Physics 280: Session 14

Plan for This Session

Questions

Announcement:

Midterm Exam, Thursday March 19th

- ➔ midterm will cover modules 1 to 5 + news
- ➔ old tests available for practice on course web-page
- ➔ 50% of problems will be from old exam
- ➔ will schedule review session next week

News

Module 5: Nuclear Weapon Delivery Systems

theguardian

Iran nuclear deal 'very close' as Netanyahu brings negotiators together

American and Iranian diplomats find common ground rejecting Israeli leader's combative approach to negotiations, but also agree serious hurdles remain to meeting March deadline

Julian Borger

Thursday 5 March 2015 10.31 EST

The long and convoluted negotiations over Iran's nuclear programme adjourned on Wednesday amid talk of continuing progress towards a comprehensive deal but of tough political decisions still to be made.

The talks will resume on March 15, probably in Geneva, as the latest deadline for agreement looms at the end of the month.

Iran's foreign minister, Mohammad Javad Zarif said a deal was "very close", telling NBC that he and his team were prepared to carry on working through the Persian New Year celebration of Nowruz starting on March 21.

Zarif has frequently argued that the standoff over Iran's nuclear ambitions is unnecessary and easy to solve, as Tehran has no intention of making a bomb and would therefore accept a great deal of transparency to reassure the international community.

Zarif's American counterpart, the US secretary of state, John Kerry, emerged from their ten hours of talks in Montreux, Switzerland, with more of a focus on the half of the glass still empty, warning: "There are still significant gaps and important choices that need to be made."

Concerns In Saudi Arabia and the Gulf States with Regards to a Possible P5+1 Accord with Iran

The New York Times | http://nyti.ms/1GZQam4

MIDDLE EAST

John Kerry, in Saudi Arabia, Reassures Gulf States on Iran Nuclear Talks

By MICHAEL R. GORDON MARCH 5, 2015

RIYADH, Saudi Arabia — Secretary of State John Kerry on Thursday sought to reassure Saudi Arabia and other Gulf states that the negotiation of a nuclear accord with Iran would not lead the Obama administration to let down its guard against any Iranian interference in the region.

With the Saudi foreign minister by his side, Mr. Kerry said at a news conference here that the administration was committed to standing up to Iran's "intervention."

"We are not seeking a grand bargain," Mr. Kerry said, offering the assurance that the administration was not pursuing a broader rapprochement with Iran that could come at the expense of its Arab rivals. "We will not take our eye off of Iran's other destabilizing actions."

Replacement of the Ohio-Class Submarines

Congressmen Rally Behind Ohio-Class Submarine Replacement

By Yasmin Tadjdeh

Congressmen gathered on Capitol Hill to tout the importance of replacing the nation's aging ballistic missile equipped Ohio-class submarines.

Navy "leg" of the Triad!

Replacement of the Ohio-Class Submarines

Congressmen Rally Behind Ohio-Class Submarine Replacement

By Yasmin Tadjdeh

During a March 4 meeting sponsored by the Submarine Industrial Base Council, Rep. Rob Wittman, R-Va., chairman of the House Armed Services Committee's subcommittee on readiness, said replacing the boats — also known as SSBNs — will be critical to the nation's strategic outlook.

"We know how critical [the Ohio-class replacement] … is to our nation's strategic position in the world and we want to make sure that SSBNs availability match Ohio-class retirement. Or make sure there is no gap in there," he said.

The United States still "rules the undersea world," Wittman said, but Congress needs to ensure it continues investing in submarine platforms.

The Navy's 2016 proposed budget request asked for $1.4 billion toward research and development for the Ohio-class replacement program, also known as the SSBN(X). The program will replace 14 subs.

Module 5: Delivery Systems

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

Part 1: Overview

Basic Propulsion Mechanisms

- None
  (examples: mines, depth charges)
- 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, shipping container)

Examples of Weapon Delivery Methods

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

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

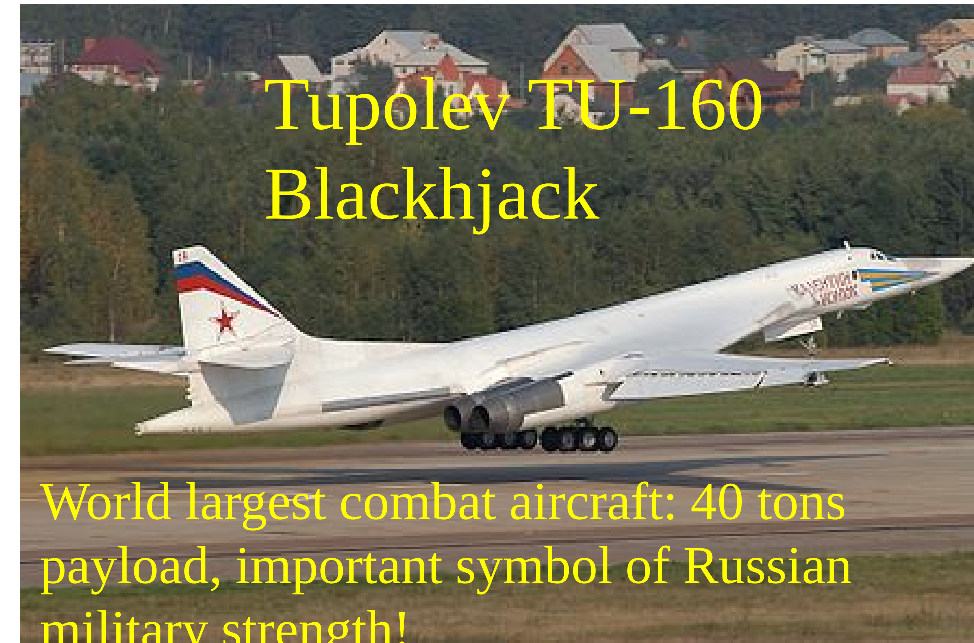
Air-Breathing Vehicles

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

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

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

Initially US nuclear weapons delivery systems were developed without a 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
- Established the SIOP (Single Integrated Operational Plan) for targeting

The U.S. Cold-War Strategic "Triad" – 2

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.)

