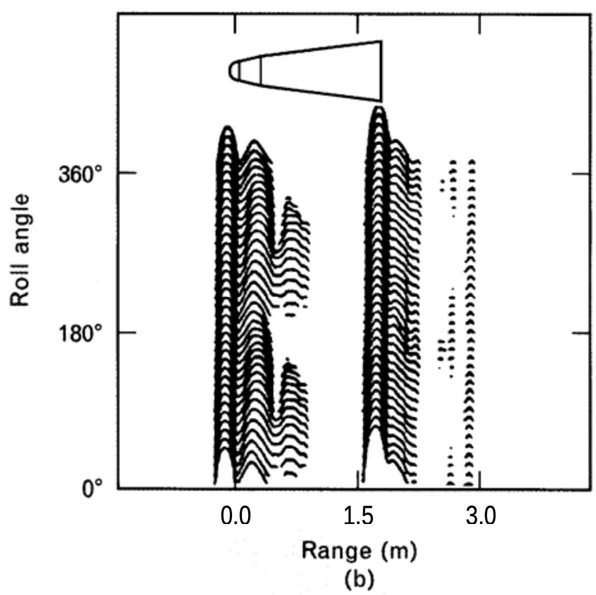
$$\text{UHF vs X-Band} \sim \left(\frac{0.66}{0.03}\right)^4 = 234{,}000$$

Examples of Radar Signals from Warheads

C-Band (5Ghz) Radar Signal
Against 1.5 Meter Long Warhead



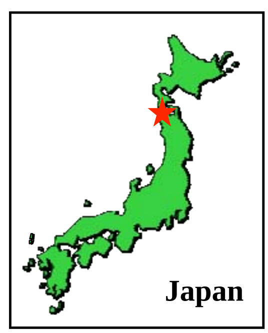
X-Band (10GHz) Radar Signal
Against 1.5 Meter Long Warhead



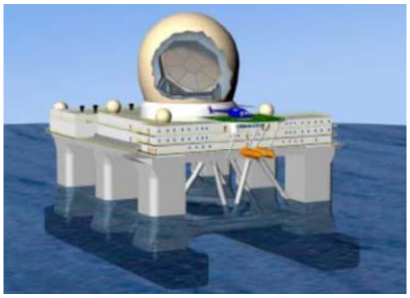
Appendix B

X-Band Radar Technology and Radar Performance Estimates Relevant to Assessing Missile Defense System Capabilities

