

# Physics 280: Session 14

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Plan for This Session

Questions

Midterm Review Session

News and discussion

Module 5: Nuclear Weapon Delivery Systems

# News and Discussion

**The New York Times**

## **North Koreans Agree to Freeze Nuclear Work; U.S. to Give Aid**

By STEVEN LEE MYERS and CHOE SANG-HUN

WASHINGTON — North Korea announced on Wednesday that it would suspend its nuclear weapons tests and uranium enrichment and allow international inspectors to monitor activities at its main nuclear complex. The surprise announcement raised the possibility of ending a diplomatic impasse that has allowed the country's nuclear program to continue for years without international oversight.

The Obama administration called the steps “important, if limited.” But the announcement seemed to signal that North Korea's new leader, Kim Jong-un, is at least willing to consider a return to negotiations and to engage with the United States, which pledged in exchange to ship tons of food aid to the isolated, impoverished nation.

# News and Discussion

## Los Angeles Times

### North Korea: What does 240,000 metric tons of food mean?

February 29, 2012 | 1:20 pm

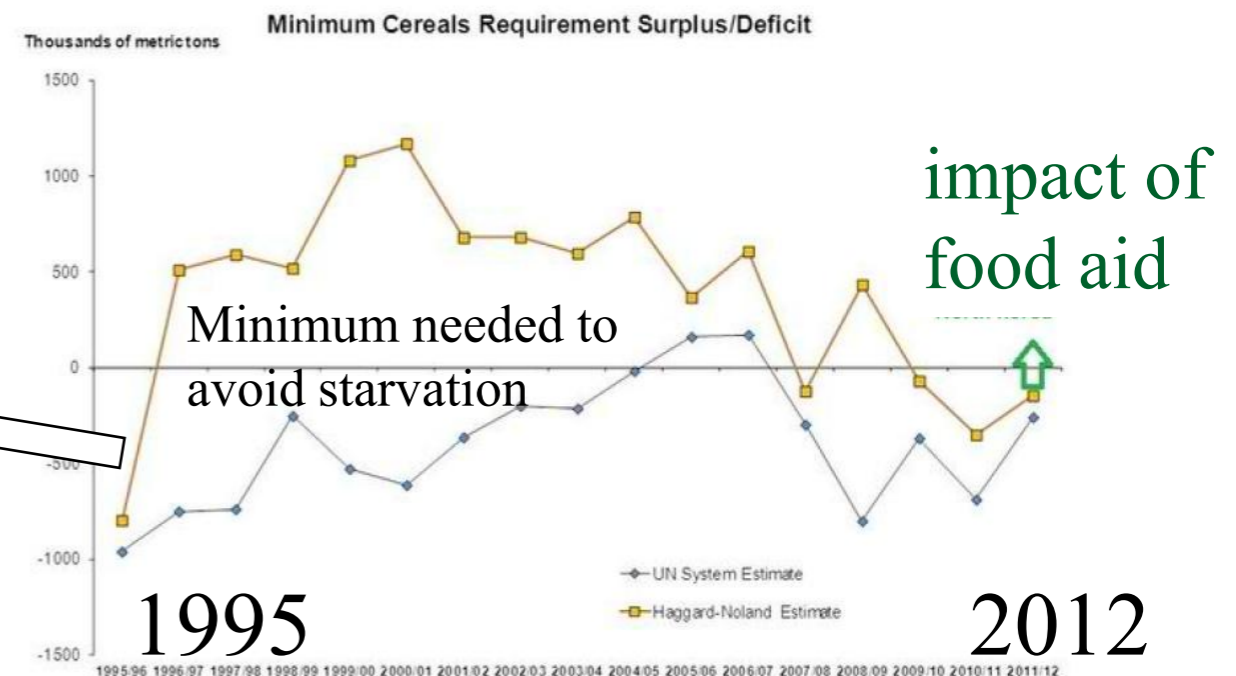
Hunger is a known menace in North Korea: In most of the country, even a bowl of rice is a rare treat. North Korea and the U.S. are poised to **strip** would bring 240,000 metric tons of food aid to the impoverished country if it suspends nuclear weapons tests and enrichment.

What would all that food really mean for North Korea? Here's a quick look.

Experts **Stephan Haggard** and **Marcus Noland** have estimated that North Korea has been falling below the minimum grain supplies needed for **eat** have enough food, as the graph below shows.

The yellow line represents their estimates; the blue line is U.N. estimates, which are somewhat lower. The Times added a green arrow to show how 240,000 metric tons of U.S. aid could change that.

**Famine in North Korea 1995 – 1998**  
unknown number of victims  
estimates 600,000 – 3000,000  
in a population of 23 million



# Midterm Exam Review Session

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Please i-vote which time slot for the midterm exam review will work better for you:

(A) 6:00 – 7:30 PM, Sunday, March 11<sup>th</sup>, 144 Loomis

(B) 7:00 – 8:30 PM, Sunday, March 11<sup>th</sup>, 144 Loomis

(C) 7:00 – 8:30 PM, Tuesday, March 13<sup>th</sup>, 151 Loomis

# Module 5: Delivery Systems

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Part 1: Overview of nuclear weapon delivery methods

Part 2: Aircraft

Part 3: Cruise missiles

Part 4: Ballistic missiles

Part 5: Technical and operational aspects

Part 6: Nuclear command and control

# Nuclear Delivery Systems

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## Part 1: Overview

# Basic Propulsion Mechanisms

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- **None**  
(examples: mines, depth charges, shipping container)
- **Explosives**  
(example: artillery shell)
- **Propellers**  
(example: torpedo, speeds ~ 50 mph)
- **Jet engines**  
(example: bomber, speeds ~ 600 mph)
- **Rocket motor**  
(example: missile, speeds ~ 18,000 mph)
- **Unconventional**  
(examples: barge, boat, Ryder truck, backpack)

# Examples of Weapon Delivery Methods

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## Air-breathing vehicles —

- Aircrafts (manned)
- Cruise missiles (unmanned aircraft)

## Rocket-propelled vehicles —

- Land-based ballistic missiles
- Submarine-based ballistic missiles
- Surface ship-based ballistic missiles\*
- Space-based ballistic missiles\*
- Short range rockets (no guidance)

## Other —

- Artillery/howitzers
- Land mines
- Torpedoes

\* Never deployed by US or USSR/Russia for nuclear weapons



# Important Attributes of Delivery Systems

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- Range
- Speed
- Accuracy
- Recallability
- Reliability
- Payload/throw-weight
- Ability to penetrate defenses
- Survivability (at deployment base)
- Capital and operational costs
- Safety

# Air-Breathing Vehicles

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## Aircraft (manned) —

- Long-range (“heavy”) bombers  
(examples: Bear, Blackjack, B52, B-1, B-2)
- Intermediate-range bombers  
(examples: B-29, FB-111, ...)
- Tactical aircraft  
(examples: F-16, F-18, F-22, ...)

## Cruise missiles (unmanned) —

- Air-launched cruise missiles (ALCMs)
- Sea-launched cruise missiles (SLCMs)
- Ground-launched cruise missiles (GLCMs)

# Rocket-Powered Vehicles

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## Land-based ballistic missiles —

- Intercontinental-range ballistic missiles (ICBMs)
- Shorter-range ballistic missiles

## Sea-based ballistic Missiles —

- Submarine-launched ballistic missiles (SLBMs)
- Surface-ship-launched ballistic missiles

# Historical Examples of Other Nuclear Weapon Delivery Methods

## Nuclear artillery shells:

- 16" naval guns
- 280 mm cannons (howitzer)

"Atomic Annie" 1953: 15-kt projectile to range of 17 miles



Operation Upshot/Knothole (1953)

## Davy Crocket Nuclear Bazooka

- 76 lb., 10–250 t yield, 1.2–2.5 mile range
- Deployed 1961–1971; 2,100 produced

## Atomic Demolition Munitions (ADMs)

Carried by back pack, 0.01 kt yield?

## Nuclear-armed torpedoes



Frederick K. Lamb © 2012

# Non-missile Delivery Methods

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“U.S. territory is more likely to be attacked with [chemical, biological, radiological, or nuclear] materials from non-missile delivery means—most likely from terrorists—than by missiles, primarily because non-missile delivery means are —

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

They also can be used without attribution.”

— *Foreign Missile Developments and the Ballistic Missile Threat Through 2015*, Unclassified Summary of a National Intelligence Estimate, December 2001

# The U.S. Cold-War Strategic “Triad” – 1

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Initially US nuclear weapons delivery systems were developed without any coherent plan, in the —

- Truman administration
- Eisenhower administration

McNamara (Kennedy’s Secretary of Defense) changed this —

- Survivable basing
- Secure command and control
- Determine how much is enough by calculation!

Concluded 400 ‘effective’ megatons (EMT) would be “enough”

- The need to give roles to the USAF and the USN defined the “Triad” paradigm, which lasted until the 1990s
- Established the SIOP (Single Integrated Operational Plan) for targeting

# The U.S. Cold-War Strategic “Triad” – 2

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## Strategic nuclear delivery vehicles (SNDVs) —

The definition of “strategic” nuclear weapons was important for arms control but was controversial during the Cold War: the Soviet Union wanted to count weapons on its periphery whereas the U.S. did not want to count these:

- Systems with intercontinental range (U.S. def.)
- Systems able to strike directly the homeland of the adversary (Soviet def.)

## Systems in the Triad —

- Intercontinental-range bombers
- Intercontinental-range ballistic missiles (ICBMs)
- Submarine-launched ballistic missiles (SLBMs)

# Module 5: Nuclear Delivery Systems

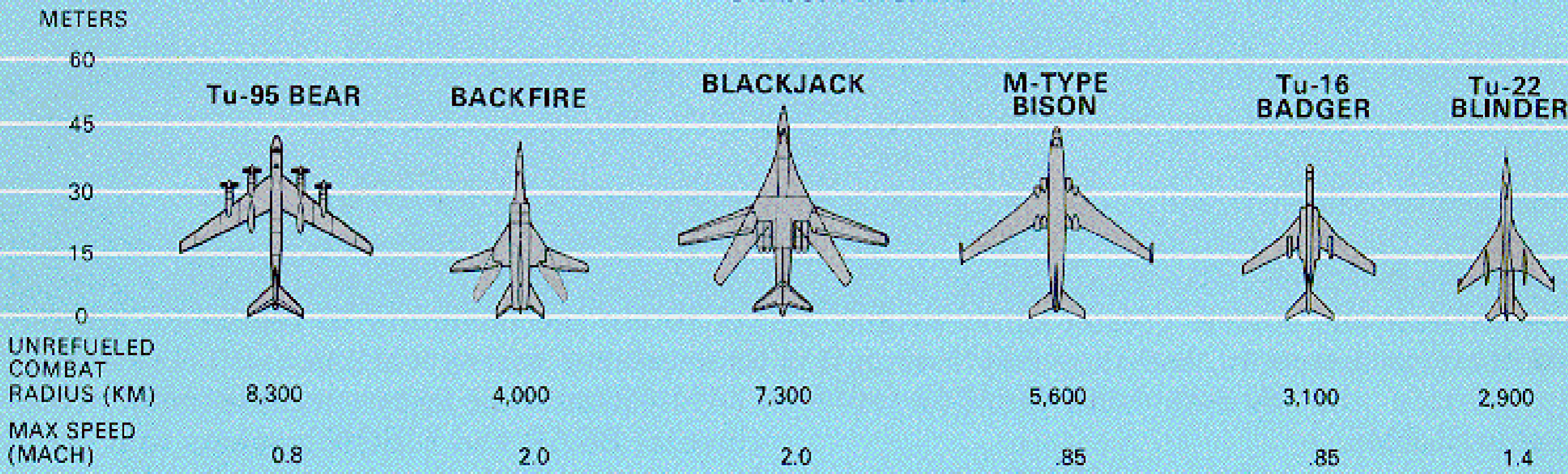
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## Part 2: Aircraft

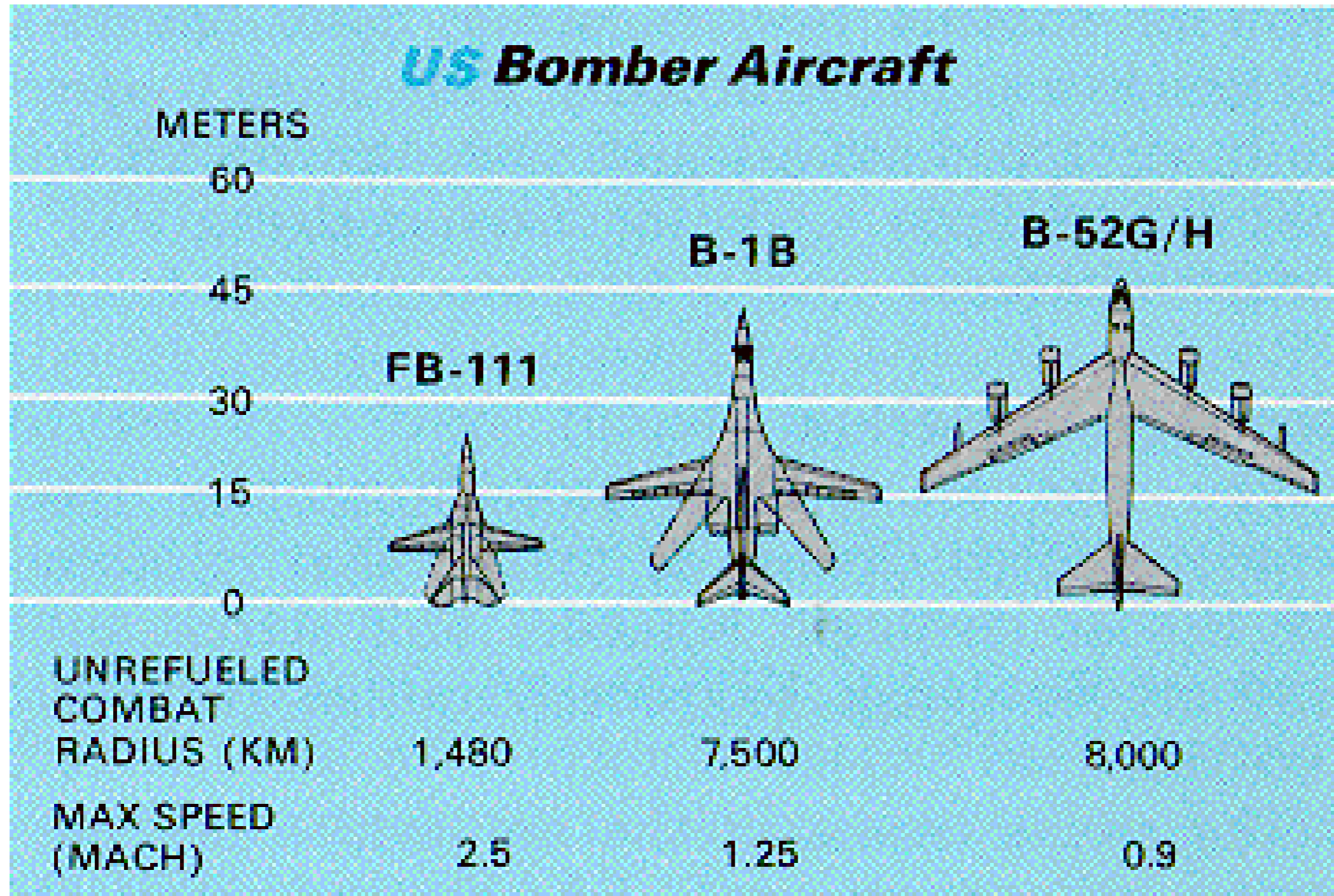


# Examples of Intercontinental Bombers – 1

## USSR Bomber Aircraft



# Examples of Intercontinental Bombers – 2



# U.S. B-2 Stealth Bomber

Speed: Mach 0.85

Height: 50,000 feet

Range: 7,600 miles

Possible payloads:

- 16 B83 gravity bombs
- 20 B61 bombs
- 80 500 lb bombs



# Currently Deployed U.S. and Russian Bombers

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## Current US bombers —

- B-52 Hs, carrying bombs
- B1-Bs, each can carry 16 bombs
- B-2, each can carry 16 bombs

## Russian bombers\* —

- Bear-H16s, carrying bombs
- Bear-H6s, carrying bombs
- Blackjacks, carrying bombs

\*Very few are currently operational

# Intercontinental Bomber Issues

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## Evolution of bomber missions —

- High-altitude bombing
- Low-altitude penetration and bombing
- As a stand-off launch platform for Air-launched cruise missiles (ALCMs)

## Operational considerations —

- Launch, release to targets, and arming of weapons requires permission from the National Command Authority (NCA) (in the United States, the President or his designated successor)
- Can be recalled until weapons (e.g., bombs, cruise missiles, or air-to-surface ballistic missiles) are dropped or fired from the bomber
- The United States has substantial in-flight refueling capability; other countries have none

# iClicker Question

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## Terrorism

Which of the following is *not* one of the “lethal triple cocktail” of factors that Richardson argues leads to terrorism?