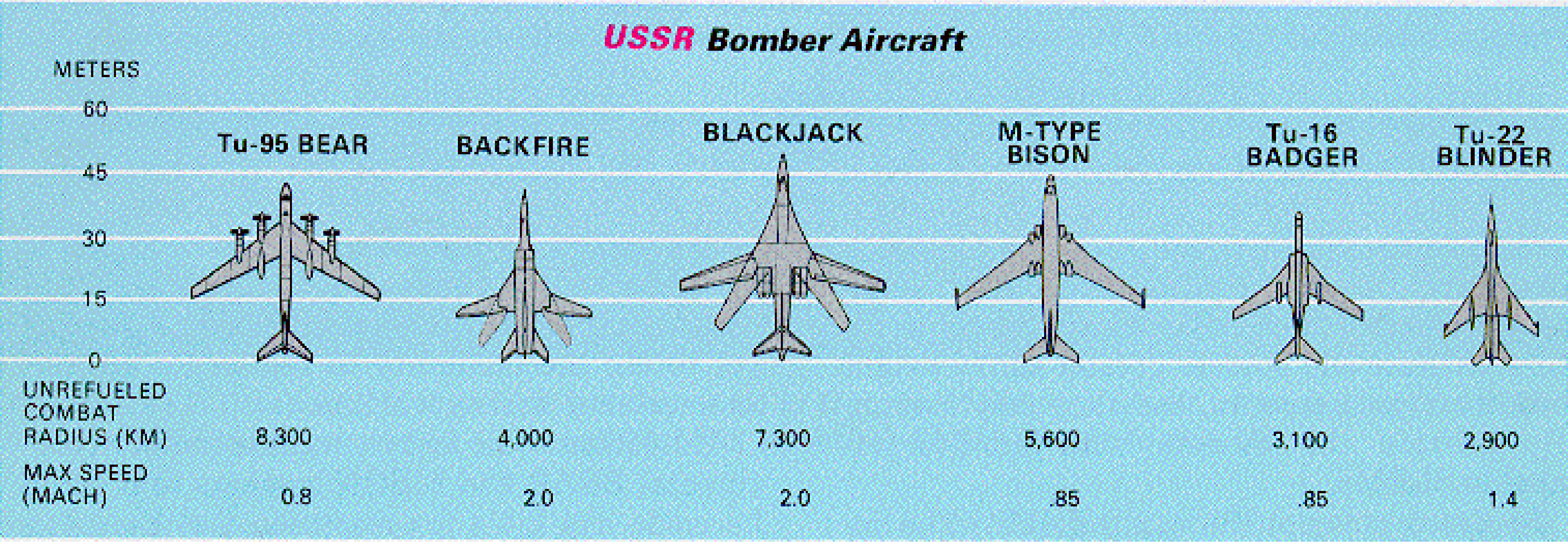
Systems in the Triad —

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

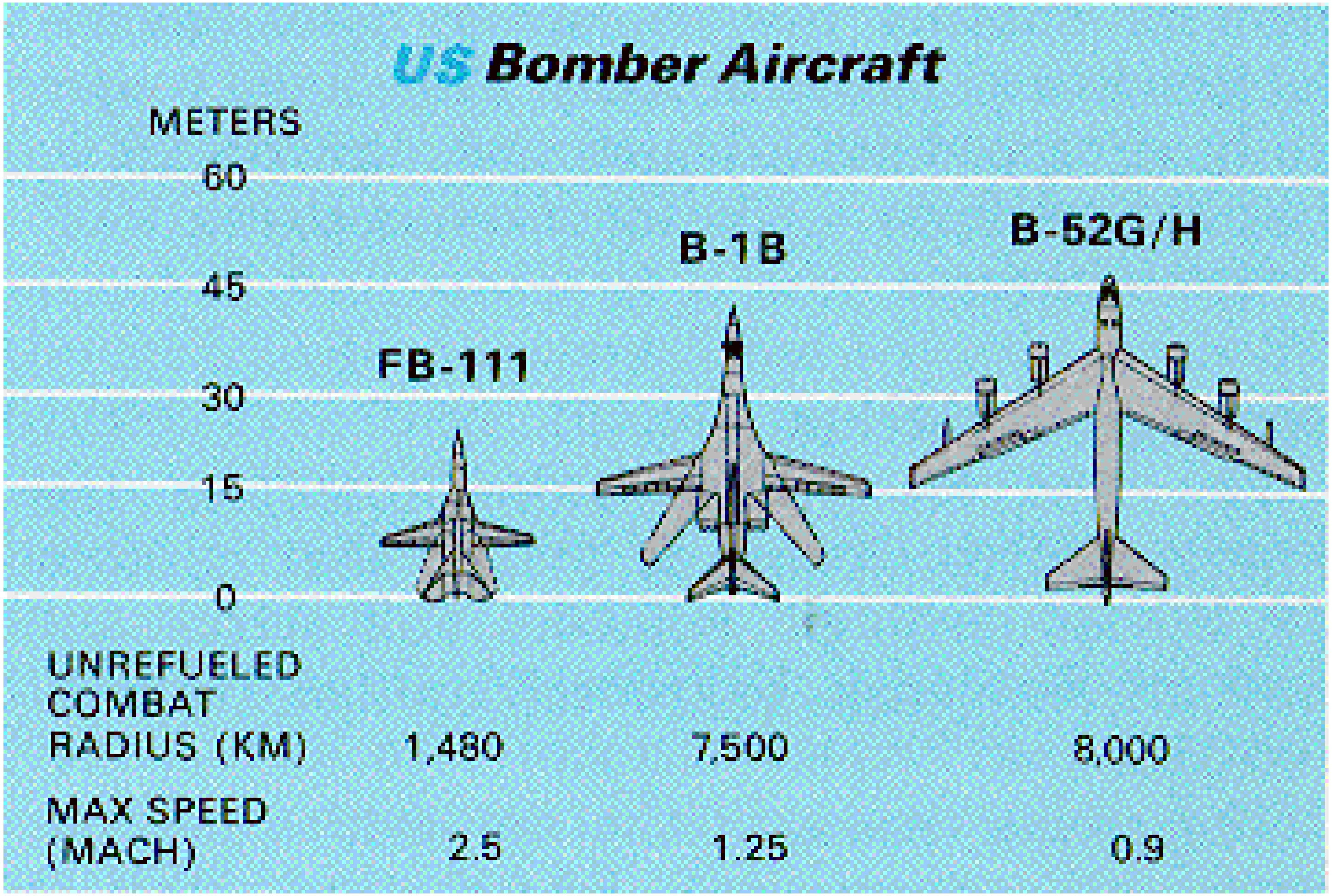
Module 5: Nuclear Delivery Systems

Part 2: Aircraft

Examples of Intercontinental Bombers – 1



Examples of Intercontinental Bombers – 2



U.S. B-2 Stealth Bomber

Speed: Mach 0.85

Altitude: 50,000 feet

Range: 7,000 miles
Refuel: 11,500 miles

Possible payloads:
- 16 B83 gravity bombs
- 20 B61 bombs
- 80 500 lb bombs

Currently Deployed U.S. and Russian Bombers

Current US bombers —

- B-52 Hs, carrying bombs, or cruise missiles
- B1-s, each can carry 16 B83 bombs
- B-2, each can carry 16 B83 bombs

Russian bombers* —

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

*Very few are currently operational

Intercontinental Bomber Issues

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

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

(A) Revenge

(B) Reaction

(C) Resources

(D) Renown

iClicker Question

iClicker Answer

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

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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

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Part 3: Cruise Missiles

Introduction to Cruise Missiles – 1 (Important)

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:

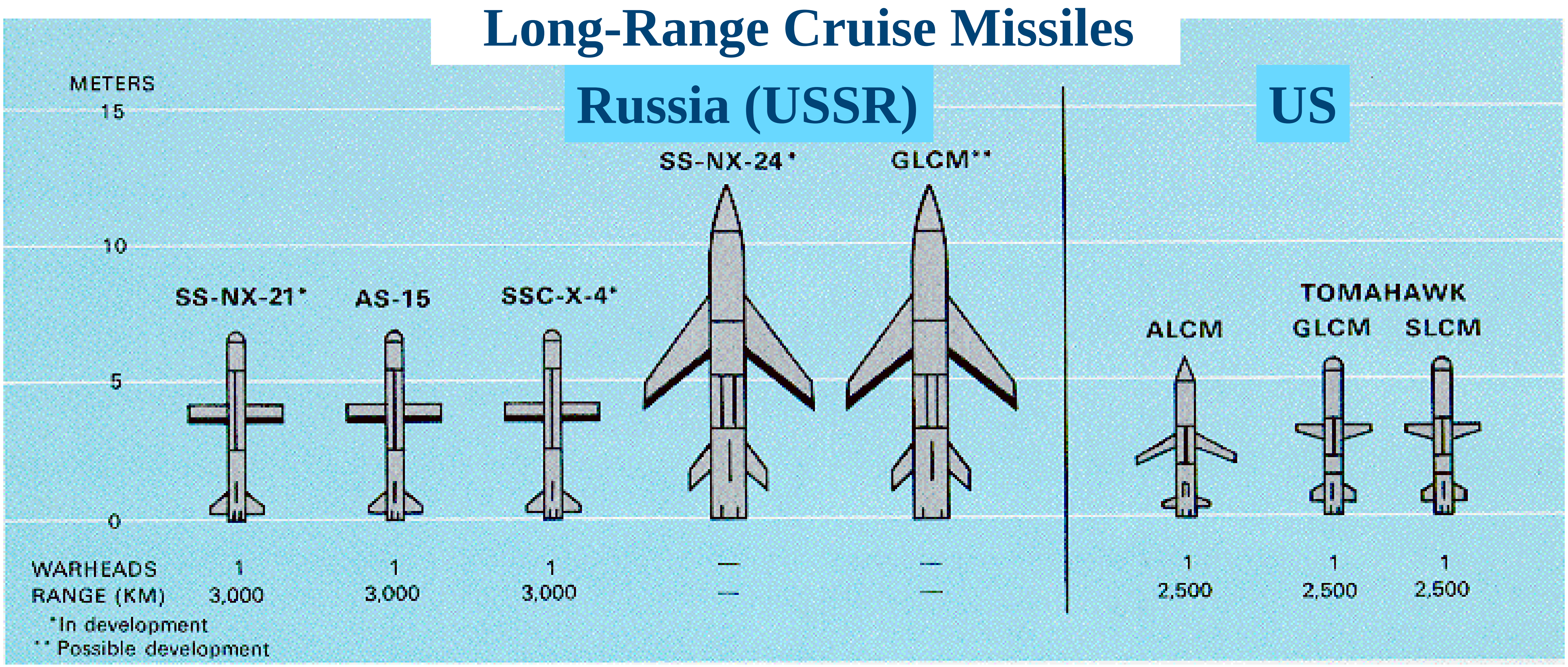
- Smaller and lighter nuclear warheads
- Efficient turbofan engines
- Highly capable miniaturized computers
- GPS, TERCOM (Terrain Contour Matching), and terminal guidance
- “Stealth” airframe technology

Introduction to Cruise Missiles – 2 (Important)