Forward Based X-Band Radar



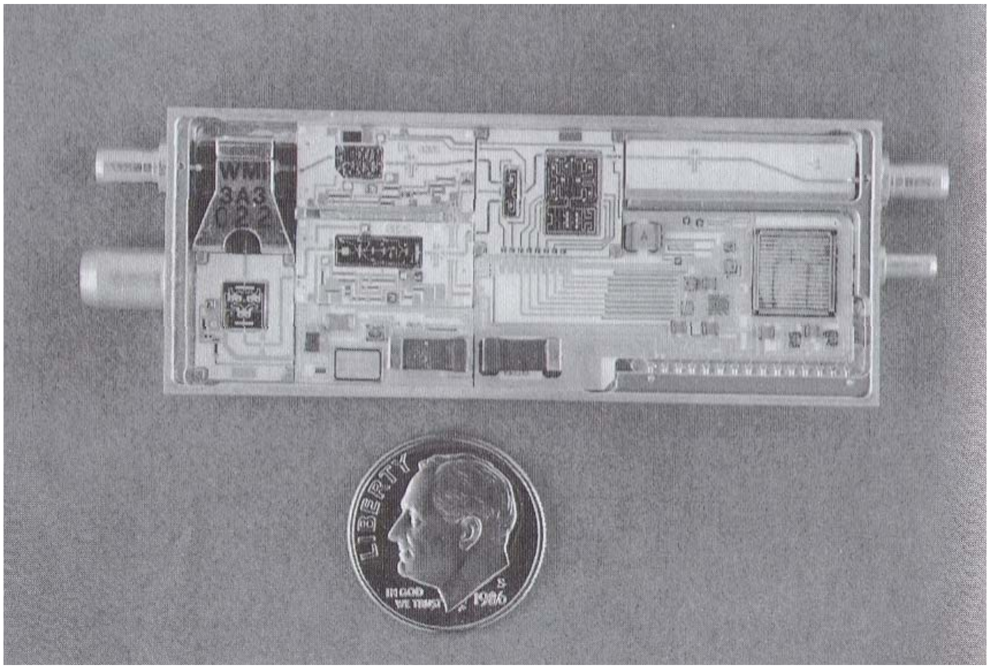
Phased-Array X-Band Radars



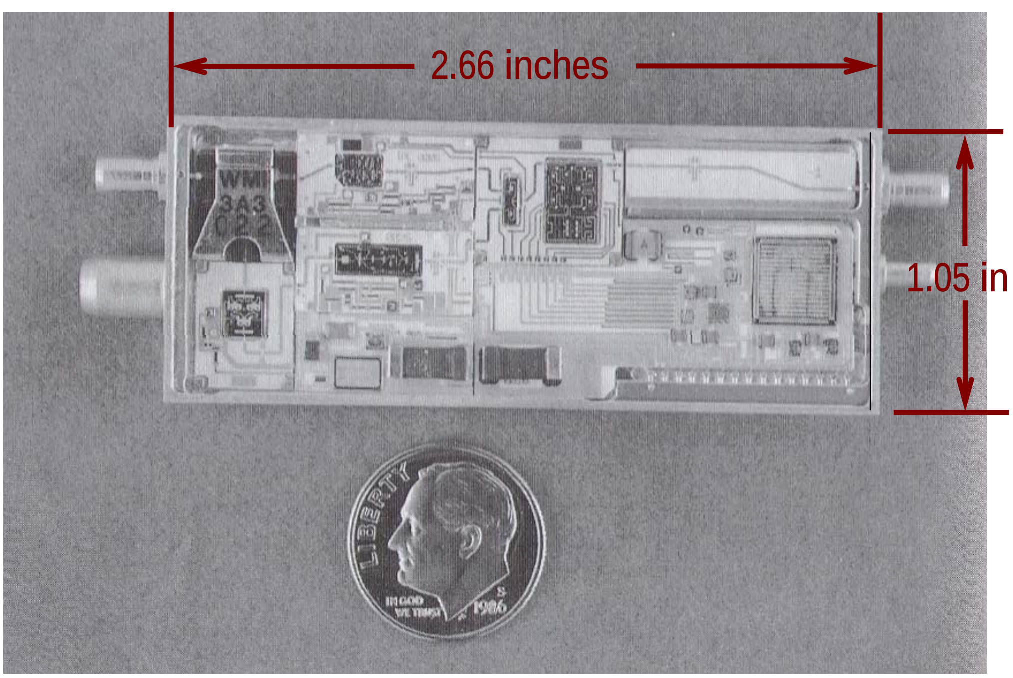
X-Band Modules

- Radar modules are based on GaAs monolithic microwave integrated circuits (MMICs).
- Such modules typically produce long pulses with high duty cycles.
- X-band radars thus use linear-frequency-modulation pulse compression to get range resolution.
- Bandwidth of 1 GHZ, corresponding to 15 cm resolution usually assumed.
- Duty cycle appears to be about 0.2.

X-Band Module



X-Band Module



X-Band Module

- About 70,000 first-generation (6-8 w peak power, 1.2-1.6 w average power) modules went to THAAD Dem/Val, 2 THAAD UOES, and the GBR-P radars. THAAD Dem/Val was dismantled for the modules for the GBR-P.
- About 60,000 second-generation (10 watt) modules were made and were used for SBX.
- Current third-generation (16 watt?) are used in THAAD EMD, THAAD Production, and FBX.
- X-band modules are apparently expensive and in short supply.

X-Band Modules per Radar

- GBR-P: 16,896
- THAAD/FBX: 25,344
- SBX: 45,264
- GBR: 69,632
- EMR (Czech): ~ 22,000 ???

- Current rate of deployment suggests about enough modules are being made each year to deploy one THAAD/FBX.
- If so, this may explain why EMR won't be available until 2011.
- Modules are expensive, ~$1,000+ each.

X-Band Radars

The new X-band radars can be divided into two groups:

- THAAD/FBX (which are the same): transportable, multipurpose (surveillance, tracking) radars
- -SBX, GBR-P,GBR, EMR. Large, specialized tracking radars. These all have highly "thinned" antennas. Their antennas all can be rotated.

Thinned Array Radars

- To get a narrow beam, want largest possible antenna.
- But filling an antenna the size of GBR-P would require 291,000 modules.
- Instead, spread modules much further apart, so only ~17,000 are needed.
- This gets a narrow beam, but radar is much less powerful than it superficially might appear.
- In particular, P-A is not appropriate figure of merit.

Capabilities of Different Phased Array Radars

Comparison of Target Acquisition Capabilities of Phased Array Radars

	Adjusted P-A (w/m^2)	Sensitivity
• GBR-P	1.2×10^5	74
• EMR	5.4×10^5	380
• THAAD/FBX	7.0×10^5	37
• SBX	1.5×10^6	2,100
• GBR	3.5×10^6	7,700
• FPS-85	6.9×10^8	100,000
• Cobra Dane	2.9×10^8	100,000