- (A) Extreme poverty
- (B) A disaffected individual
- (C) A legitimizing ideology
- (D) An enabling community

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# iClicker Answer

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- (A) **Extreme poverty**
- (B) A disaffected individual
- (C) A legitimizing ideology
- (D) An enabling community



# iClicker Question

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Which one of the following is *not* one of Richardson's "Three Goals of Terrorists"?

- (A) Revenge
- (B) Reaction
- (C) Resources
- (D) Renown

# Blank

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# iClicker Answer

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- (C) **Resources**
- (D) Renown

# iClicker Question

---

Which one of the following delivery vehicles was *not* considered a leg of the Cold War nuclear “Triad”?

- (A) Submarine-launched ballistic missiles
- (B) Ship-launched ballistic missiles
- (C) Land-based intercontinental ballistic missiles
- (D) Land-based intercontinental bombers

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- (D) Land-based intercontinental bombers

# Module 5: Nuclear Delivery Systems

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## Part 3: Cruise Missiles

# Introduction to Cruise Missiles – 1 (Important)

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Cruise missiles (CMs) are pilotless vehicles powered by jet engines:

- Fly within the atmosphere
- Speeds are subsonic

Although cruise missiles were conceived 60 years ago, CMs did not become important until the late 1970s, when technological advances made them militarily useful. These advances were:

- Smaller and lighter nuclear warheads
- Efficient turbofan engines
- Highly capable miniaturized computers
- GPS, TERCOM, and terminal guidance
- “Stealth” airframe technology



# Introduction to Cruise Missiles – 2 (Important)

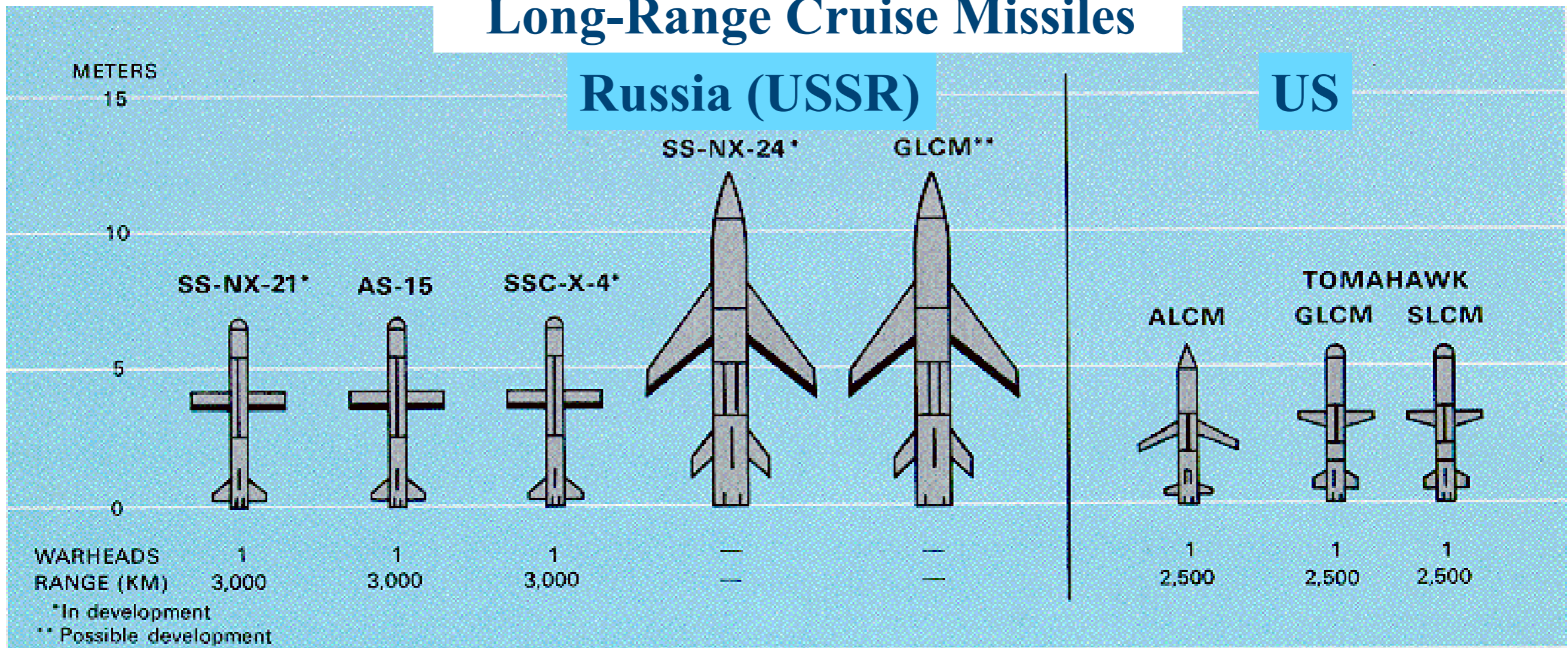
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## Key properties —

- Small
- Easily stored and launched
- Highly penetrating
- Versatile
- Highly accurate
- Very cheap (about ~ \$1 million per copy)

# Long-Range Cruise Missiles – 1

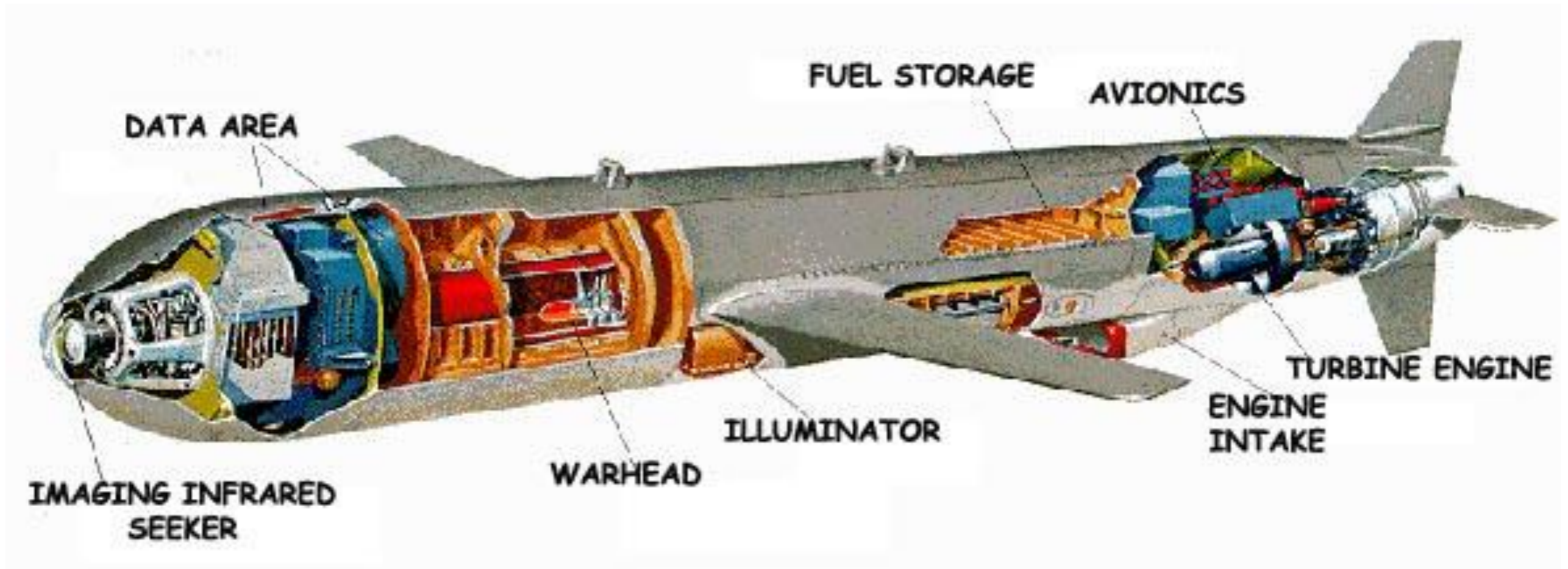
## Long-Range Cruise Missiles



range : 1000 – 2000 miles

pay loads : 500 – 1200 lbs

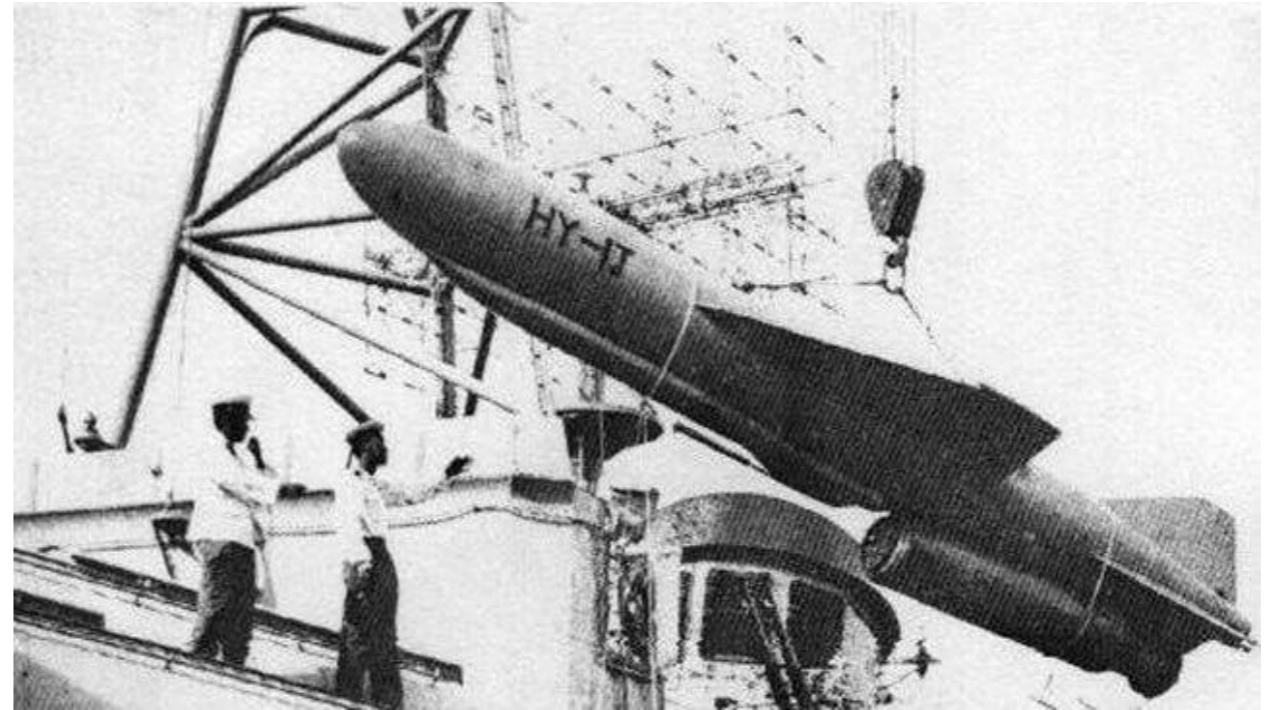
# Long-Range Cruise Missiles – 2



## Conventionally-Armed Tomahawk Cruise Missile

velocity: 550 mph  
pay load: 1000 lbs  
range : 1550 miles

# Chinese Silkworm Anti-Ship Cruise Missile



Chinese CSS-C-2 SILKWORM / HY-1 / SY-1 Anti-Ship Cruise Missile

Velocity: 680 mph  
payload: 660 lbs  
range: 180 miles

# Physics 280: Session 15

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**Midterm Exam Review: Sunday, March 11th  
at 7:00 – 8.30 PM in 144 Loomis**

**Extra Credit Opportunity: Simulation , 356 Armory  
3.30pm – 5.00pm, see Dave after class today!**

**Midterm Exam: Thursday, March 15<sup>th</sup> in MSEB 100**

## Plan for This Session

Student questions

Module 5: Nuclear Weapon Delivery Methods (cont'd)

# Cruise Missiles – 2 Cont'd

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## Key properties —

- Small
- Easily stored and launched
- Highly penetrating
- Versatile
- Highly accurate
- Very cheap (about ~ \$1 million per copy)

# Launching Cruise Missiles – 1



# Launching Cruise Missiles – 2





# Cruise-Missile Guidance – 1



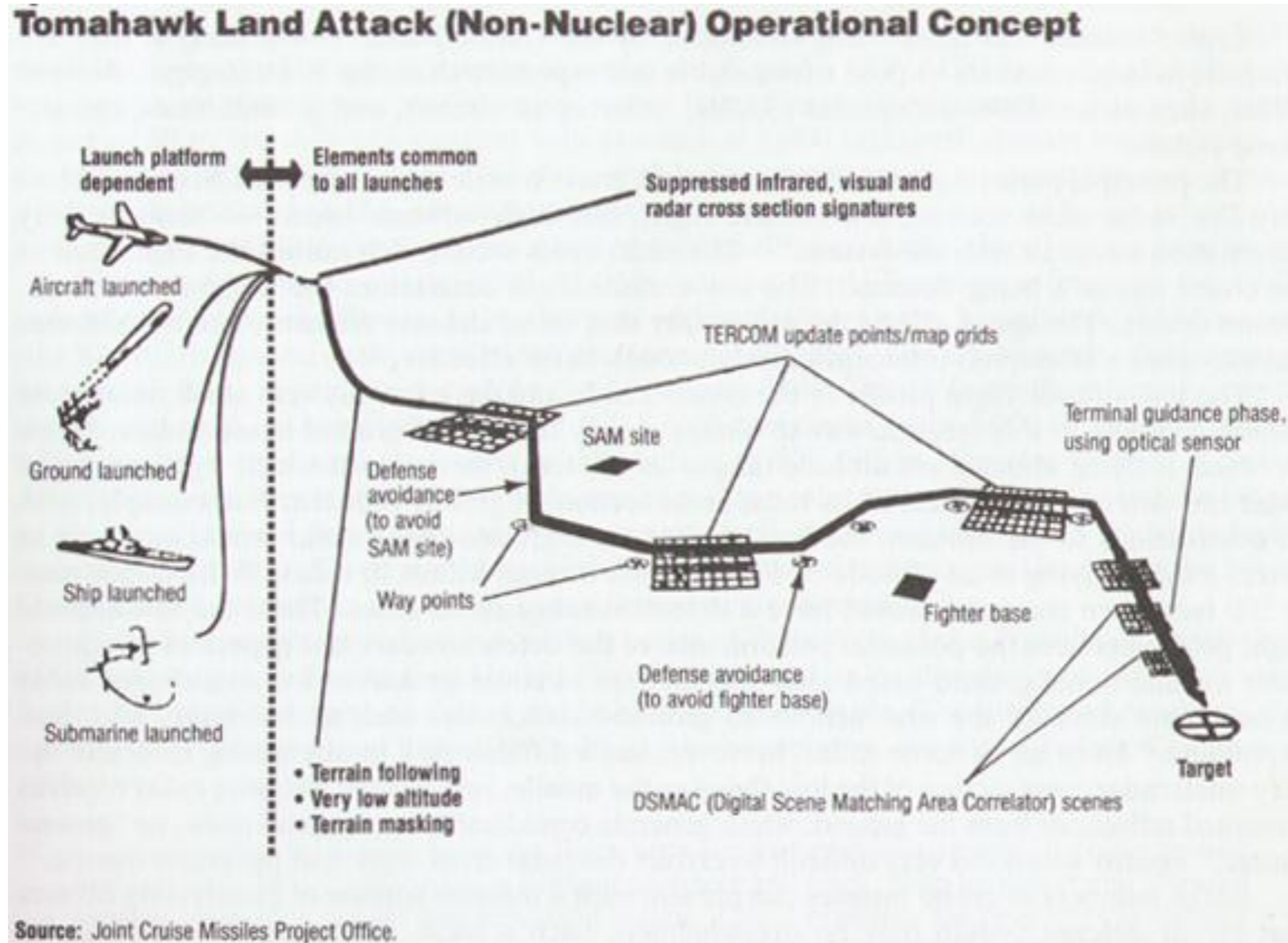
**TERCOM: Terrain Contour Matching**

**DSMAC: Digital Scene Matching Area Correlation**

# Cruise-Missile Guidance – 2



# Cruise-Missile Guidance – 3



# Accuracy of Cruise Missiles



# Implications of Cruise Missiles – 1

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Like MIRVs, the US developed and deployed CMs without coherent plan that considered the offensive, defensive, and long-range impact of their deployment.