Key properties —

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

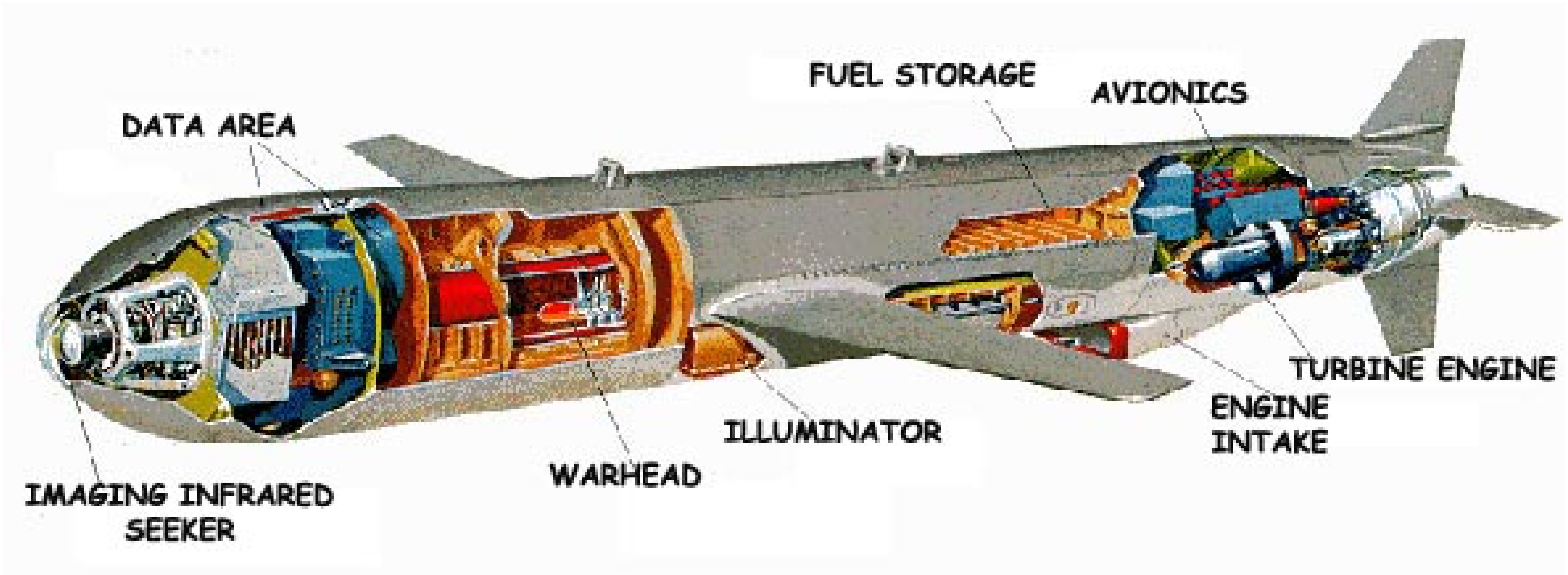
Long-Range Cruise Missiles – 1



range :1000 – 2000 miles

pay loads : 500 – 1200 lbs

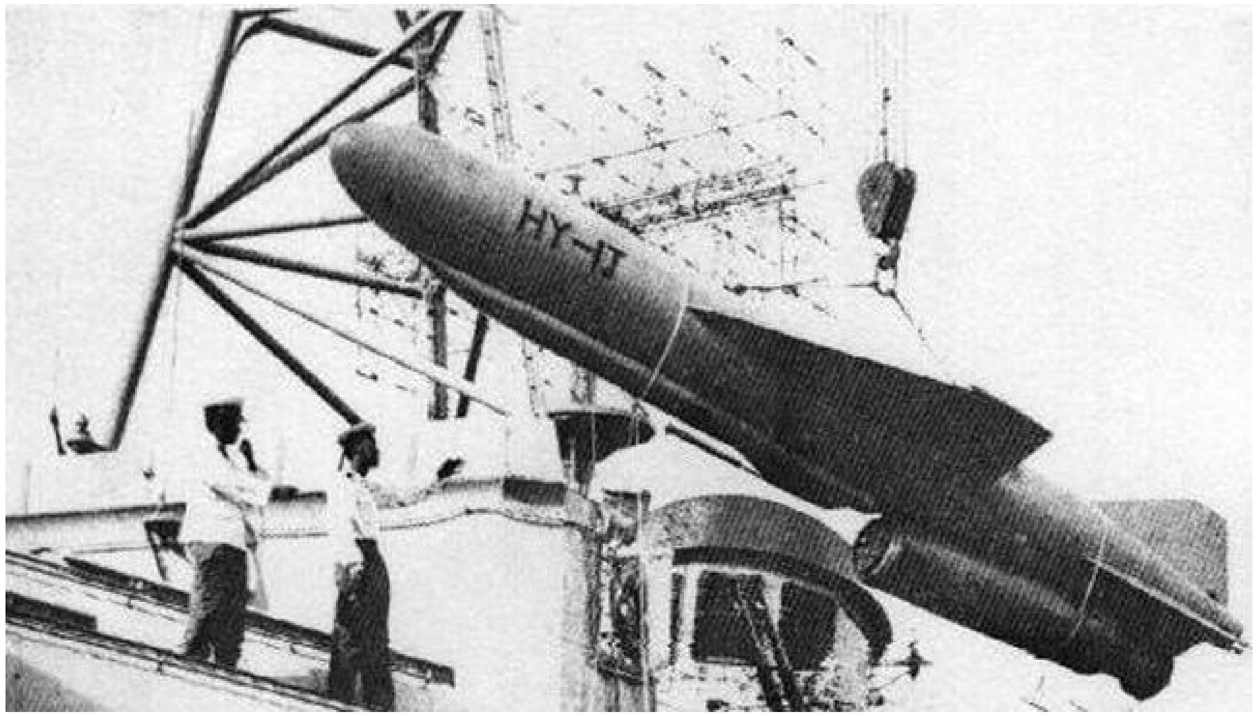
Long-Range Cruise Missiles – 2



Conventionally-Armed Tomahawk Cruise Missile

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

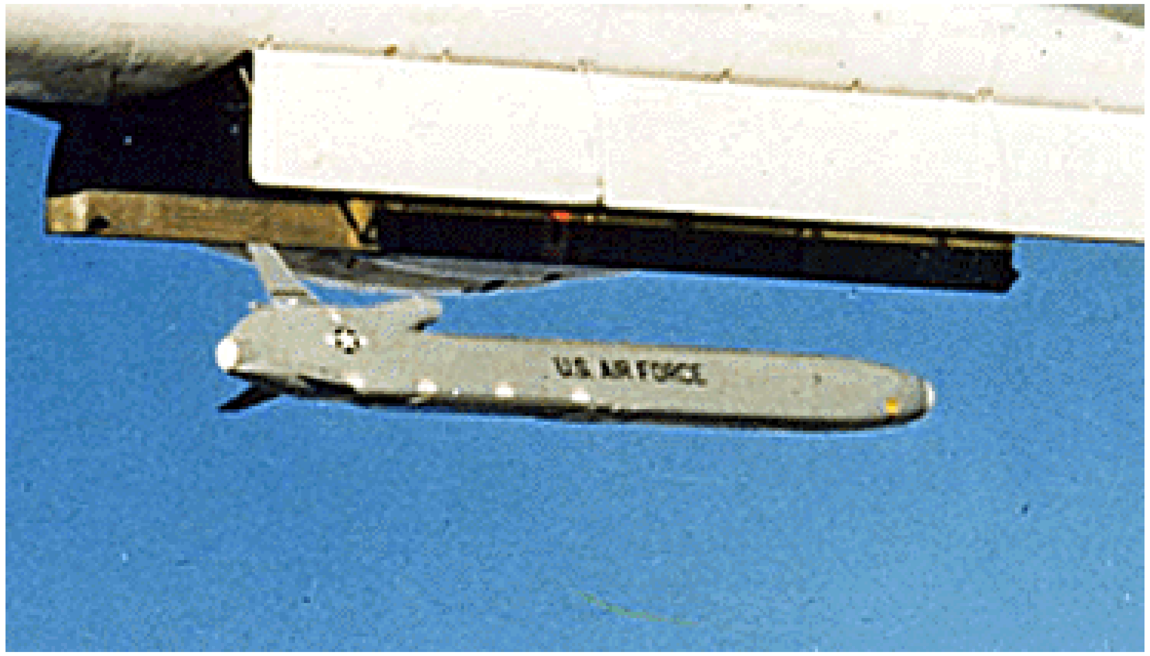
Chinese Silkworm Anti-Ship Cruise Missile