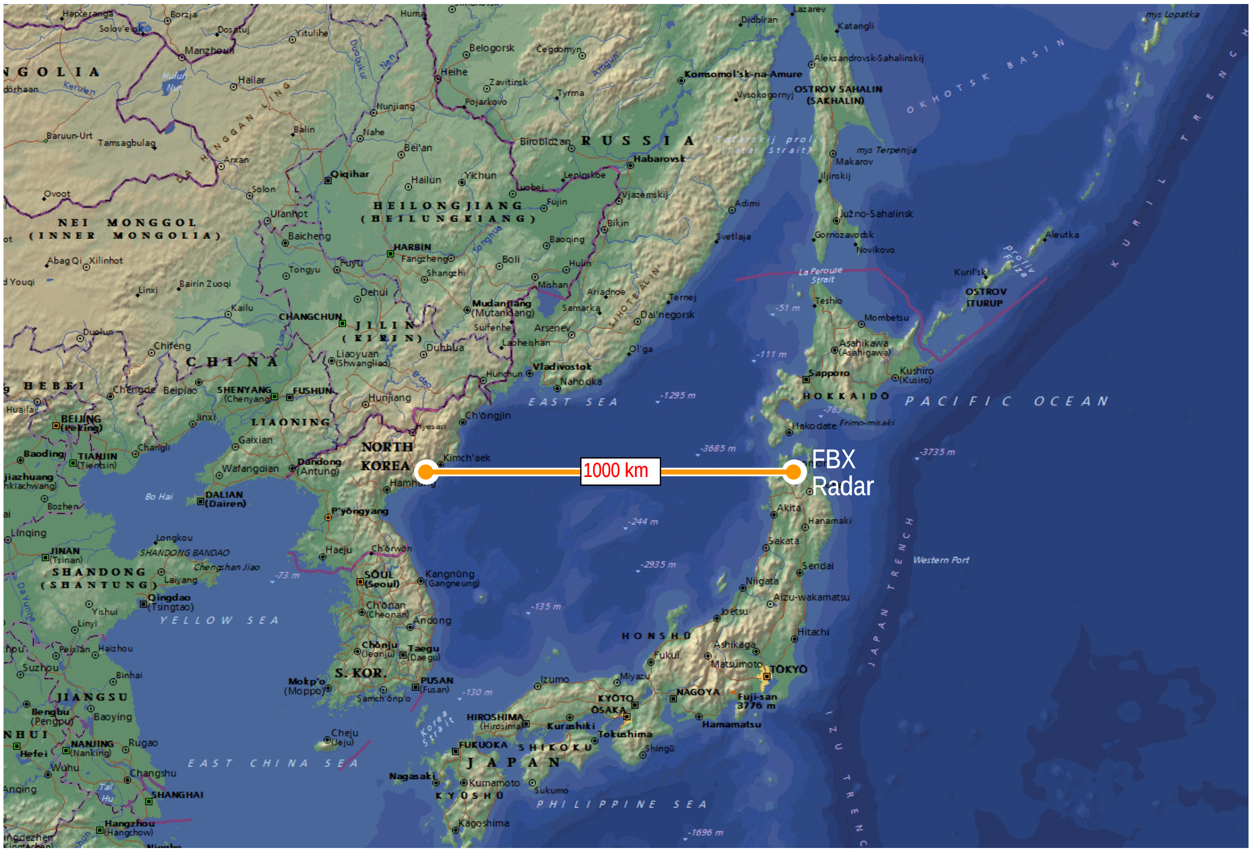
Sensitivity = S/N at 1,000 km for 1 m^2 target with 1 msec pulse
Adjusted P-A = P * A * Thinning Ratio (0.065 for SBX, GBR)

Radar Data and Calculations Courtesy of George Nelson Lewis, Peace Studies Program, Cornell University

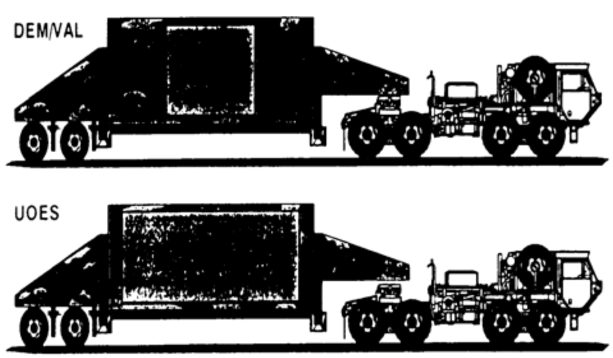
EMR vs Iran Warhead to West Coast of U.S.

- If EMR sensitivity is 380, then a 1 millisecond dwell time, gives a S/N of 0.025 for a 0.01 m^2 target at 3,500 km.
- Thus to get S/N =20, would require about 4.0 seconds of dwell time.
- An ICBM would move several beam widths in this time.
- Beam width = 0.03 / 12.5 × 3,500 = 8.4 km

Distance of Japan-Based FBX from Postulated ICBM Launch Site



Technical Characteristics of THAAD X-Band Mobile Ground-Based Radar



	DEM/VAL	UOES
Frequency (GHz)	X-Band	X-Band
Array Size (m^2)	4.6	9.2
Solid State T/R modules	12,672	25,344
Subarrays (Transmit/Receive)	36/36	72/72
Max Scan (degrees : Az : El)	53/53	53/53
Mechanical Tilt (degrees)	10 - 60	10 - 60

Fig. 2. The DEM/VAL and UOES Array Differences