## Military history —

- Cruise missiles were the US countermeasure to the heavy Soviet investment in air defenses
- They capitalized on the temporary US lead in this technology
- However, the US was more vulnerable to CMs than Russia and this came back to haunt the US

# Implications of Cruise Missiles – 2

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## Implications for U.S. security—

- Very small (hard to find and count with National Technical Means)
- Can be based almost anywhere (hard to count)
- Dual capable (almost impossible to distinguish nuclear from high-explosive warhead)
- Cheap (can be produced in very large numbers)

“Several countries could develop a mechanism to launch SRBMs, MRBMs, or land-attack cruise missiles from forward-based ships or other platforms; a few are likely to do so—more likely for cruise missiles— before 2015.”

– *Foreign Missile Developments and the Ballistic Missile Threat Through 2015*,  
Unclassified Summary of a National Intelligence Estimate, December 2001

# Module 5: Nuclear Delivery Methods

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## Part 4: Ballistic Missiles

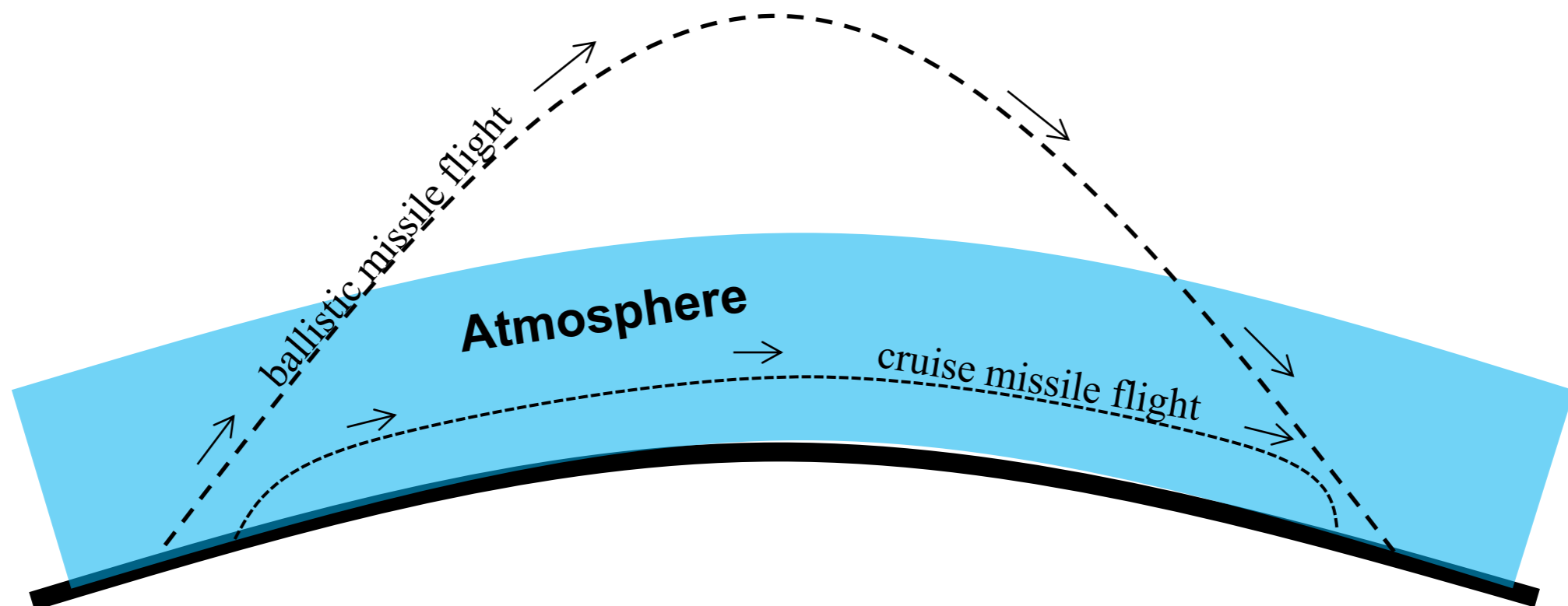
# Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

## Air breathing systems:

- o carry the fuel on board but take the oxidizer from the atmospheres → operate endo-atmospheric

## Ballistic missiles:

- o carry fuel and oxidizer → can operate exo-atmospheric





# Attributes of Ballistic Missiles

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## Basing modes —

- Fixed (e.g., blast-hardened silos in the ground)
- Mobile (e.g., on railroad cars)

## Propellants —

- Liquid (fuel and oxidizer are separate)
- Solid (fuel and oxidizer are mixed)

## Payloads —

- Single warhead + penetration aids (“penaids”)
- Multiple warheads + penetration aids

# Categories of Ballistic Missiles Based on Their Ranges (Important)

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Short-range ballistic missiles (SRBMs) —

- Ranges under 1,000 km

Medium-range ballistic missiles (MRBMs) —

- Ranges between 1,000 km and 3,000 km

Intermediate-range ballistic missiles (IRBMs) —

- Ranges between 3,000 km and 5,500 km

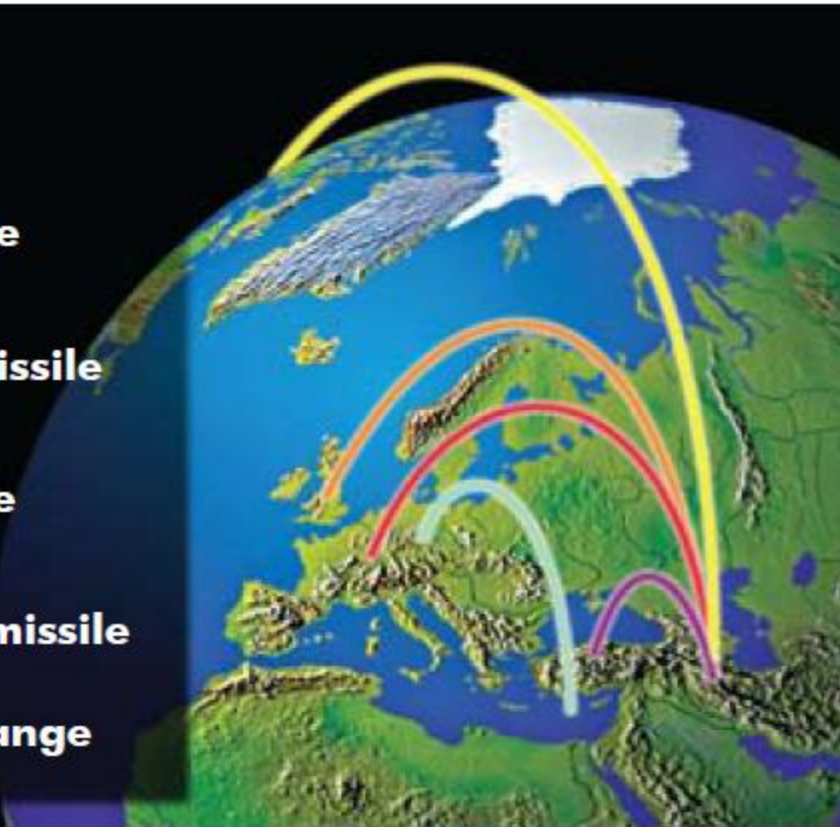
Intercontinental-range ballistic missiles (ICBMs, SLBMs) —

- Limited-range ICBMs (LRICBMs): 5,500 to 8,000 km
- Full-range ICBMs (FRICBMs): > 8,000 km
- Ranges of US and Russian ICBMs are ~ 12,000 km

These categories are not fluid, because they are based on the performance characteristics of the missile.

# Categories of Ballistic Missiles Based on Their Ranges (Important)

	<b>SRBM Short-range ballistic missile</b> <1,000 km (621 mi)
	<b>MRBM Medium-range ballistic missile</b> 1,000-3,000 km (621-1,864 mi)
	<b>IRBM Intermediate-range ballistic missile</b> 3,000-5,500 km (1,864-3,418 mi)
	<b>ICBM Intercontinental ballistic missile</b> >5,500 km (3,418 mi)
	<b>SLBM Submarine-launched ballistic missile</b> Any ballistic missile launched from a submarine, regardless of maximum range



Source: national air and space intelligence center

“Ballistic and Cruise Missile Threat”, 2009

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# Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

PHASES OF BALLISTIC MISSILE TRAJECTORY



# Categories of Ballistic Missiles Based on Their Purposes

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Tactical ballistic missiles (TBMs) —

- For use on the battlefield (e.g., on a particular front)
- Usually have shorter ranges (SRBMs)

Theater ballistic missiles (TBMs) —

- For use in an entire theater of war (e.g., the Middle East)
- Usually have longer ranges than tactical missiles

Strategic ballistic missiles (an example of SNDVs) —

- For attacking the homeland of the adversary
- May have longer, perhaps intercontinental ranges

These categories are fluid, because they are based on the intent of the user at the time the missile is fired.

# Missile Guidance Technologies

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## Inertial —

- Uses gyroscopes and accelerometers
- No contact with outside world

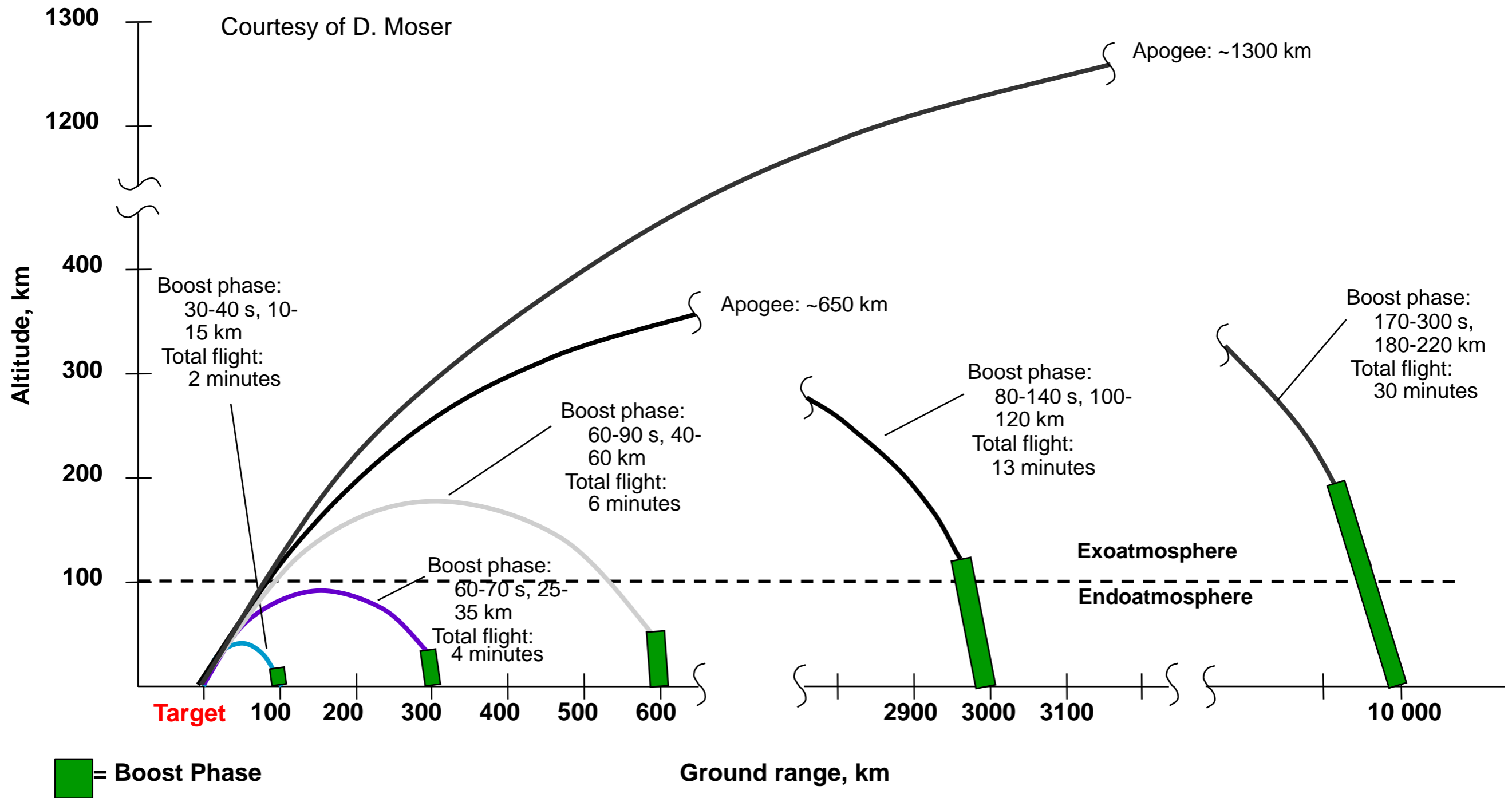
## Stellar —

- Star trackers update inertial guidance system

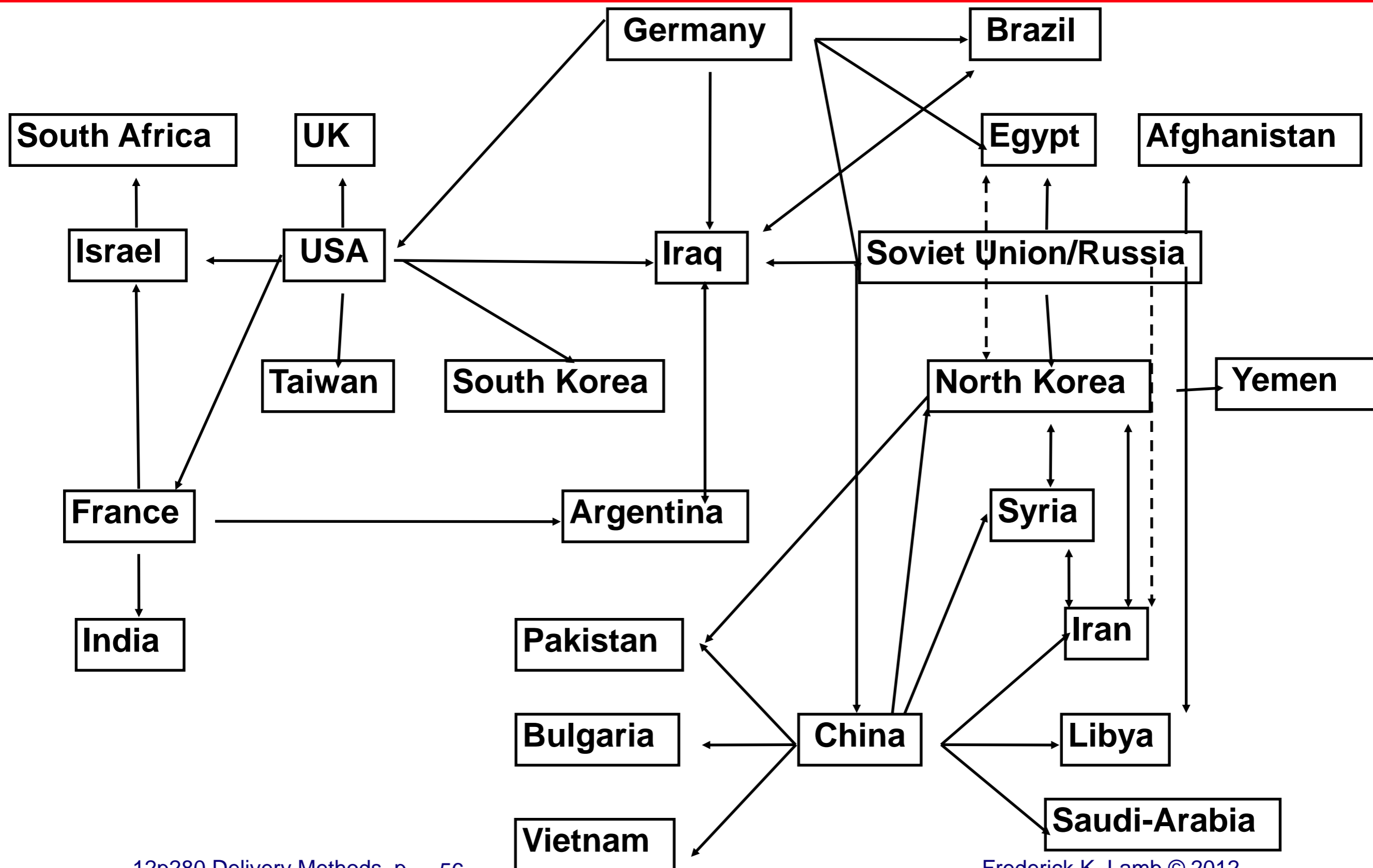
## Satellite —

- Uses accurate (atomic) clocks on satellites
- Uses coded radio transmissions
- Uses sophisticated receivers
- Can determine both position and velocity very accurately using signals from 3 to 4 satellites