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

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

Launching Cruise Missiles – 1

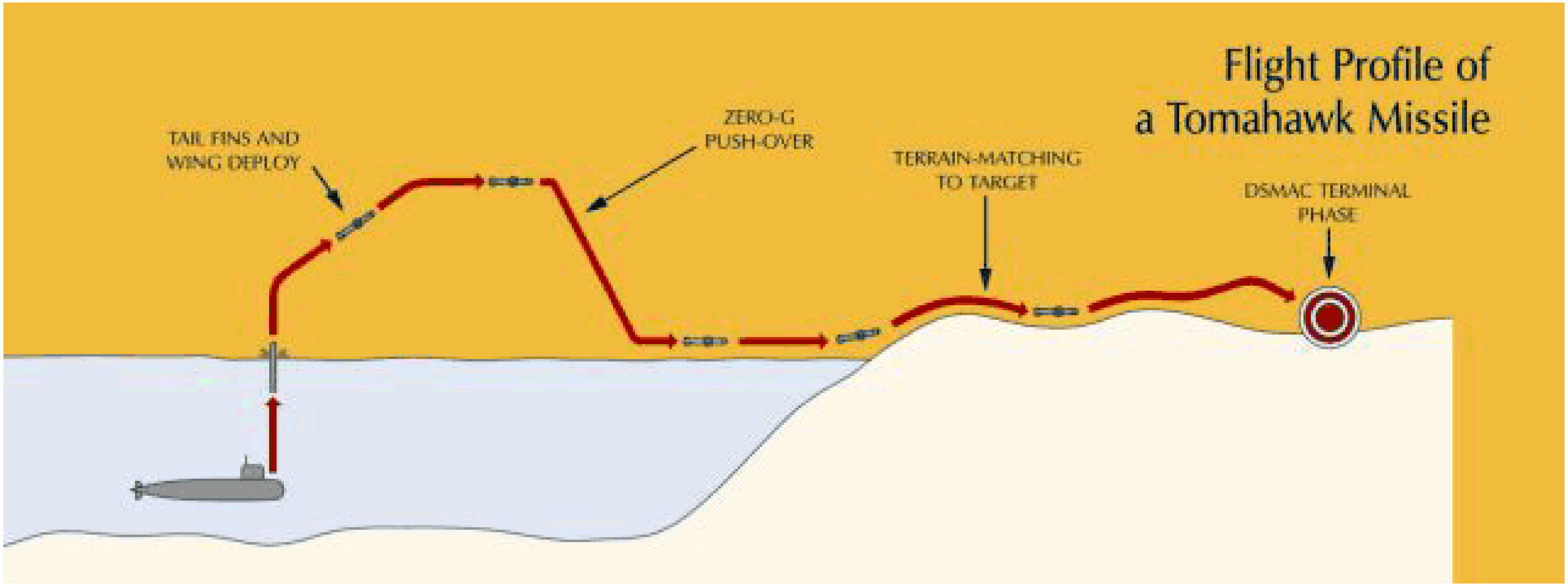


Launching Cruise Missiles – 2

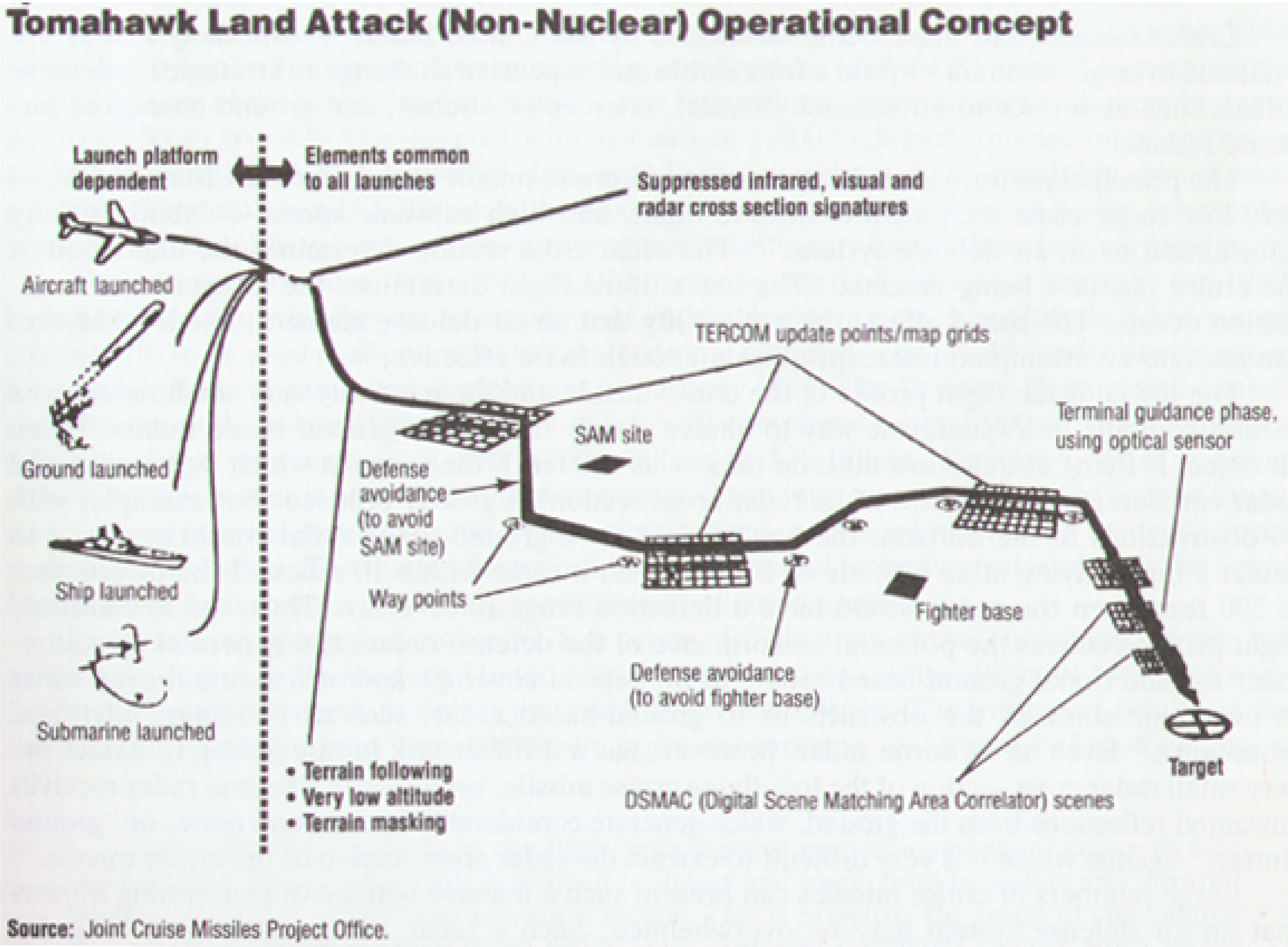
Cruise-Missile Guidance – 1

TERCOM: Terrain Contour Matching
DSMAC: Digital Scene Matching Area Correlation

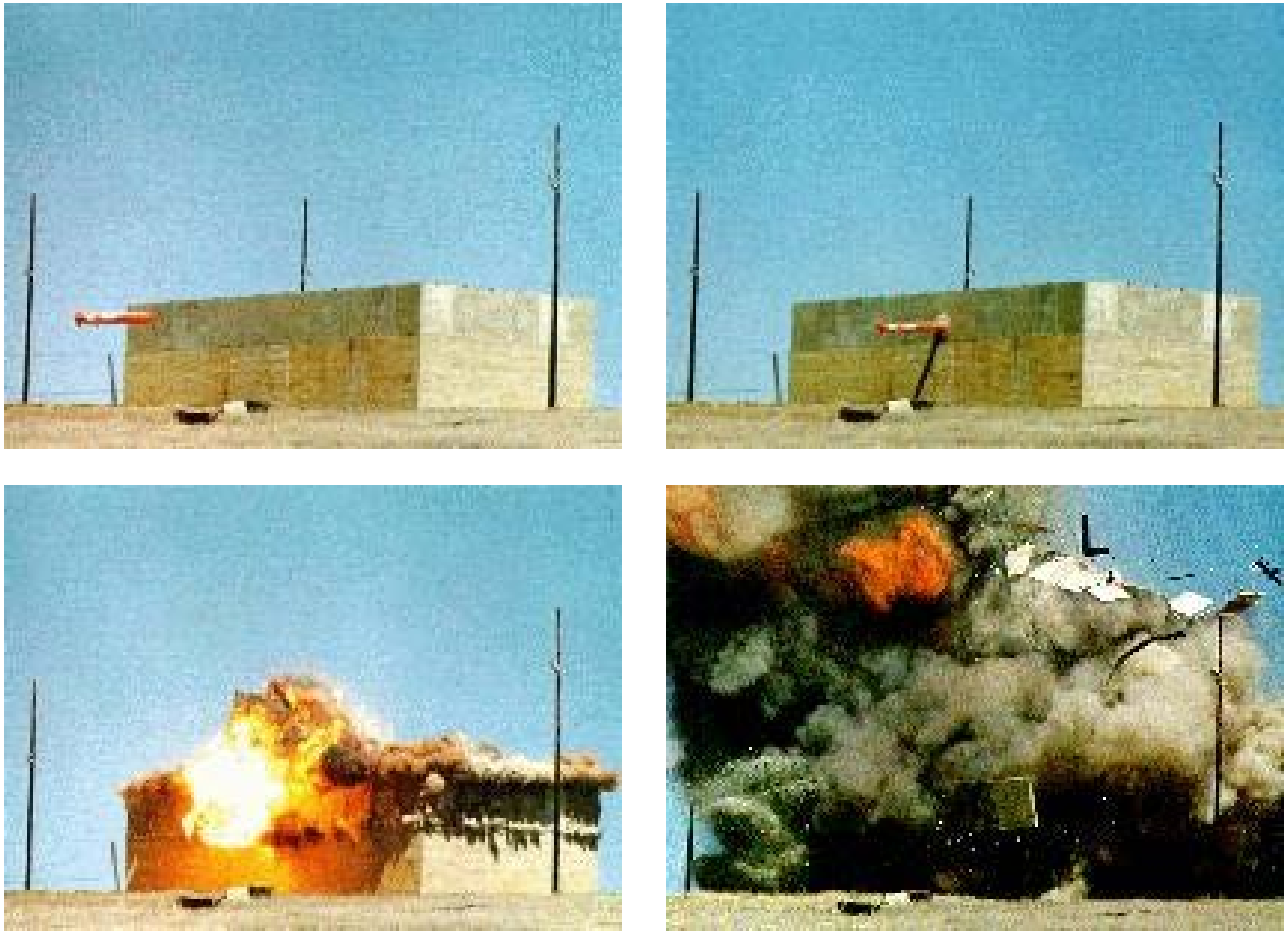
Cruise-Missile Guidance – 2



Cruise-Missile Guidance – 3



Accuracy of Cruise Missiles



Implications of Cruise Missiles – 1

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 is more vulnerable to CMs than Russia due to the proximity of potential targets to the sea shores.