# Trajectories and Phases of Flight of Missiles With Various Ranges



# Proliferation of Ballistic Missile Technologies

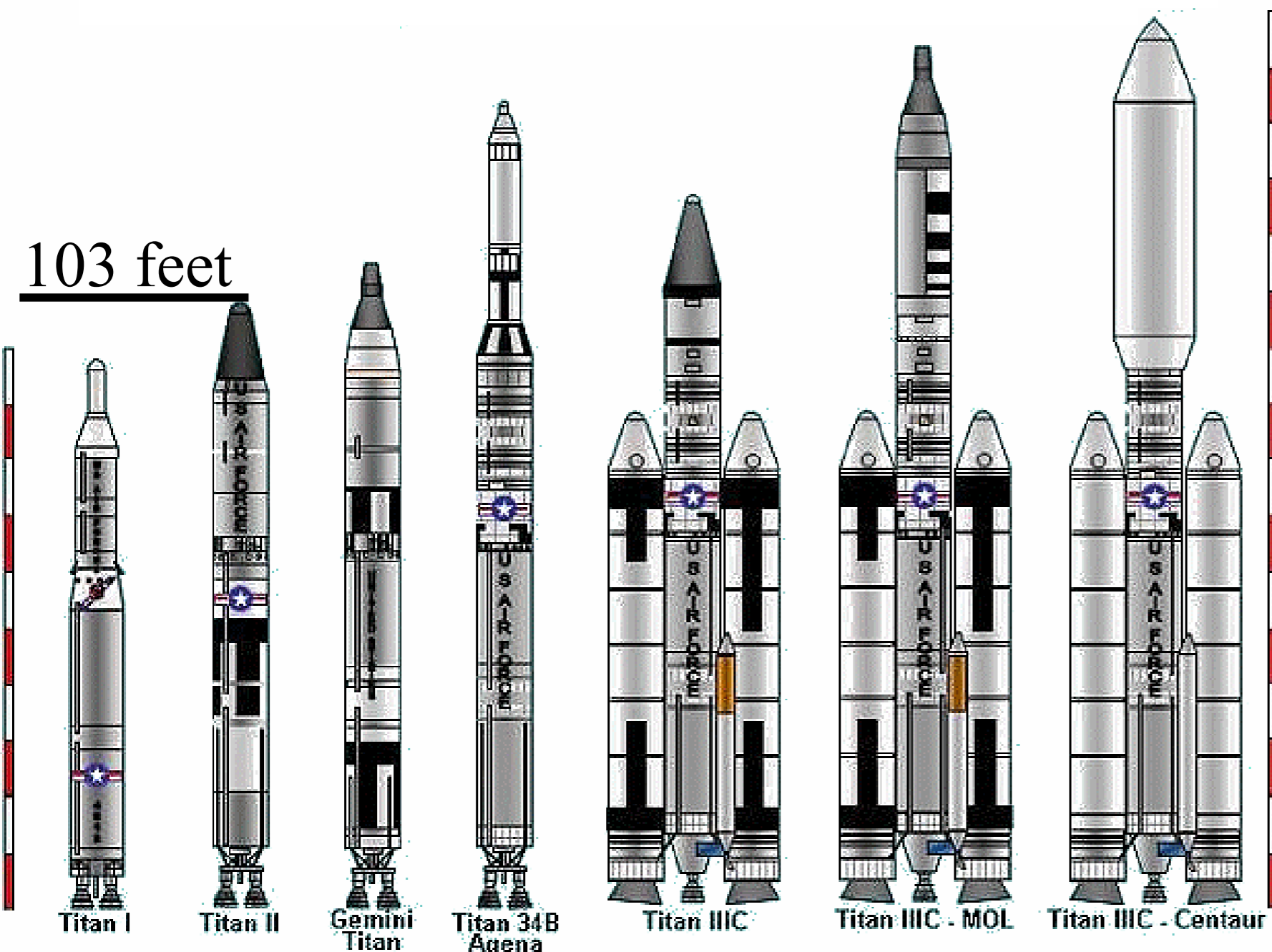




# Titan Family of Missiles and Launch Vehicles

1959 – 2005 ICMB & civilian uses

103 feet



**TIME Magazine**, Monday September 29<sup>th</sup> 1980

## **Light on the Road to Damascus**

### **Titan terror explodes in the Arkansas hills**

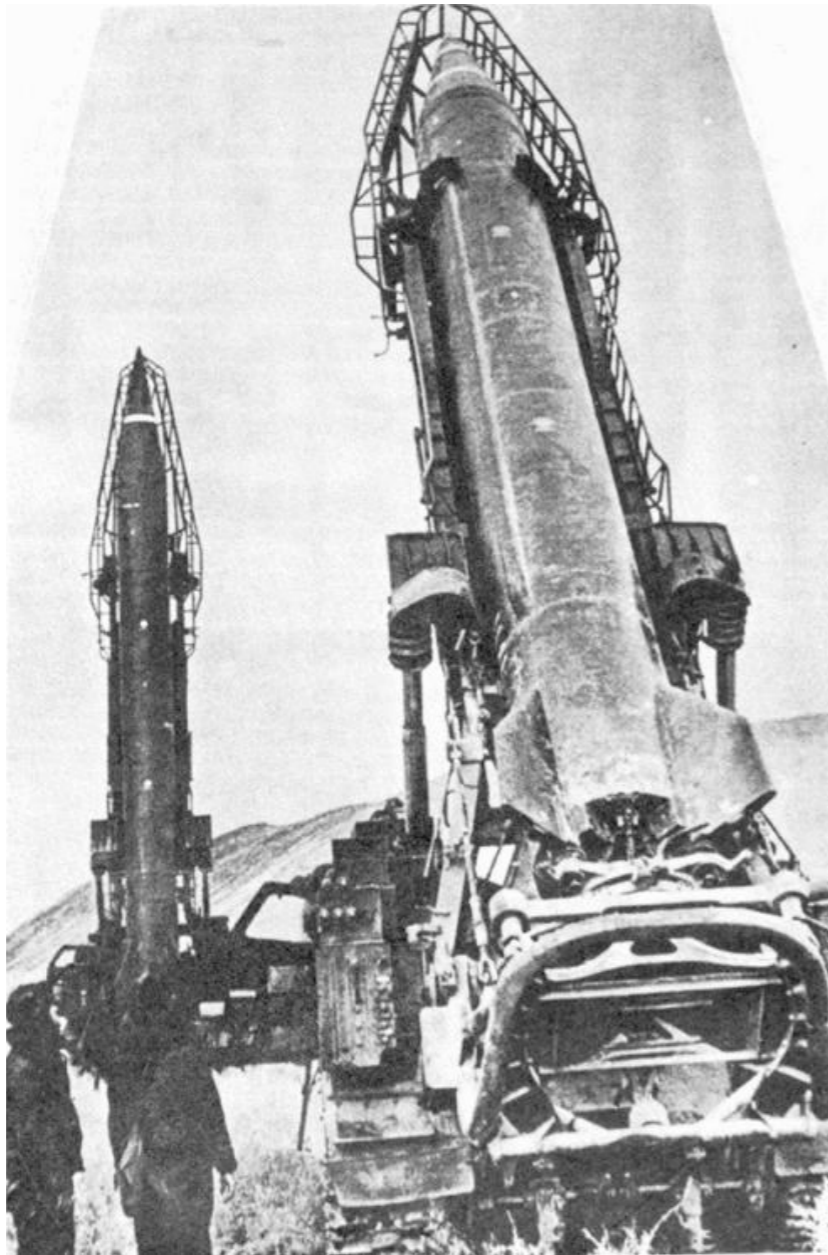
Shortly after sunset one day last week, a maintenance worker on the third level of a silo housing a 103-ft. Titan II Intercontinental ballistic missile near Damascus, in the Arkansas hills north of Little Rock, dropped the socket of a wrench. The 3-lb. tool plummeted 70 ft. and punctured a fuel tank. As flammable vapors escaped, officials urged the 1,400 people living in a five-mile radius of the silo to flee. The instructions: "Don't take time to close your doors—just get out." And with good reason. At 3:01 a.m., as technicians gave up trying to plug the leak and began climbing from the silo, the mixture of fuel and oxygen exploded. Orange flames and smoke spewed out, lighting up the sky over Damascus. The blast blew off a 750-ton concrete cover. One worker was killed; 21 others were hurt.

Today: LGM-30G Minuteman III → 3 stage solid rocket fuel

Range: 11,000km +

Speed : 24,100 km/h or 6.7km/s (terminal phase)

# Soviet Scud Missiles and Derivatives - 1

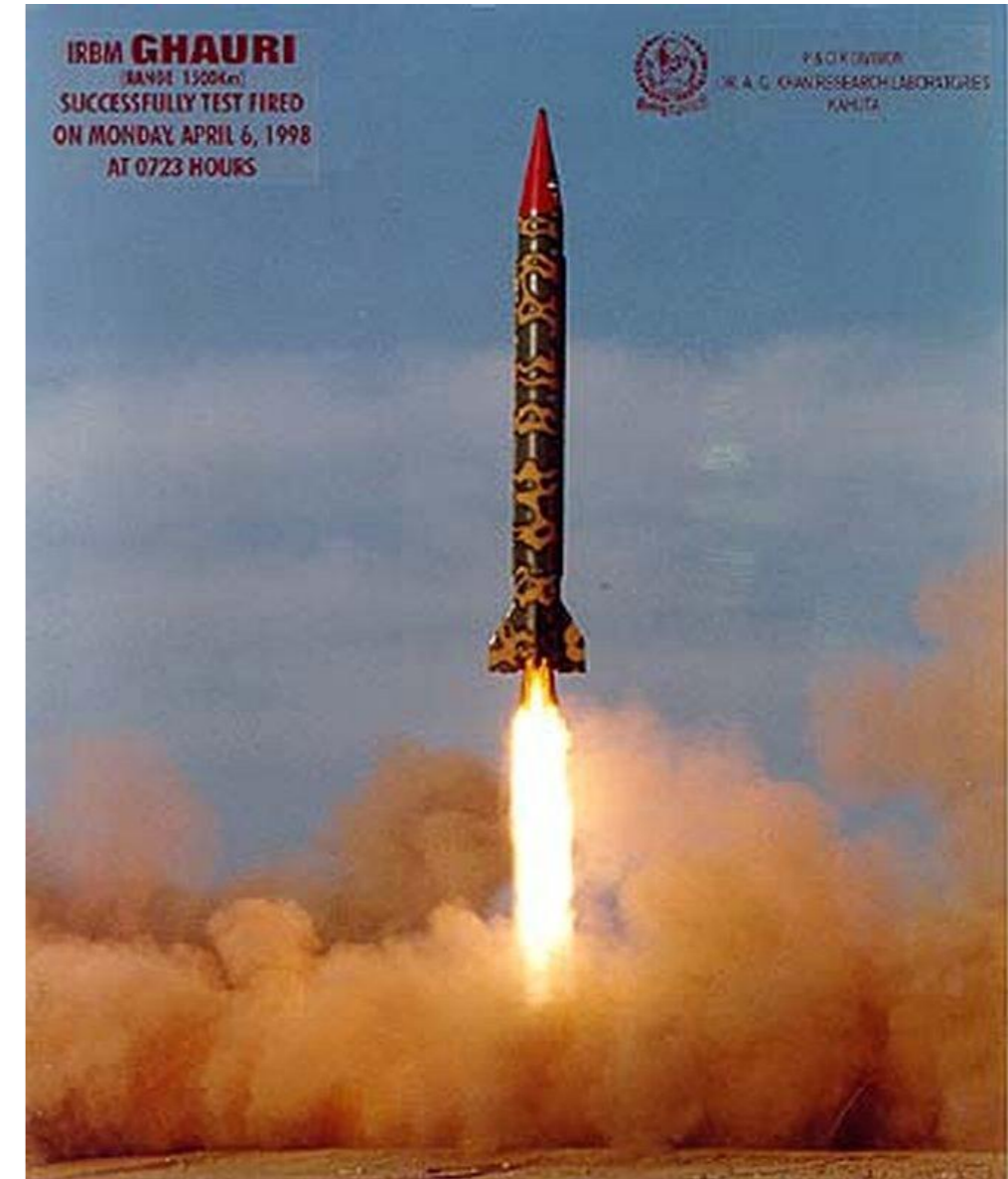


Soviet Scud-B Missile  
(based on the German V2)  
Range: 300 km



Iraqi Al-Hussein SRBM  
Range: 600–650 km

# Scud Missiles and Derivatives – 2



Pakistan's Ghauri MRBM and transporter (range 1,300 km). It is almost identical to North Korea's No Dong MRBM, which is based on Scud technology that North Korea got from Egypt in the 1970s.

# iClicker Question

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Which one of the following technologies was *not* crucial in developing militarily useful cruise missiles?

Lighter metals for the airframes

More efficient engines

Much smaller and more capable computers

GPS and other methods for more accurate guidance

“Stealth” technologies to make them harder to detect

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# iClicker Answer

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Which one of the following delivery vehicles was *not* considered a leg of the Cold War nuclear “Triad”?

Submarine-launched ballistic missiles

Ship-launched ballistic missiles

Land-based intercontinental ballistic missiles

Land-based intercontinental bombers



# Blank

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# iClicker Answer

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Which one of the following delivery vehicles was *not* considered a leg of the Cold War nuclear “Triad”?

Submarine-launched ballistic missiles

**Ship-launched ballistic missiles**

Land-based intercontinental ballistic missiles

Land-based intercontinental bombers

# iClicker Question

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Which one of the following strategic nuclear delivery vehicles can be recalled after launch?

Submarine-launched ballistic missiles

Land-based intercontinental ballistic missiles

Land-based intercontinental bombers

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# iClicker Question

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Which one of the following strategic nuclear delivery vehicles can be recalled after launch?

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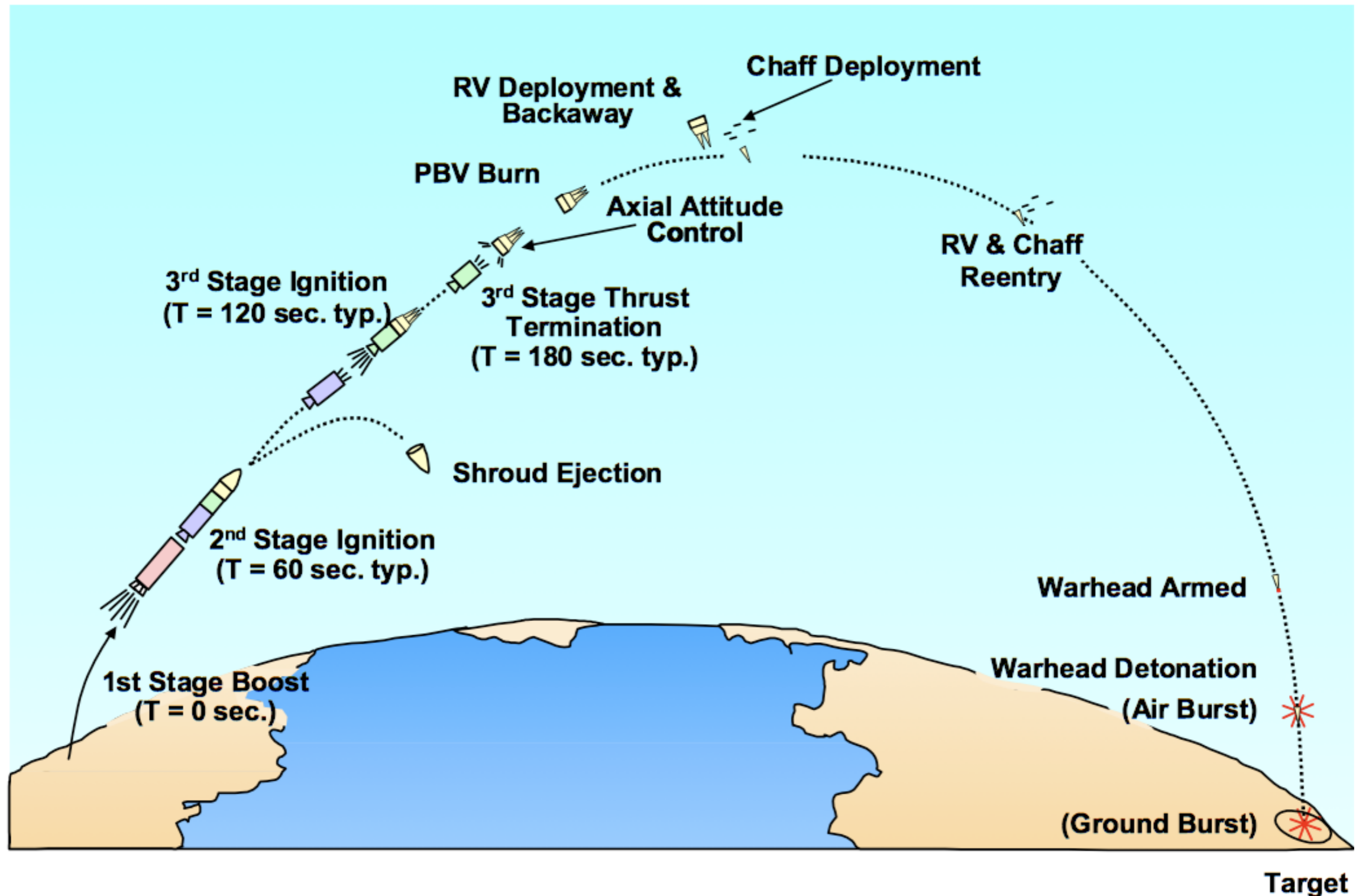
**Land-based intercontinental bombers**

# Re-Entry Vehicles (RVs)

## Basic types —

- MRV = multiple RV
  - Final stage carries more than 1 RV
  - Final stage has no propulsion
  - RVs are *not* independently targetable
- MIRV = multiple, independently targetable RV
  - Final stage carries more than 1 RV
  - Final stage has guidance package and propulsion
  - RVs are independently targetable
- MARV = maneuverable RV
  - RV has a guidance package
  - RV maneuvers during the terminal phase, using, e.g., thrusters or aerodynamic forces

# Flight of a Minuteman ICBM (Schematic)



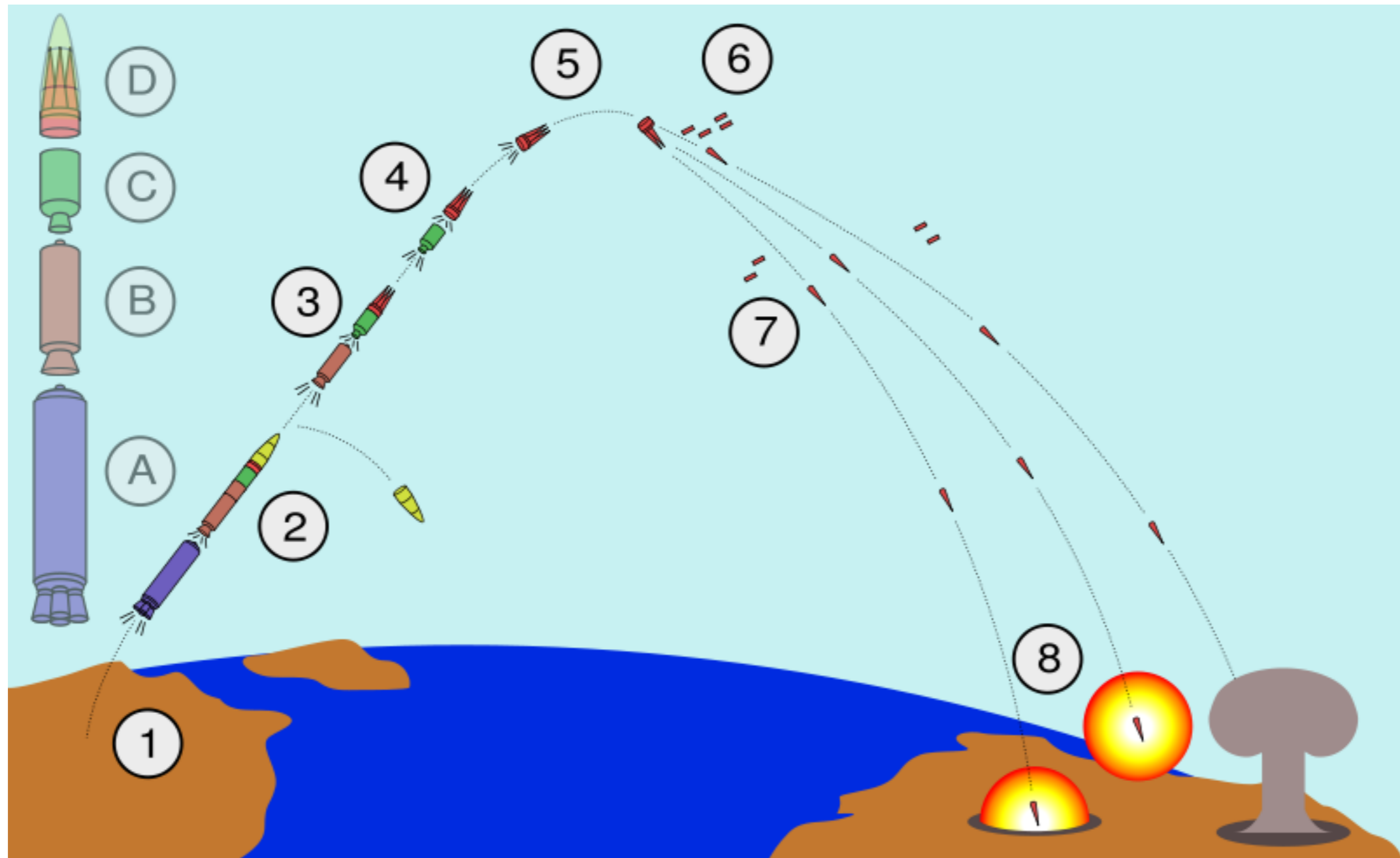
# Flight of MIRV'd ICBMs

Four phases of the flight of an intercontinental-range missile armed with MIRVs (Multiple Independently Targetable Reentry Vehicles)—

- Boost phase (lasts about 1–5 min)
  - Rocket motors are burning
  - Missile rises through the atmosphere and enters near-Earth space
  - Stages drop away as they burn out
- Post-boost phase (lasts 5–10 min)
  - Bus separates from the final stage
  - Bus maneuvers and releases RVs
- Midcourse phase (lasts about 20 min)
  - RVs fall ballistically around the Earth, in space
- Terminal phase (lasts about 20–60 sec)
  - RVs re-enter the Earth's atmosphere and encounter aerodynamic forces
  - RVs fall toward targets, until detonation or impact



# Flight of a MIRV'd ICBM (Schematic)



# Flight of a MIRV'd ICBM (Schematic)

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1. The missile launches out of its silo by firing its 1st stage boost motor (*A*).
2. About 60 seconds after launch, the 1st stage drops off and the 2nd stage motor (*B*) ignites. The missile shroud is ejected.
3. About 120 seconds after launch, the 3rd stage motor (*C*) ignites and separates from the 2nd stage.
4. About 180 seconds after launch, 3rd stage thrust terminates and the Post-Boost Vehicle (*D*) separates from the rocket.
5. The Post-Boost Vehicle maneuvers itself and prepares for re-entry vehicle (RV) deployment.
6. The RVs, as well as decoys and chaff, are deployed during backaway.
7. The RVs and chaff re-enter the atmosphere at high speeds and are armed in flight.
8. The nuclear warheads detonate, either as air bursts or ground bursts.

# MIRV Technology



MX Peacekeeper MIRV



Soviet SS-20 ICBM MIRV

# MIRV Technology



MX Peacekeeper missile tested at Kwajalein Atoll

Source: [www.smdc.army.mil/kwaj/Media/Photo/missions.htm](http://www.smdc.army.mil/kwaj/Media/Photo/missions.htm)

# Historical Examples of US and Russian ICBMs

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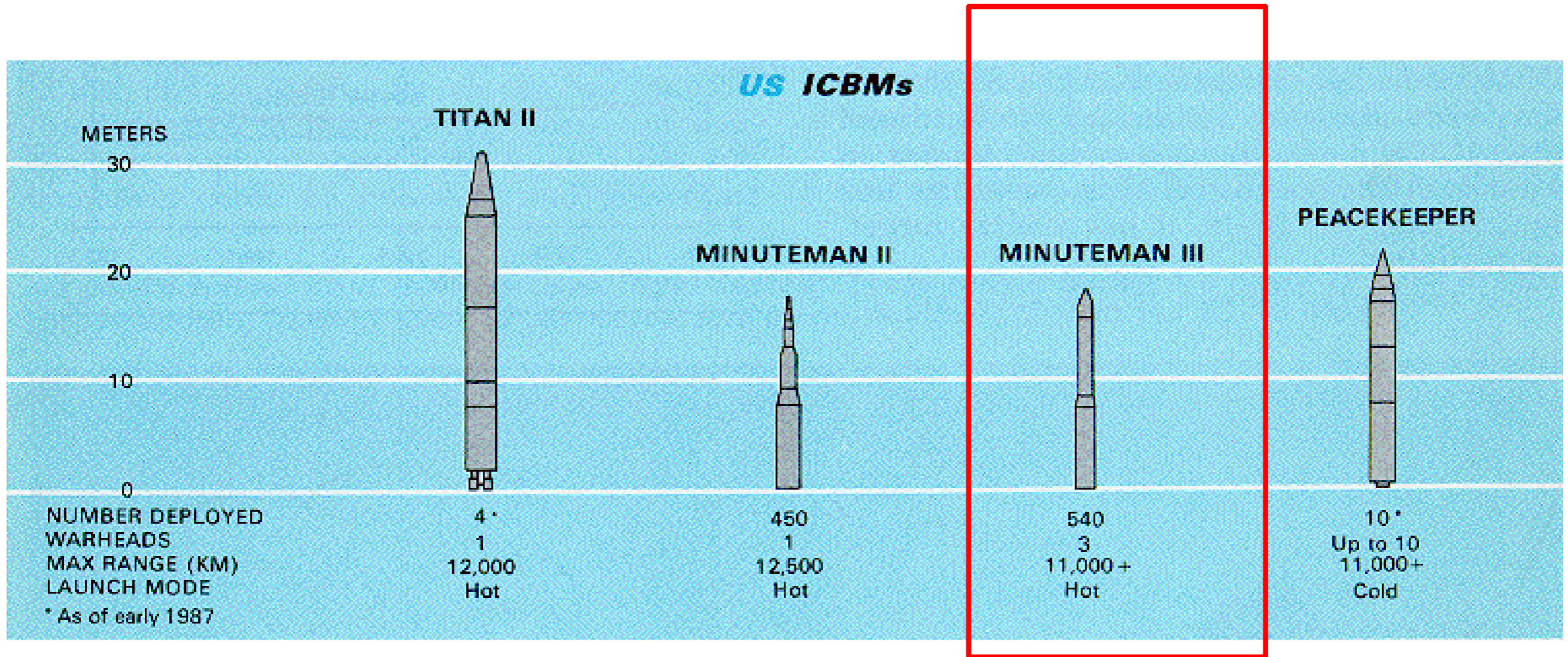
## Recent US ICBMs —

- MMIII Solid-propellant, range ~ 12,000 km, 3 warheads
- MX Solid-propellant, range ~ 12,000 km, 10 warheads

## Recent Russian ICBMs —

- SS-18 Liquid-propellant (storable), range ~ 12,000 km, 12 to 18 warheads
- SS-24 Solid-propellant, range > 9,000 km
- SS-25 Solid-propellant, range > 9,000 km

# US ICBMs – 1



current land based  
US ICMB

# US ICBMs – 2

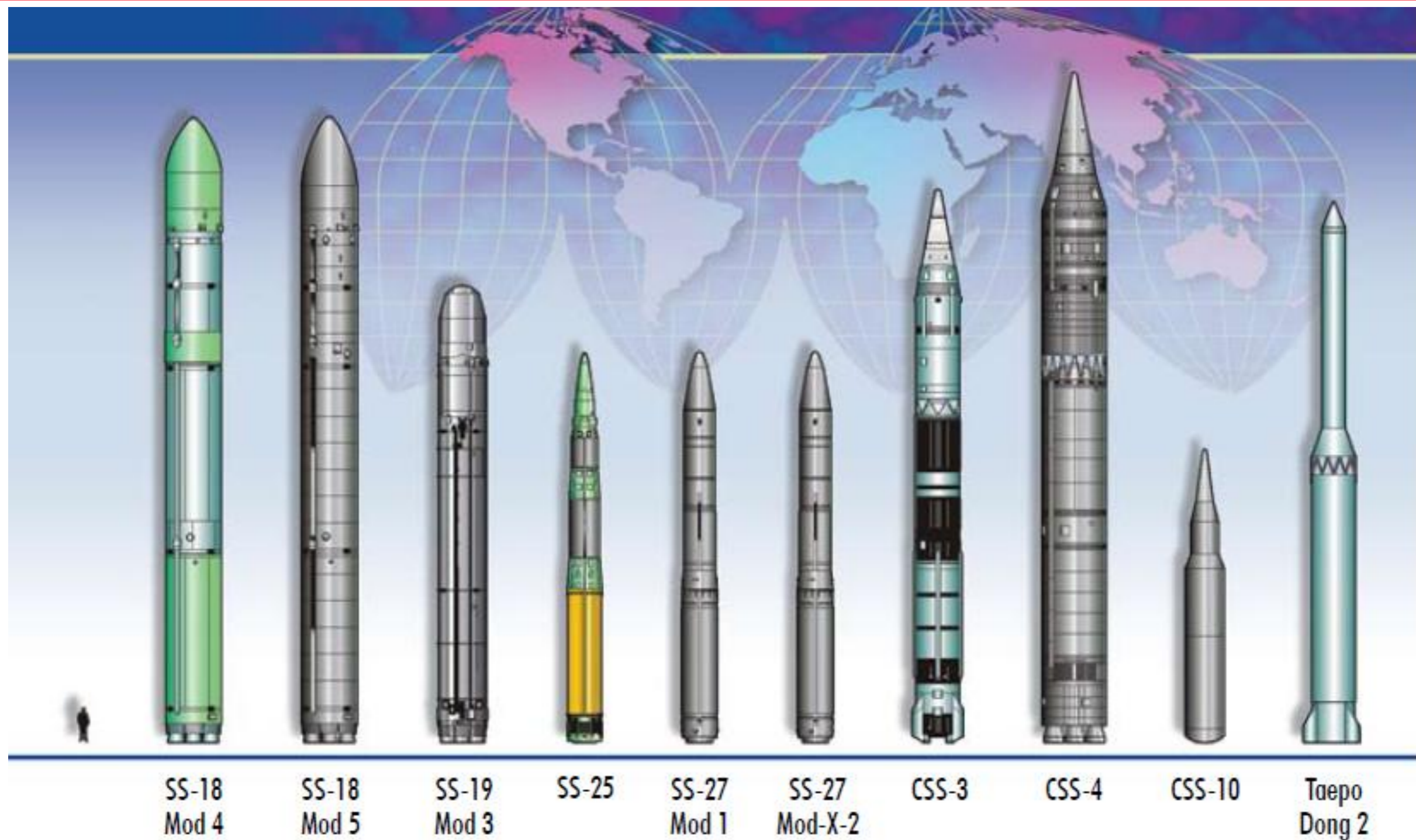


Launch of a Minuteman



Launch of an MX

# Russian, Chinese (and North Korean) ICBMs – 1



Source: national air and space intelligence center  
“Ballistic and Cruise Missile Threat”, 2009