Implications of Cruise Missiles – 2

Implications for U.S. security—

- Very small (hard to find 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 large numbers)

"Several countries could develop a mechanism to launch SRBMs, MRBMs, or land-attack cruise missiles from forward-based ships or other platforms"

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

Physics 280: Session 15

Plan for This Session

Vote on schedule for Midterm Review Session

(a) Sunday March 15th 6-8pm

(b) Tuesday March 17th 7-9pm

(c) Wednesday March 18th 7-9pm

Midterm Exam, Thursday March 19th, 2.00-3.20pm

Module 5: Nuclear Weapon Delivery Systems

Module 5: Nuclear Delivery Methods

Part 4: Ballistic Missiles

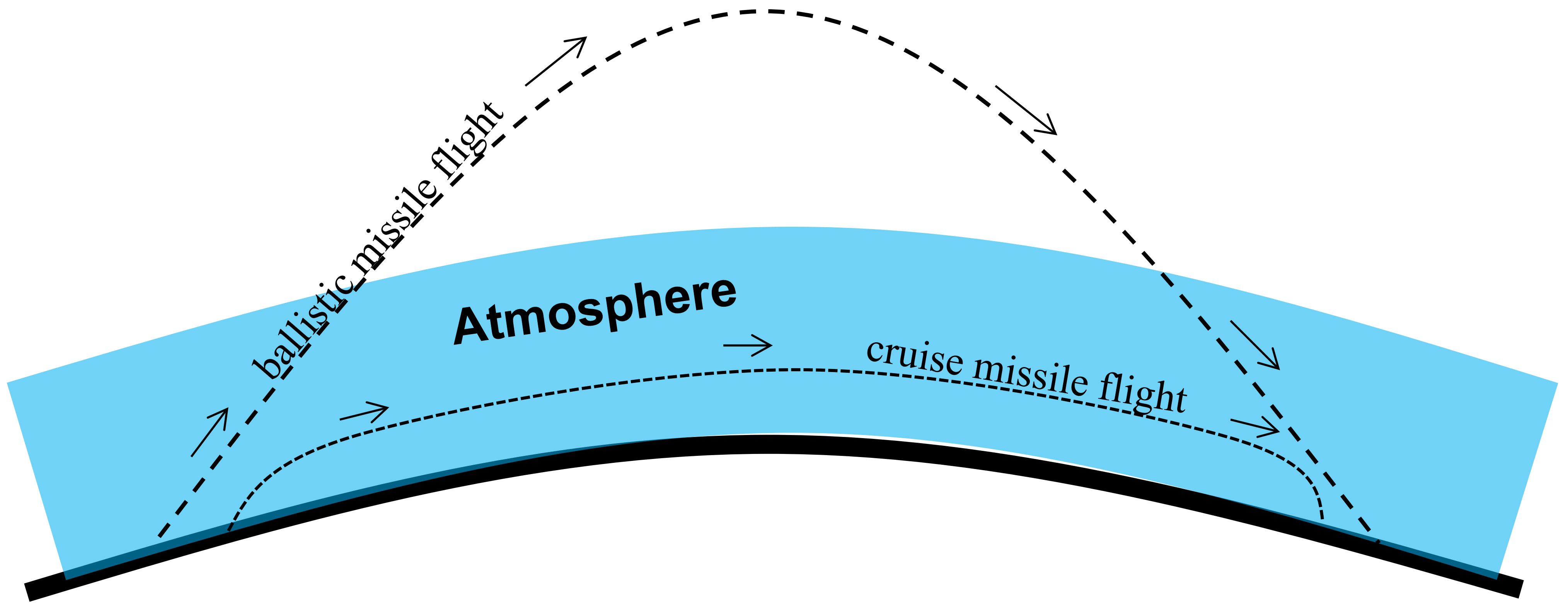
Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

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

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)

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) —

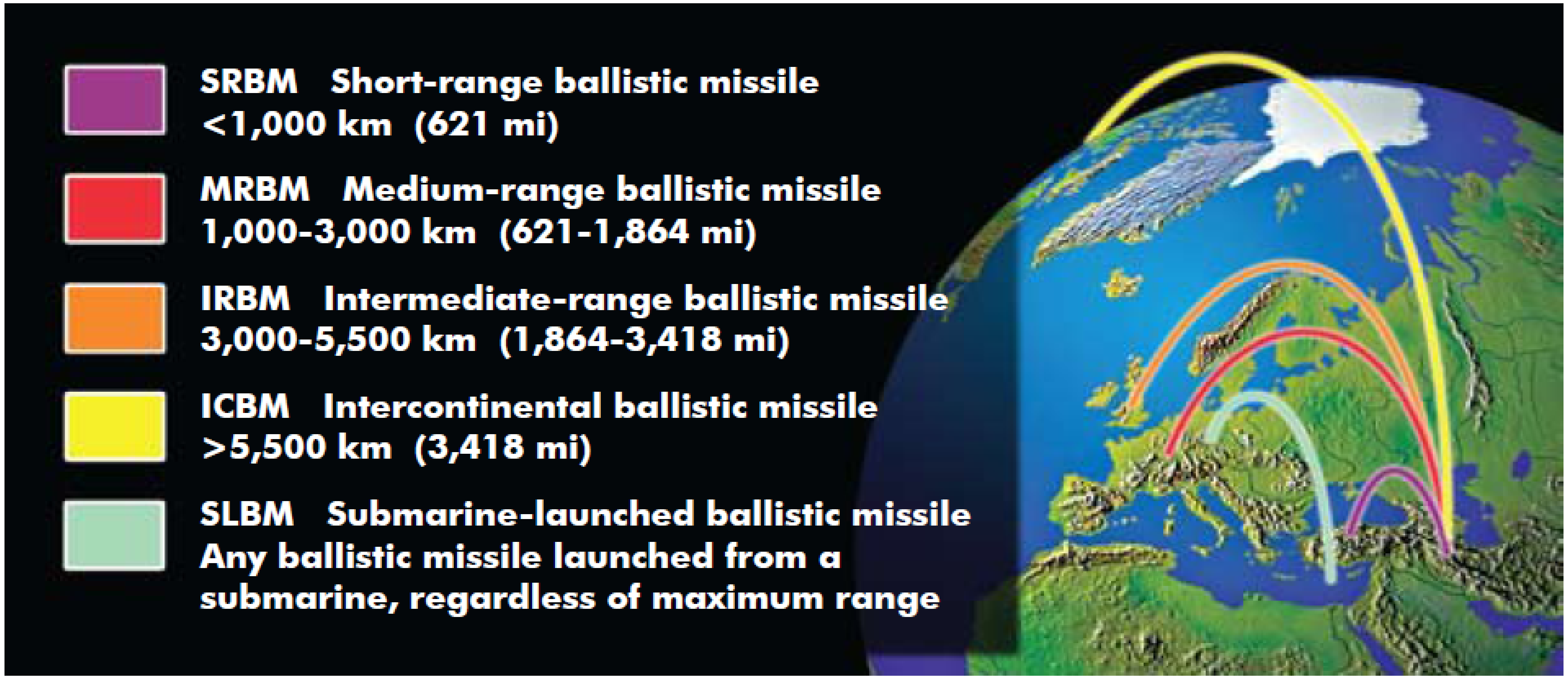
- Ranges between 3,000 km and 5,500 km

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)



Source: national air and space intelligence center

"Ballistic and Cruise Missile Threat", 2009

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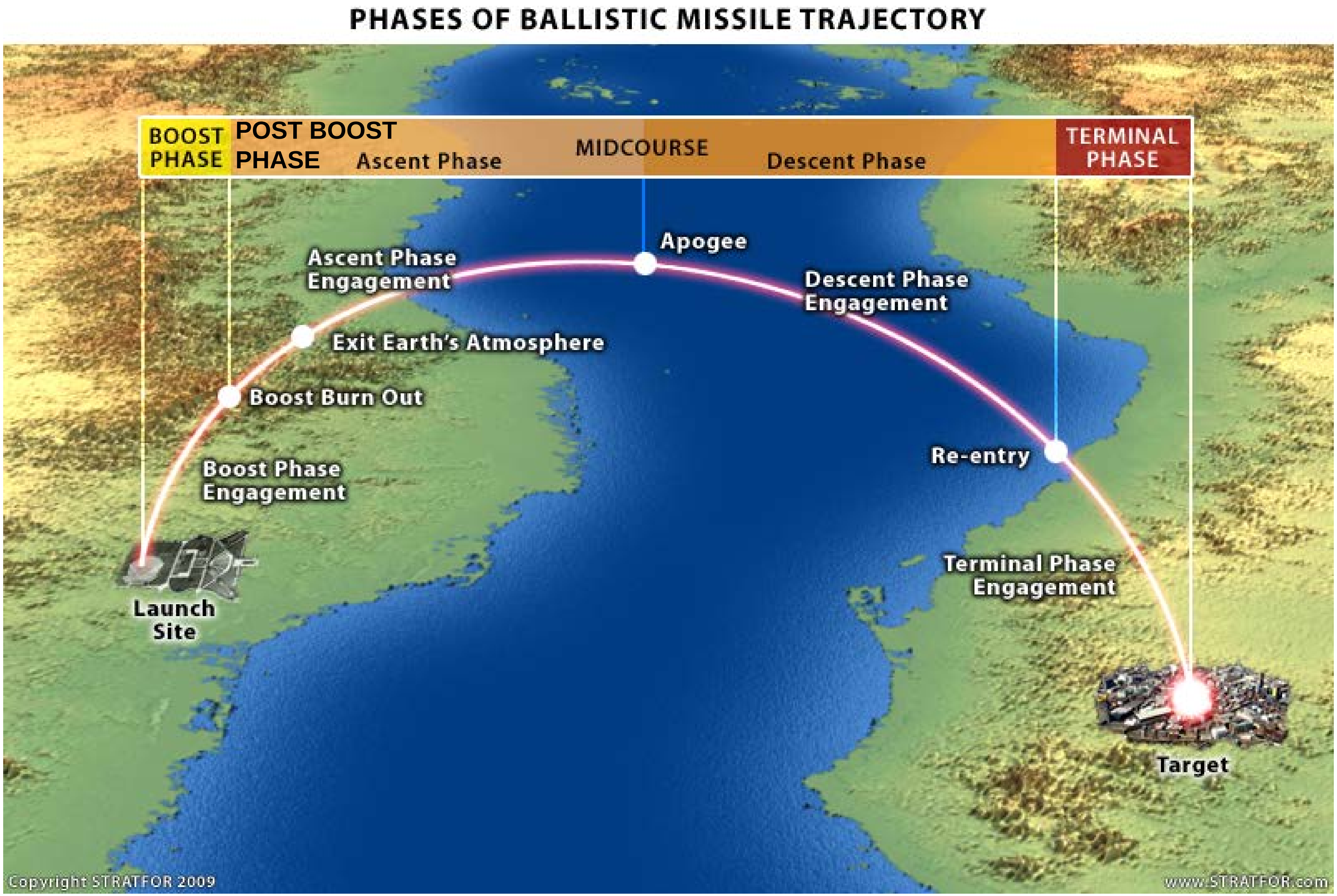
Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