# Russian, Chinese (and North Korean) ICBMs – 2

Missile	Number of Stages	Warheads per Missile	Propellant	Deployment Mode	Maximum Range* (miles)	Number of Launchers
<b>Russia</b>						
SS-18 Mod 4	2 + PBV	10	Liquid	Silo	5,500+	104
SS-18 Mod 5	2 + PBV	10	Liquid	Silo	6,000+	(total for Mods 4 & 5)
SS-19 Mod 3	2 + PBV	6	Liquid	Silo	5,500+	122
SS-25	3 + PBV	1	Solid	Road-mobile	7,000	201
SS-27 Mod 1	3 + PBV	1	Solid	Silo & road-mobile	7,000	54
SS-27 Mod-X-2	3 + PBV	Multiple	Solid	Silo & road-mobile	7,000	Not yet deployed
<b>China</b>						
CSS-3	2	1	Liquid	Silo & transportable	3,400+	10 to 15
CSS-4 Mod 2	2	1	Liquid	Silo	8,000+	About 20
CSS-10 Mod 1	3	1	Solid	Road-mobile	4,500+	Fewer than 15
CSS-10 Mod 2	3	1	Solid	Road-mobile	7,000+	Fewer than 15
<b>North Korea</b>						
Taepo Dong 2	2	1	Liquid	Undetermined	3,400+	Not yet deployed

Source: national air and space intelligence center  
 “Ballistic and Cruise Missile Threat”, 2009

# Russian, Chinese (and North Korean) ICBMs – 3



The Russian Dnepr space launch vehicle is based on the SS-18 ICBM.



Chinese CSS-10 Road-Mobile Launcher



Russian SS-27 Road-Mobile Launcher

# Physics 280: Session 17

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**Extra Credit Opportunity: Simulation**  
**356 Armory, 3.30pm – 5.00pm**

**Midterm Exam Review: Sunday, March 11th**  
**7:00 – 8.30 PM in 144 Loomis**

**Midterm Exam: Thursday, March 15<sup>th</sup>**  
**2:00pm – 3.30pm in MSEB 100**

## Plan for This Session

Student questions

Module 5: Nuclear Weapon Delivery Methods (cont'd)

# Module 5: Nuclear Delivery Methods

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## Part 4: Ballistic Missiles (Cont'd)

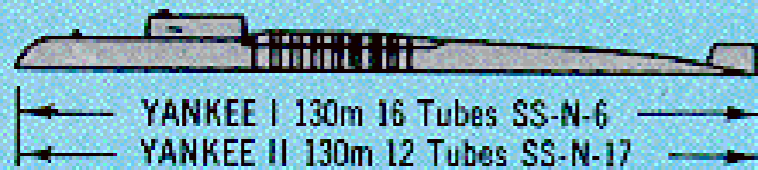
# US and Russian SSBNs

## Nuclear-Powered Ballistic Missile Submarines

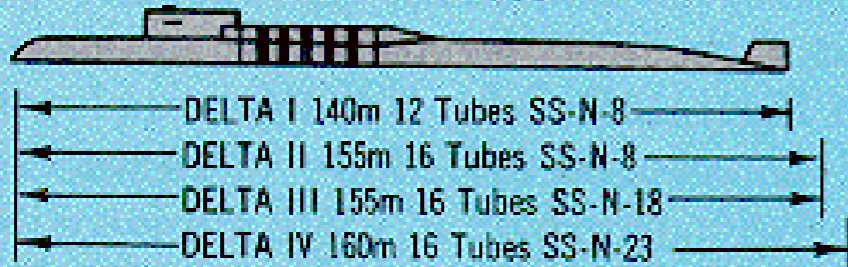
**USSR**

**US**

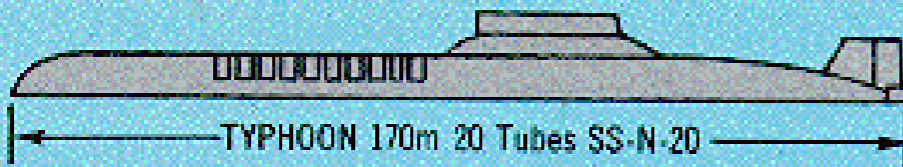
### YANKEE-Class



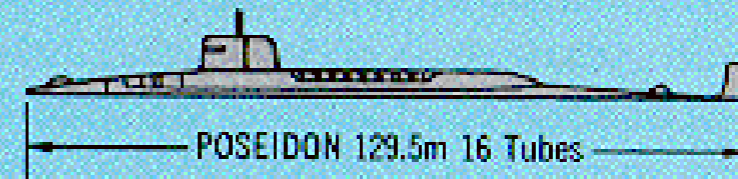
### DELTA-Class



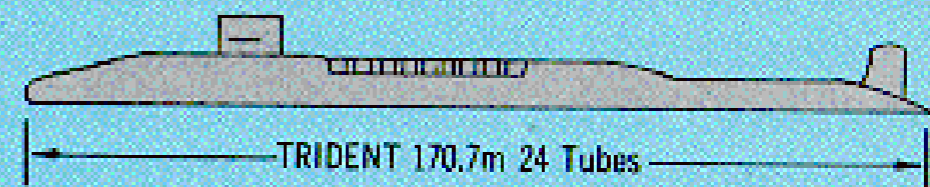
### TYPHOON-Class



### POSEIDON SSBN

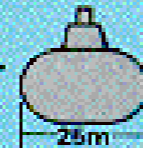


### TRIDENT (OHIO-Class) SSBN



Comparative  
Cross-Sections  
of SSBNs

TYPHOON-  
Class



OHIO-  
Class



# US Trident SSBN (14 SSBNs, 4 SSGNs)



Trident Missile Tubes  
With Covers Open

24 Trident C4 SLBMs  
8 MIRVs with 100kt W76  
→ up to 192 targets  
SLBM range 7400 km

Trident Submarine Underway

speed : 20 knots  
SSBN range : unlimited  
deployment : 70-90 days, two rotating crews  
Displacement : 16500 tons  
Length : 170 m  
width : 13 m

# US Trident SSBN



# Submarine-Based Missiles

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## US SLBMs —

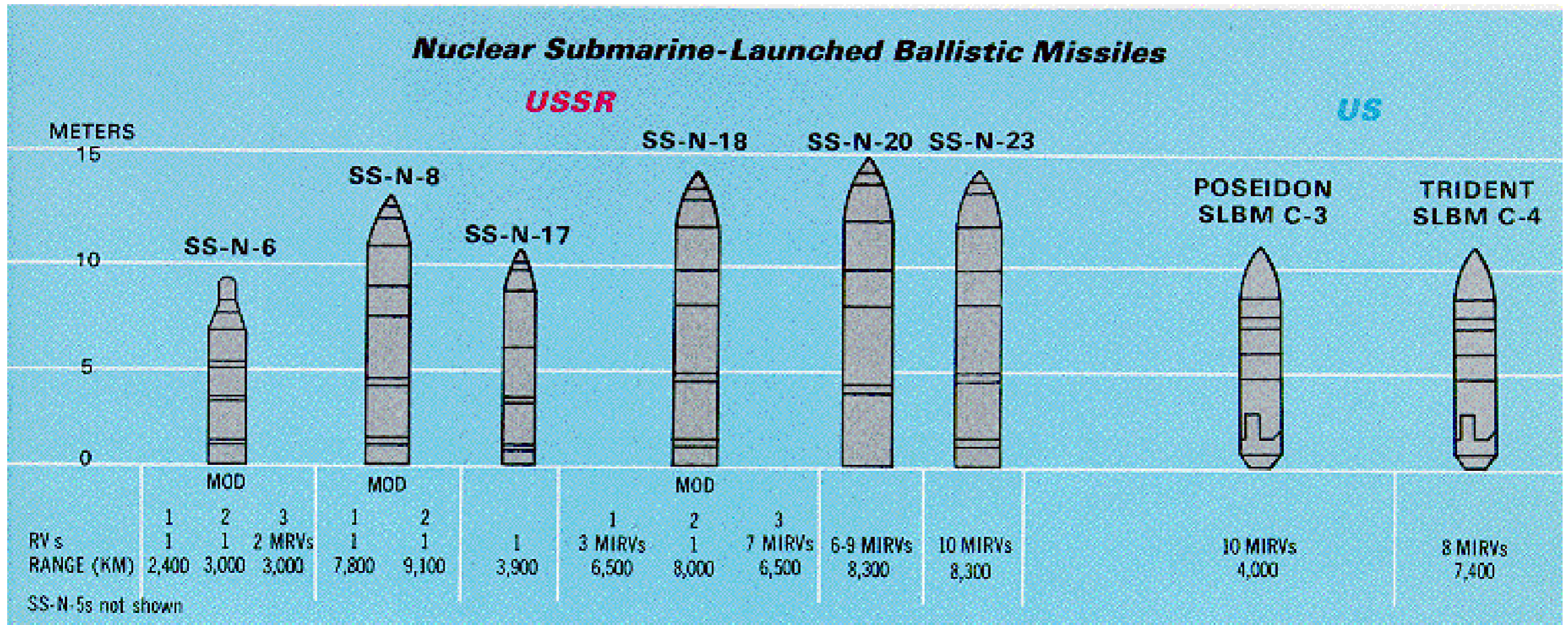
- Trident C4 missiles carried 8 MIRVs each (solid propellant, range 7400 km)
- Trident D5 missiles carry 8 MIRVs each (solid propellant, range 7400 km)

## Russian SLBMs —

- SS-N-8 missiles carried 1 warhead each (range 9100 km, 64 warheads total)
- SS-N-18 missiles carried 3 warheads each (liquid propellant, range 6500 km)
- SS-N-20 missiles carried 10 warheads each (solid propellant, range 8300 km)
- SS-N-23 missiles carried 4 warheads each (liquid propellant, range 8300 km)



# US and Russian SLBMs



# iClicker Question

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Which one of the following technologies was *not* crucial in developing militarily useful cruise missiles?

- (A) Lighter metals for the airframes
- (B) More efficient engines
- (C) Much smaller and more capable computers
- (D) GPS and other methods for more accurate guidance
- (E) “Stealth” technologies to make them harder to detect

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# iClicker Answer

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Which one of the following technologies was *not* crucial in developing militarily useful cruise missiles?

- (A) **Lighter metals for the airframes**
- (B) More efficient engines
- (C) Much smaller and more capable computers
- (D) GPS and other methods for more accurate guidance
- (D) “Stealth” technologies to make them harder to detect

# iClicker Question

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On U.S. submarines with nuclear-armed ballistic missiles, who must agree in order for them to be launched?

- (A) The captain
- (B) The captain and the first officer
- (C) All officers
- (D) A majority of the crew
- (E) All of the crew

# Blank

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# iClicker Question

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On U.S. submarines with nuclear-armed ballistic missiles, who must agree in order for them to be launched?

The captain

The first officer

**The captain and the first officer**

A majority of the crew

All of the crew members

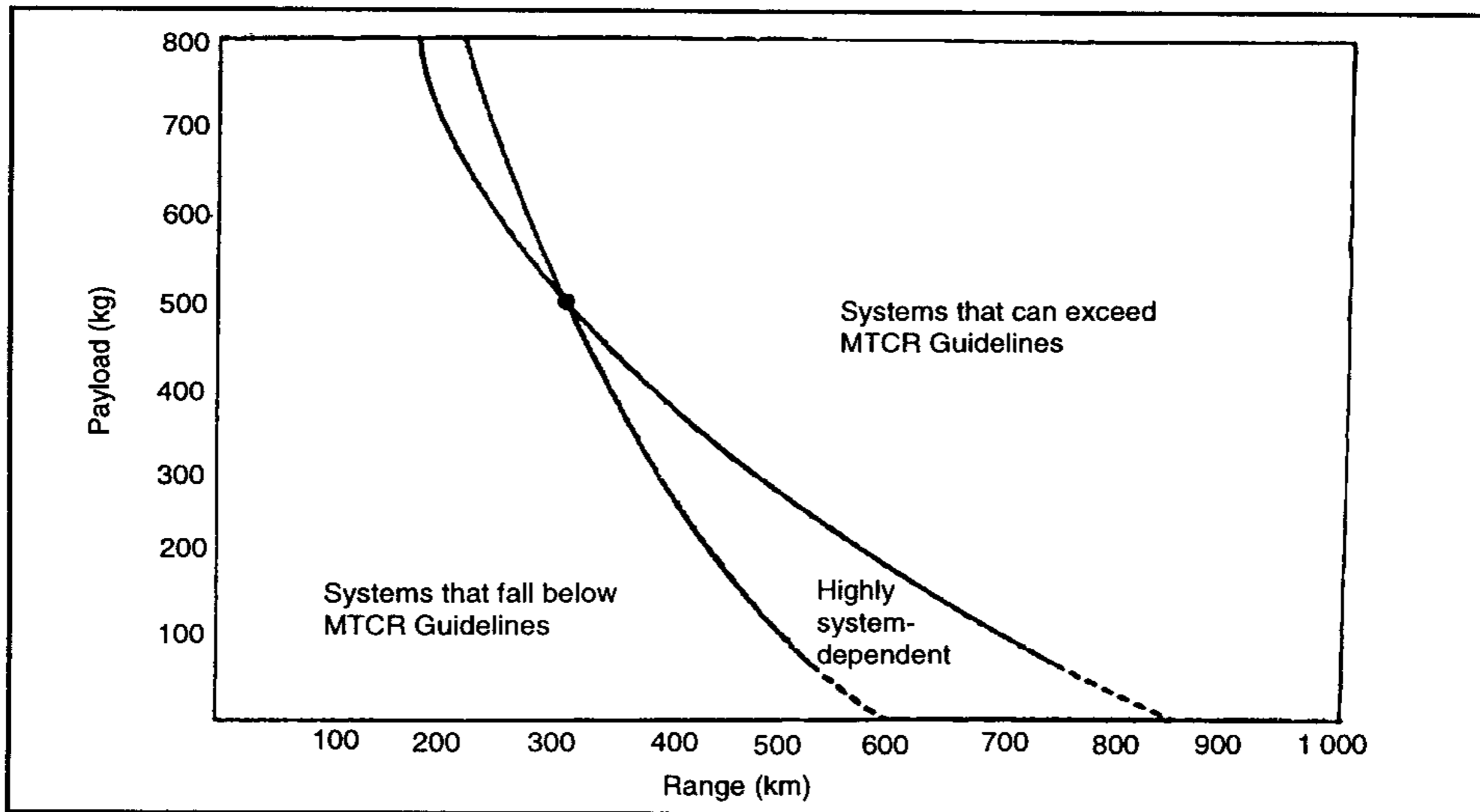
# Module 5: Nuclear Delivery Systems

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## Part 5: Technical and Operational Aspects

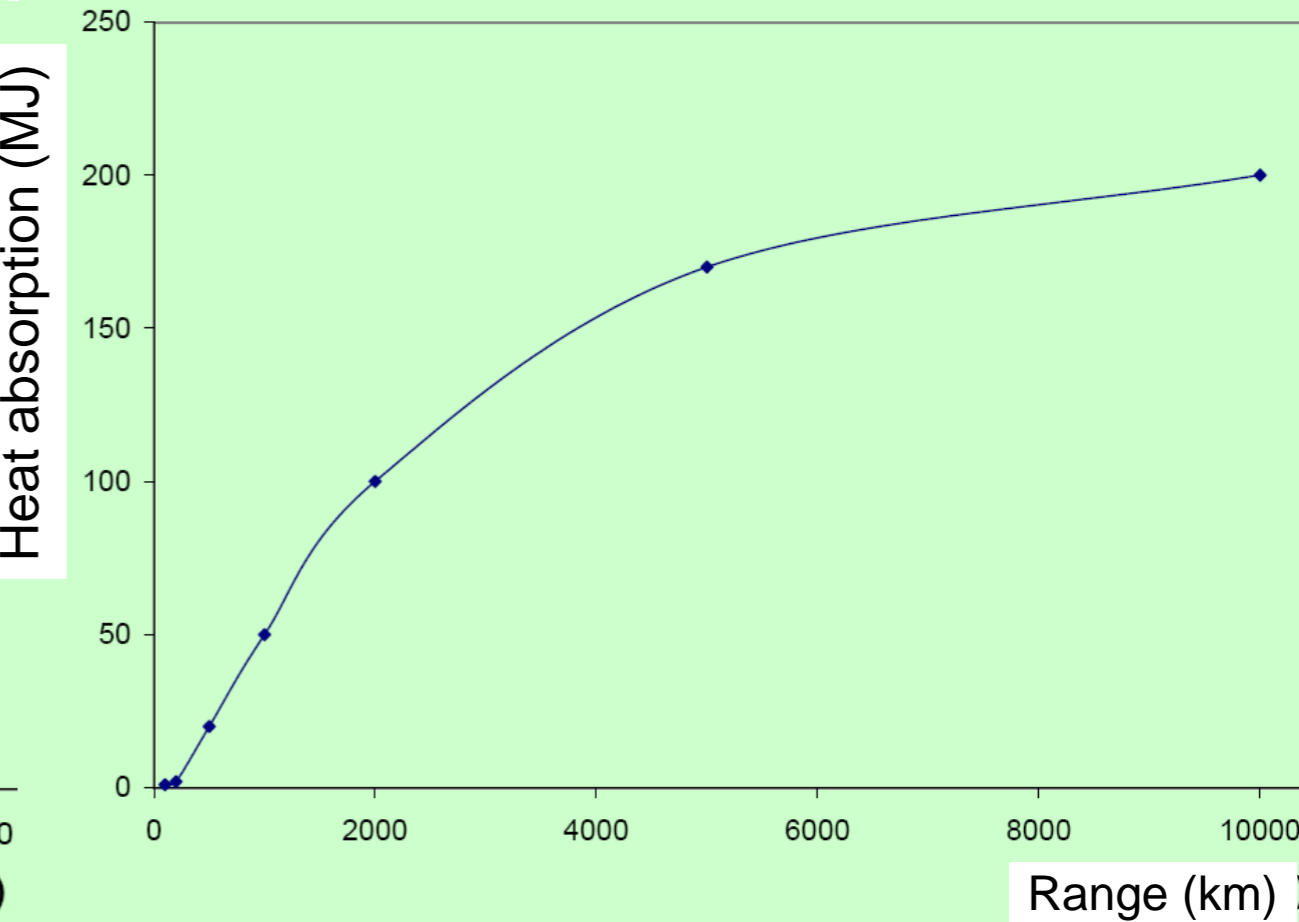
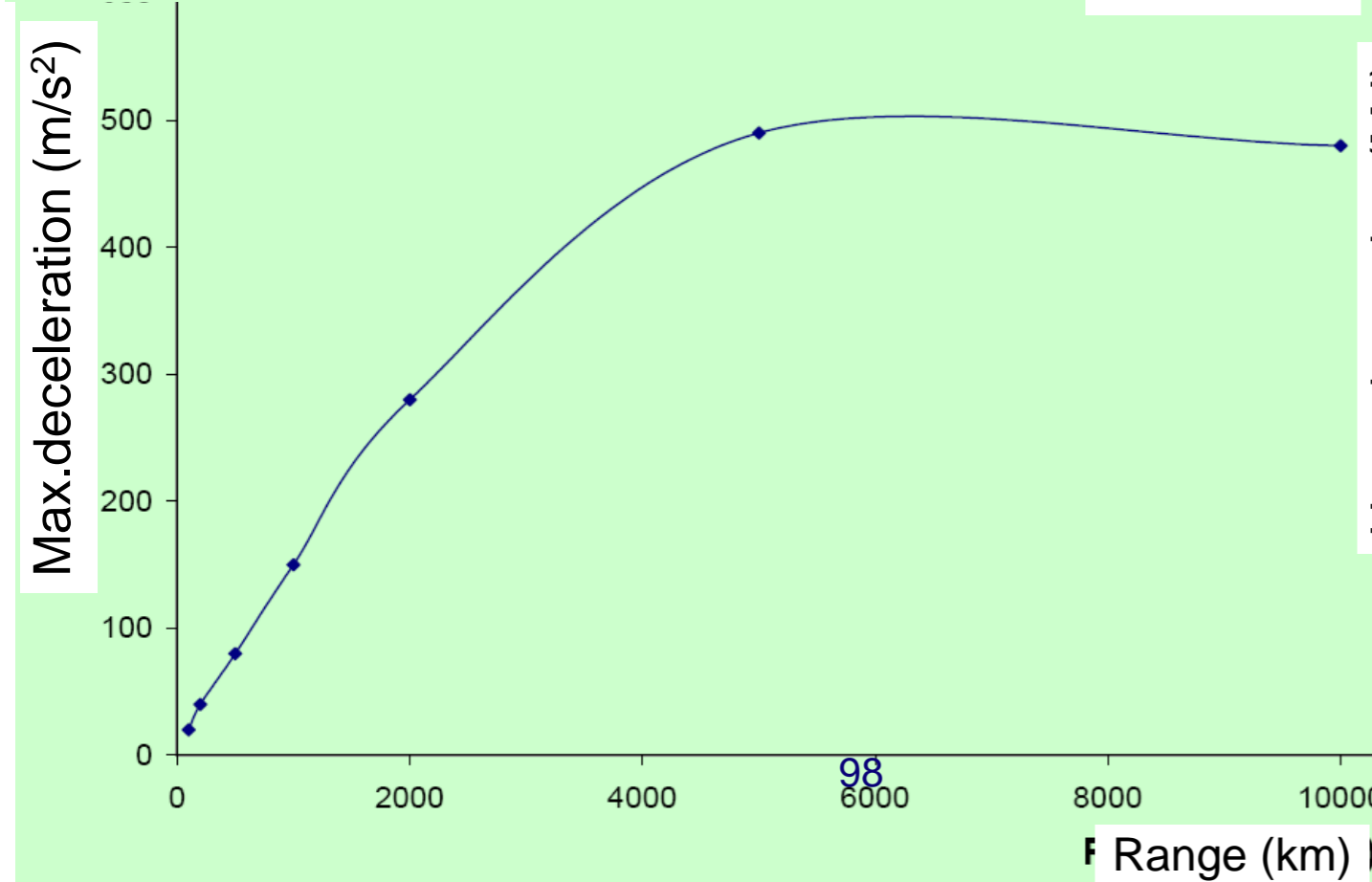
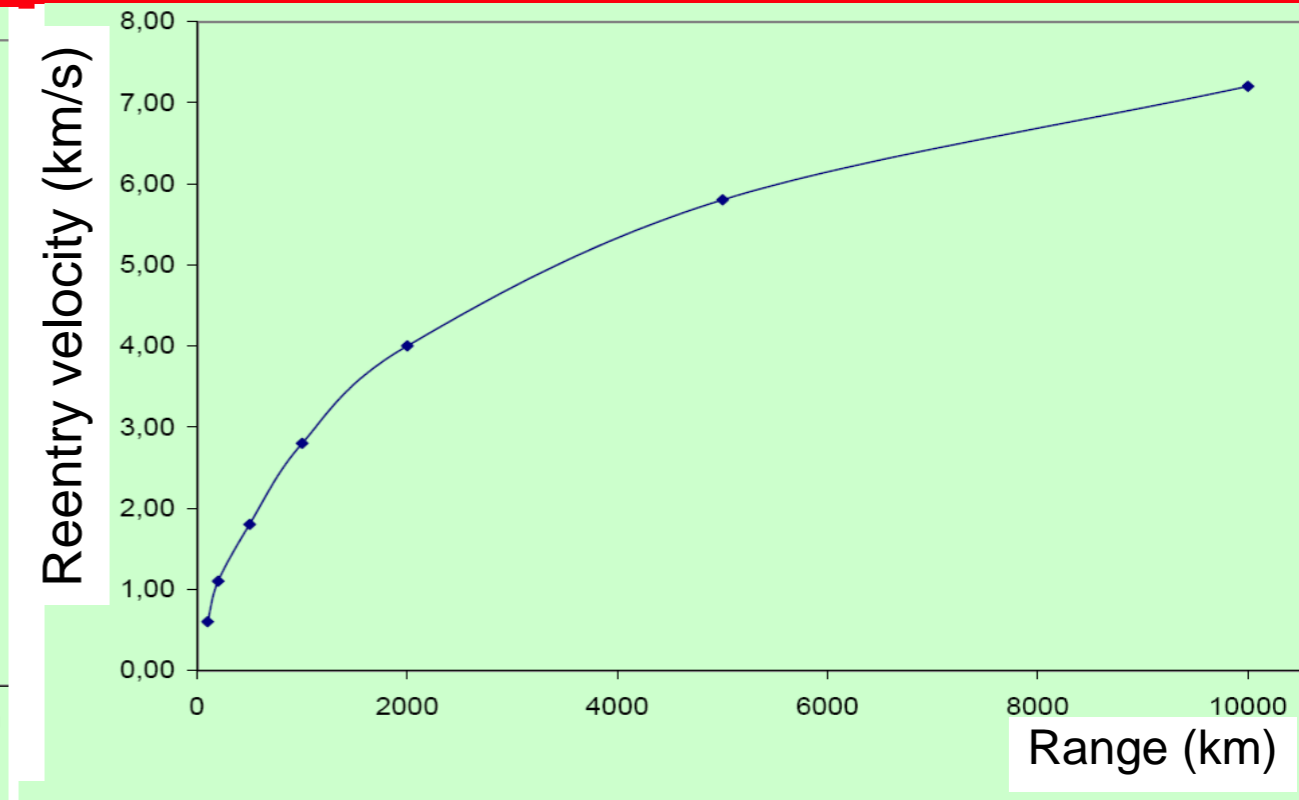
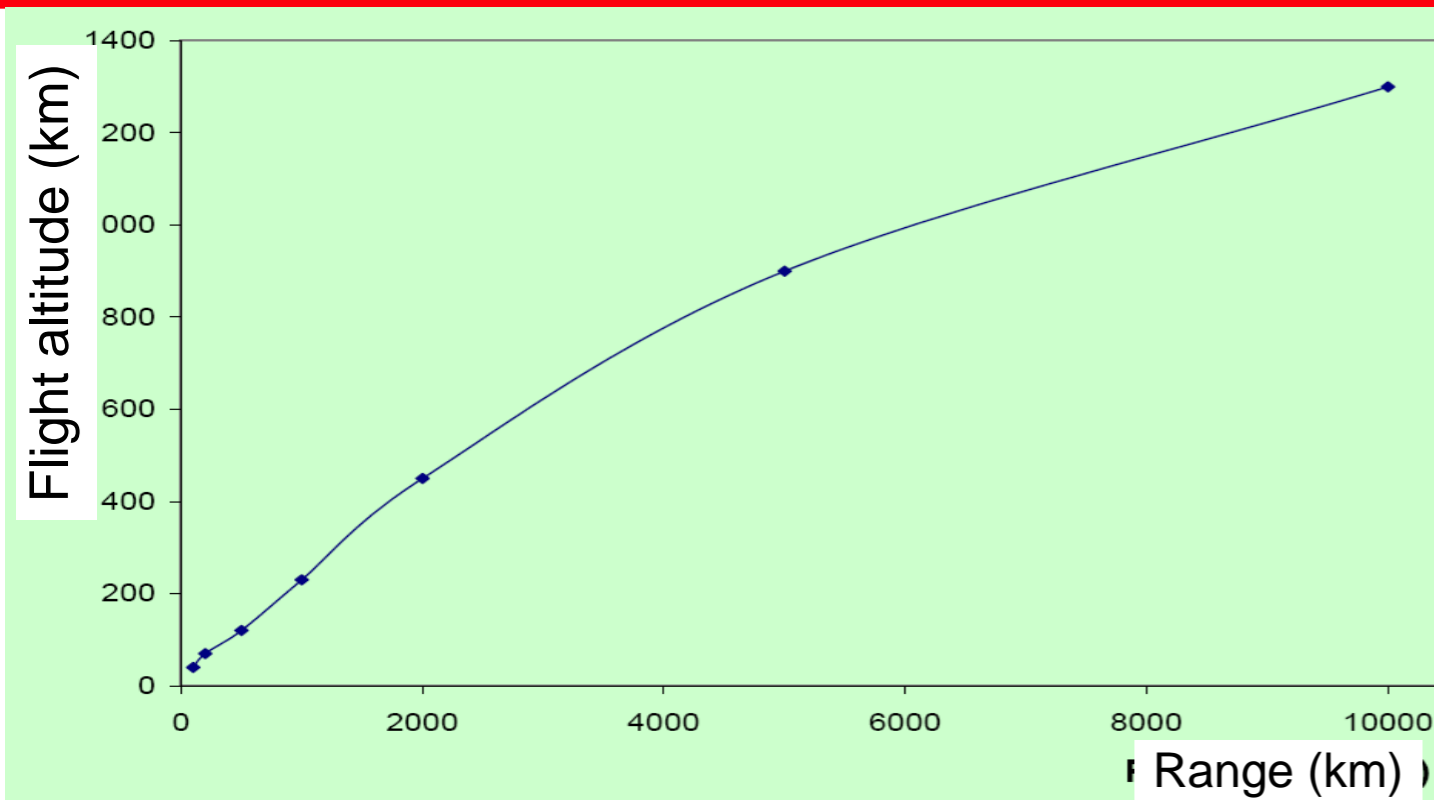