Basic phases of flight of a (MIRVed) intercontinental ballistic missile (ICBMs and SLBMs) —

- Boost phase: rocket motors burning
- Post-boost phase (release of payload from bus)
- Midcourse phase: ballistic motion in space
- Terminal phase: re-entrance into atmosphere and passage through atmosphere

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



Categories of Ballistic Missiles Based on Their Purposes

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 – Strategic Nuclear Weapons Delivery Vehicle) —

- For attacking the homeland of the adversary
- May have longer, possibly 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

Inertial —

- Uses gyroscopes and accelerometers
- No contact with outside world

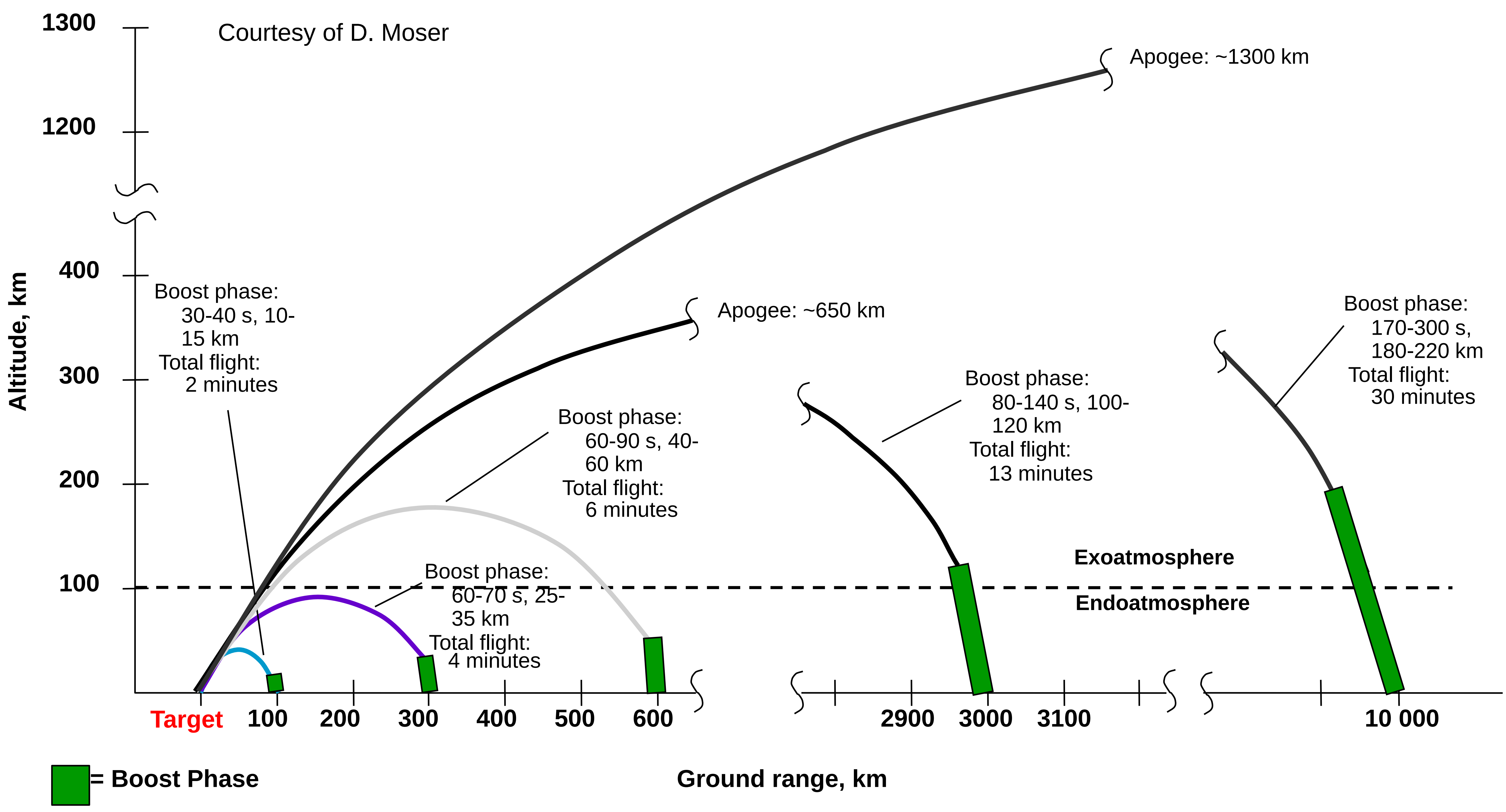
Stellar —

- Star trackers update inertial guidance system

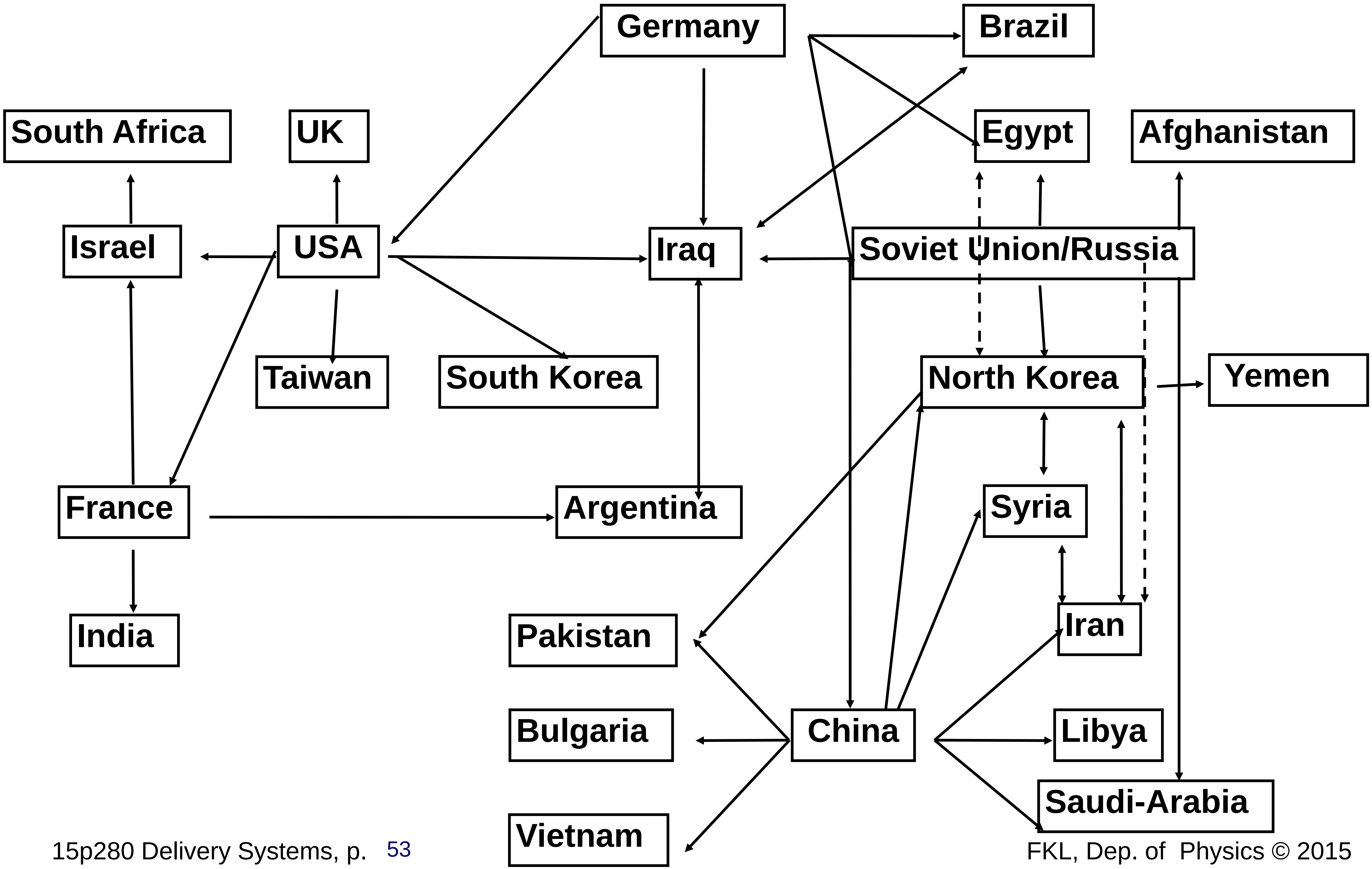
Satellite —

- 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

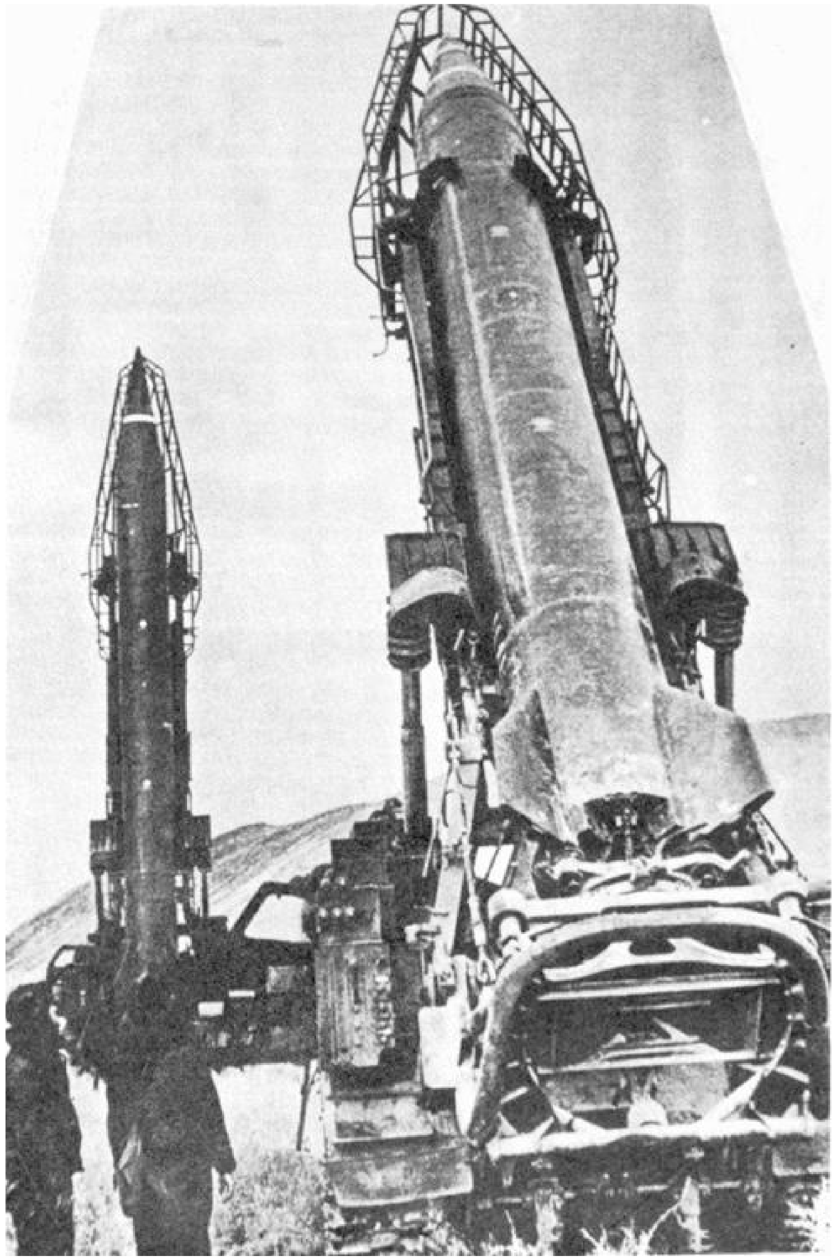
Trajectories and Phases of Flight of Missiles With Various Ranges



Proliferation of Ballistic Missile Technologies



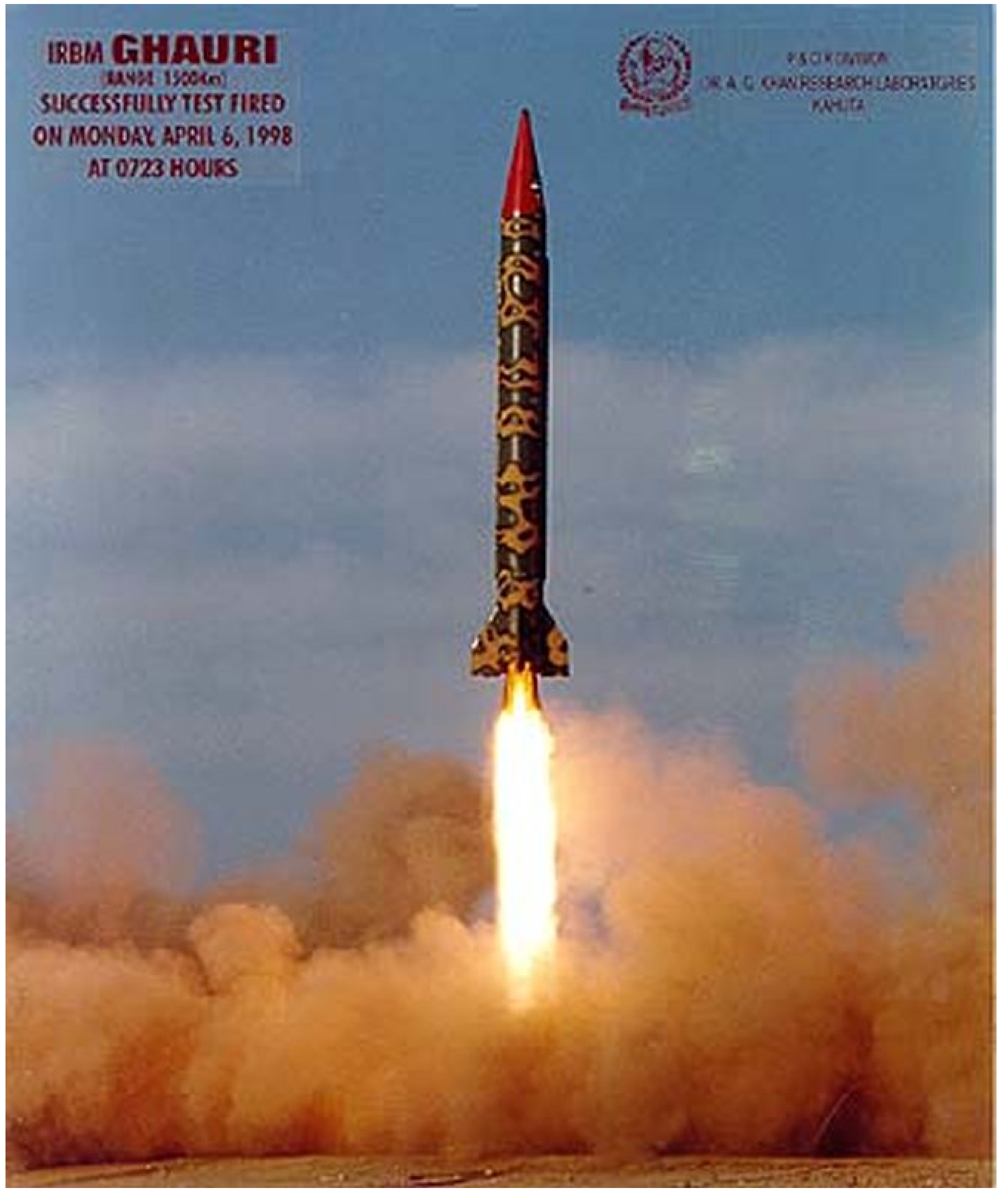
Soviet Scud Missiles and Derivatives - 1