# Range-Payload Tradeoff

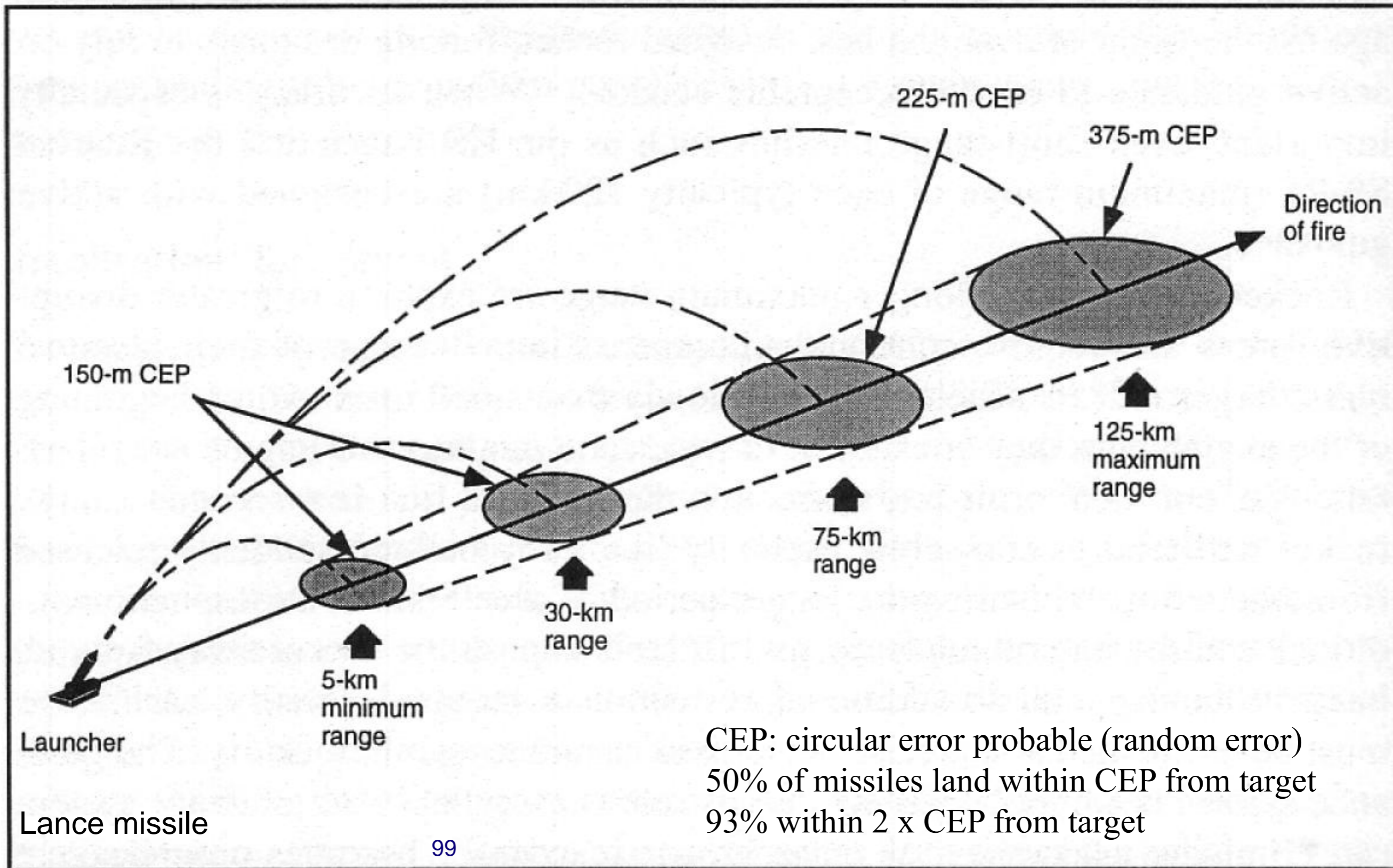


MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

# The Performance Required for Missile Warheads Increases Greatly with Increasing Missile Range



# Missile Range–Accuracy Tradeoff



# ICBM Accuracy & Vulnerability

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Missile accuracy steadily improved during the Cold War as the result of technological innovation.

As ICBMs become more accurate, they become more vulnerable to attack by the adversary, increasing crisis instability.

Each ICBM and each SLBM was armed with more and more warheads during the Cold War.

As each missile was armed with more warheads, it became a greater threat to the nuclear forces of the adversary and a more attractive target for a pre-emptive or first strike, increasing crisis instability.

# Silo-Based Missiles

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## Vulnerable to attack

- Silo locations are known very accurately
- MIRVed missiles make it possible to launch several warheads against each silo

## Effect of silo hardness

- Hardening is expensive
- US assumes its silos can withstand 2,000 psi (5 psi will completely destroy a brick house)
- US assumes Russian silos can withstand 5,000 psi (example of 'worst-case' analysis)
- To destroy a silo this hard, a 300 kt warhead would have to land within 100 m

# Silo-Based Missiles

## Effect of missile accuracy

- Theoretically, missile survival is very sensitive to the miss distance  $D$  of incoming warheads
- An an example, assume
  - 1,000 Minuteman silos are hardened to 2,000 psi
  - Two 1.5 MT warheads are targeted to explode at ground level on each silo
- Computations predict
  - If  $D = 300$  ft, then 20 missiles survive (60 if 5,000 psi)
  - If  $D = 500$  ft, then 200 missiles survive (600 if 5,000 psi)

# Ballistic Missile Accuracy

The accuracy of a ballistic missile—like the value of *any* physical quantity—can only be specified *statistically*.

Important concepts:

- D = total miss distance
- CEP = “circular error probable” (random error)
- B = Bias (systematic error)

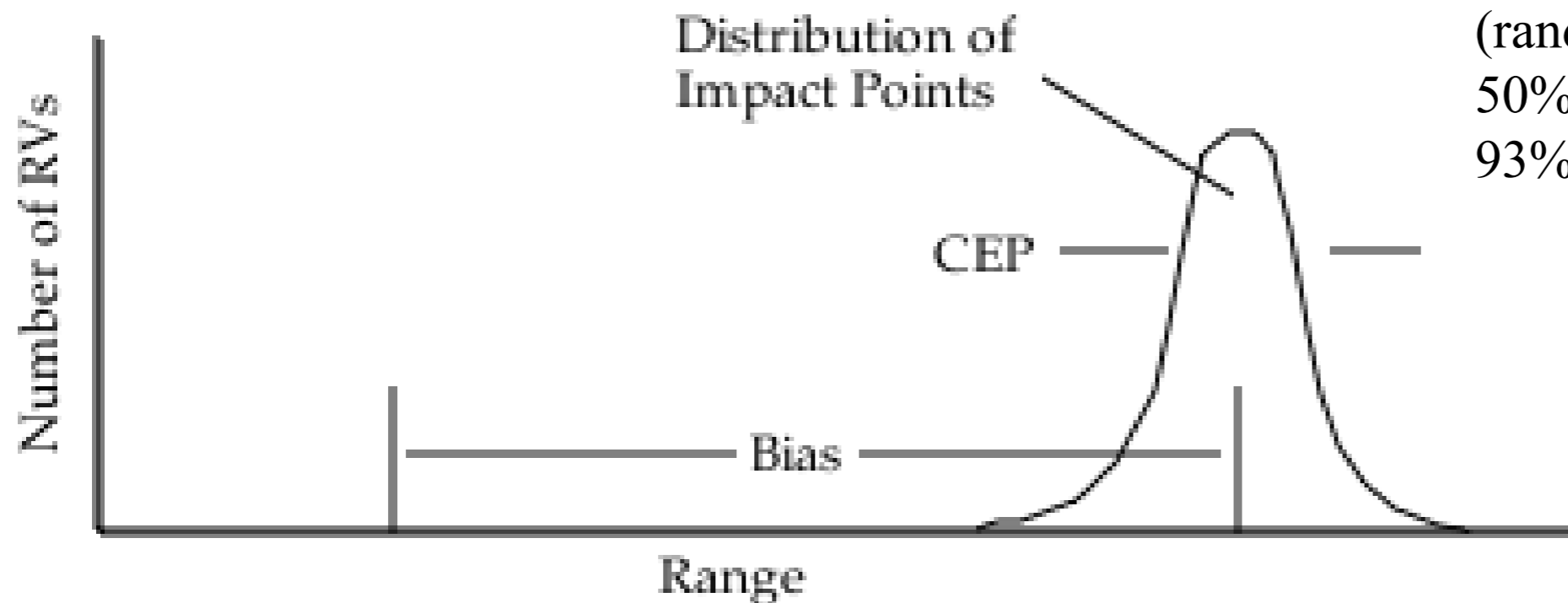
Algebraic relation —

$$D = (B^2 + CEP^2)^{1/2}$$

CEP is *not* a measure of the miss distance. The miss distance is *at least as large* as the CEP, but can be *much larger* if there is significant bias.

# Ballistic Missile Accuracy

## Distribution of RV impact points —



CEP: circular error probable  
(random error)  
50% of missiles land within CEP,  
93% within 2 x CEP from target



# Ballistic Missile Accuracy

## Published CEPs for some ICBMs and SLBMs

	Missile	CEP
US	MMIII	220 m
	Trident I	450 m
	Trident II	100 m
Russia	SS-18	450 m
	SS-N-18	600 m

# Sources of Systematic Error

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- Gravitational field variations
- Atmospheric drag variations

# Gravitational Field Variations

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Some possible causes —

- Bumps on the Earth (mountains)
- Mass concentrations (masscons)
- Gravitational pull of the Moon

(Motion of the Moon changes  $g$  by 3 ppm. An error in  $g$  of 3 ppm introduces a bias of 300 ft.)

The Earth's gravitational field is carefully measured over US and R (E-W) test ranges —

- US: Vandenberg to Kwajalein
- R: Plesetsk to Kamchatka and Tyuratam to Pacific

But wartime trajectories would be N-S over pole.

# Atmospheric Drag Variations

---

Some possible sources —

- Jet streams
- Pressure fronts
- Surface winds  
(30 mph surface wind introduces a bias of 300 ft.)

Density of the atmosphere —

- Is a factor of 2 greater in the day than at night
- Varies significantly with the season
- Is affected by warm and cold fronts

Data from military weather satellites and from models of weather over SU targets were reportedly used to update US warheads twice per day

# Uncertainties on Silo-Based Missiles

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## Fundamental uncertainties

- Missile accuracy
- Warhead yield
- Silo hardness

## Operational uncertainties

- Timing of attack
- System reliability
- Wind and weather
- Effects of other warheads (fratricide)
- Extent of 'collateral damage'  
( 'digging out' missiles creates enormous fallout)

# Effects of Explosive Yield, Missile Accuracy, and Silo Hardness on Land-Base Missile Vulnerability

Probability of destroying (“killing”) a missile silo:

$$P_K = 1 - e^{-K/f(H)}$$

- A 10-fold increase of warhead yield  $Y$  increases the kill factor  $K$  by about a factor of 5.
- A 10-fold decrease in the warhead miss distance  $D$  increases the kill factor  $K$  by 100.
- For a kill factor of 20, a 10-fold increase in the silo hardness from 300 psi to 3000 psi reduces the probability of silo destruction from about 85% to about 35%.

# Counterforce Capabilities in 1985

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U.S. ICBMs:  $K = 107,000$

U.S. SLBMs:  $K = 48,000$

U.S. Trident II D5:  $K = (475,000)$

Russia ICBMs:  $K = 131,000$

Russia SLBMs:  $K = 9,500$

# Submarine-Based Missiles

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## Operational considerations

- Relative vulnerability  
(size of operational areas, ASW threat, counter-ASW capability)
- Ability to survive
- US SSBNs are quieter than Russian SSBNs  
(but Russia is improving rapidly)
- US leads in anti-submarine warfare (ASW) capability  
and access to high seas
- Fraction of forces on-station  
(duration of patrols, time required for repairs)
- System reliability
- Effectiveness of command and control



# Submarine-Based Missiles

## Effective number of warheads (example)

- United States

$$\begin{array}{ll} 2688 & \text{[SLBM warheads]} \\ \times 0.75 & \text{[fraction typically on-station]} \\ \times 0.90 & \text{[estimated reliability]} \\ = 1,814 & \text{[effective number of warheads]} \end{array}$$

- Russia

$$\begin{array}{ll} 2384 & \text{[SLBM warheads]} \\ \times 0.25 & \text{[fraction typically on-station]} \\ \times 0.70 & \text{[estimated reliability]} \\ = 447 & \text{[effective number of warheads]} \end{array}$$

These examples show that many factors *other than just the number of warheads* are important in comparing the effectiveness of nuclear forces.

# Module 5: Nuclear Delivery Systems

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## Part 5: Nuclear Command and Control

# Nuclear Command and Control – 1

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## C3I: Command, Control, Communication, Intelligence

### Specific goals—

- Provide strategic and tactical warning
- Provide damage assessments
- Execute war orders from National Command Authority before, during, and after initial attack
- Evaluate effectiveness of retaliation
- Monitor development of hostilities, provide command and control for days, weeks, months

# Nuclear Command and Control – 2

Some important aspects and implications —

- Organizational structure of command and control
- Available strategic communications, command, control and intelligence (C<sup>3</sup>I) assets
- Vulnerability of strategic C<sup>3</sup>I assets to attack

Alert levels —

**DEFCON 5** Normal peacetime readiness

**DEFCON 4** Normal, increased intelligence and strengthened security measures

**DEFCON 3** Increase in force readiness above normal readiness intelligence and strengthened security measures

**DEFCON 3** Increase in force readiness above normal readiness

**DEFCON 2** Further Increase in force readiness

**DEFCON 1** Maximum force readiness.

# Nuclear Command and Control – 3

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## Satellite systems

- Early warning
- Reconnaissance
- Electronic signals
- Weather
- Communication
- Navigation

# Response Times for Attack or Breakout



# The Threat of Accidental Nuclear War

## 20 Dangerous Incidents

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- 1) November 5, 1956: Suez Crisis Coincidence
- 2) November 24, 1961: BMEWS Communication Failure
- 3) August 23, 1962: B-52 Navigation Error
- 4) August-October, 1962: U2 Flights into Soviet Airspace
- 5) October 24, 1962- Cuban Missile Crisis: A Soviet Satellite Explodes
- 6) October 25, 1962- Cuban Missile Crisis: Intruder in Duluth
- 7) October 26, 1962- Cuban Missile Crisis: ICBM Test Launch
- 8) October 26, 1962- Cuban Missile Crisis: Unannounced Titan Missile Launch
- 9) October 26, 1962- Cuban Missile Crisis: Malstrom Air Force Base
- 10) October, 1962- Cuban Missile Crisis: NATO Readiness

Source: [www.nuclearfiles.org/kinuclearweapons/anwindex.html](http://www.nuclearfiles.org/kinuclearweapons/anwindex.html)

# The Threat of Accidental Nuclear War

## 20 Dangerous Incidents

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- 11) October, 1962- Cuban Missile Crisis: British Alerts
- 12) October 28, 1962- Cuban Missile Crisis: Moorestown False Alarm
- 13) October 28, 1962- Cuban Missile Crisis: False Warning Due to Satellite
- 14) November 2, 1962: The Penkovsky False Warning
- 15) November, 1965: Power Failure and Faulty Bomb Alarms
- 16) January 21, 1968: B-52 Crash near Thule
- 17) October 24-25, 1973: False Alarm During Middle East Crisis
- 18) November 9, 1979: Computer Exercise Tape**
- 19) June , 1980: Faulty Computer Chip**
- 20) January 25, 1995: Russian False Alarm**

Source: [www.nuclearfiles.org/kinuclearweapons/anwindex.html](http://www.nuclearfiles.org/kinuclearweapons/anwindex.html)



# The Threat of Accidental Nuclear War

## 20 Dangerous Incidents

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"The lesson from this is that a guy called Vasili Arkhipov saved the world," said Thomas Blanton, director of the National Security Archive. He was referring to the Soviet captain who prevailed on his fellow officers not to fire the nuclear torpedo.

That scientific rocket caused a dangerous moment in the nuclear age. Russia was poised, for a few moments at least, to launch a full-scale nuclear attack on the United States. In fact, President Boris Yeltsin stated the next day that he had activated his "nuclear football"—a device that allows the Russian president to communicate with his top military advisers and review the situation online—for the first time.

# Possible Risk Reduction Measures

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- Put ballistic missiles on low-level alert
- Reduce number of warheads on missiles
- Remove warheads to storage
- Disable missiles by having safety switches pinned open and immobilized
- Allow inspections and cooperative verification

Source: B. Blair, H. Feiveson, F. von Hippel, Taking Nuclear Weapons off Hair-Trigger Alert, Scientific American, November 1997

# iClicker Question

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What is the definition of an ICBM?

Range > 4,800 km

Range > 5,500 km

Range > 6,300 km

Range > 10,000 km

Range > 12,000 km

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# iClicker Question

---

What is the definition of an ICBM?

Range > 4,800 km

**Range > 5,500 km**

Range > 6,300 km

Range > 10,000 km

Range > 12,000 km

# iClicker Question

---

What is the definition of a MRBM?

500 km < Range < 1,000 km

1,000 km < Range < 1,500 km

1,000 km < Range < 2,000 km

1,000 km < Range < 3,000 km

3,000 km < Range < 5,500 km

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# iClicker Question

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What is the definition of a MRBM?

500 km < Range < 1,000 km

1,000 km < Range < 1,500 km

1,000 km < Range < 2,000 km

**1,000 km < Range < 3,000 km**

3,000 km < Range < 5,500 km



# End of Module 5

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