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

Iraqi Al-Hussein SRBM
Range: 600–650 km

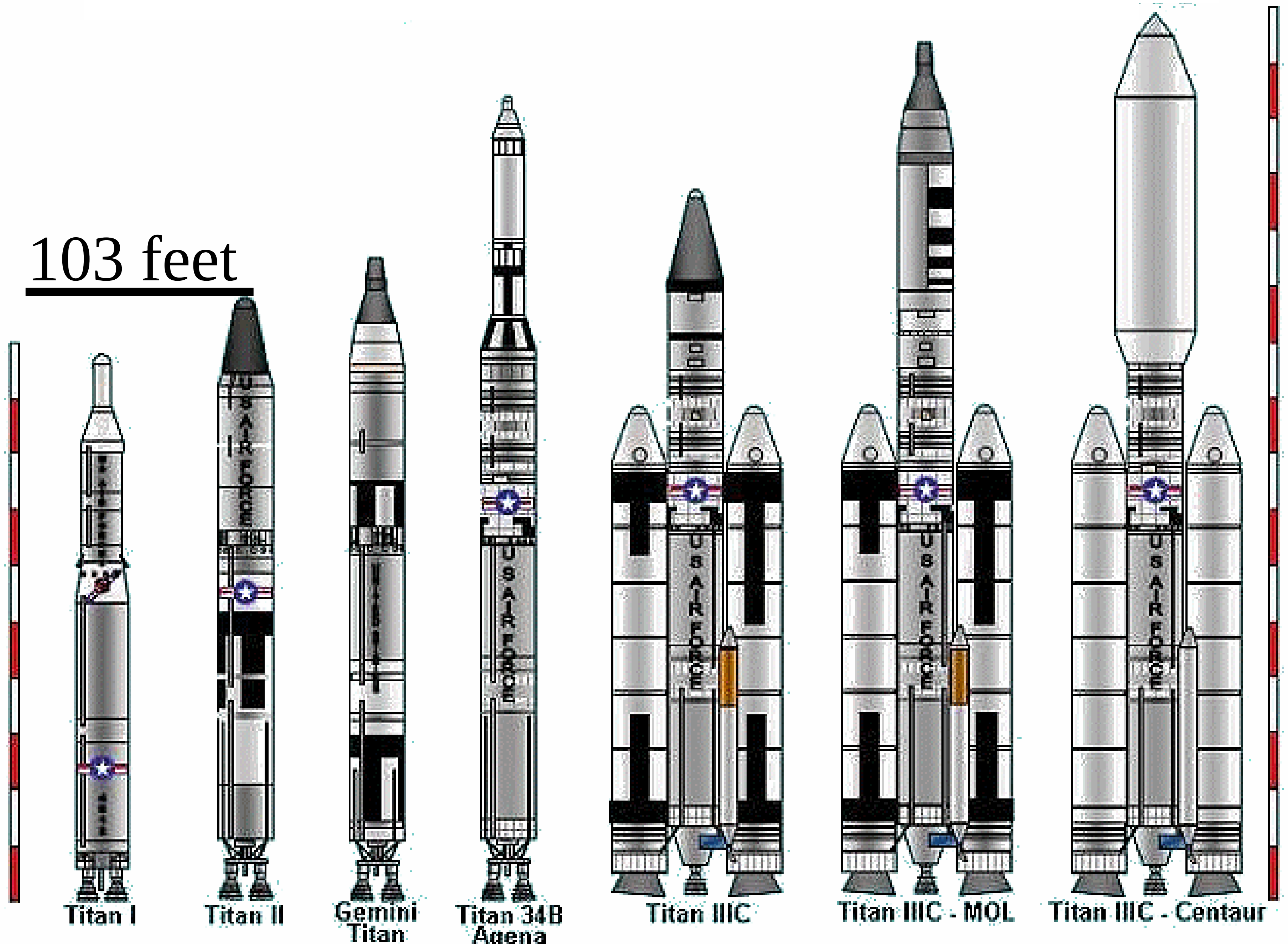
Scud Missiles and Derivatives – 2



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.

Titan Family of Missiles and Launch Vehicles

1959 – 2005 ICMB & civilian uses



TIME Magazine, Monday September 29th 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)

iClicker Answer

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

A. Light carbon fiber materials 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 Question

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

A. Submarine-launched ballistic missiles
B. Land-based intercontinental ballistic missiles
C. Land-based intercontinental bombers

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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

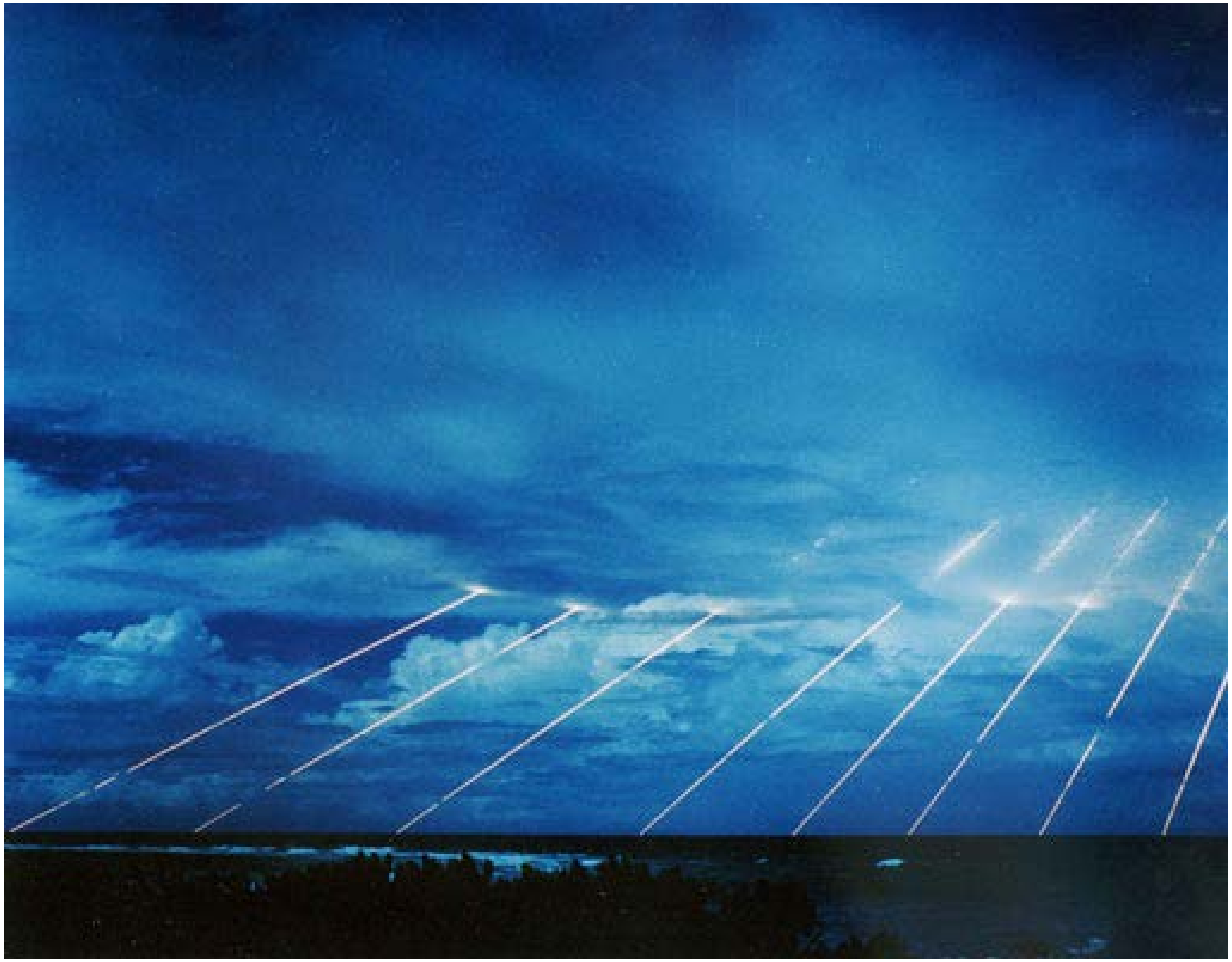
MK21 re-entry vehicles on Peacekeeper MIRV bus

MIRV Technology

MX Peacekeeper MIRV

Soviet ICBM MIRV

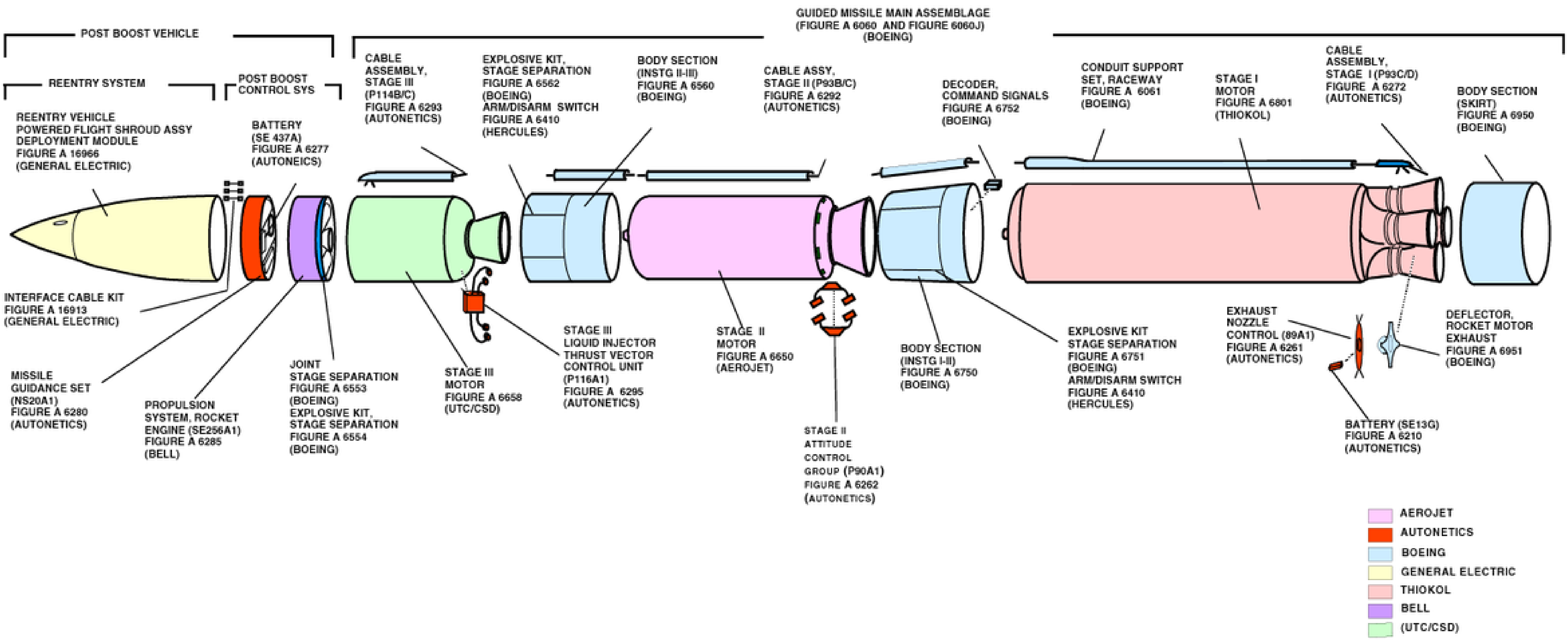
MIRV Technology



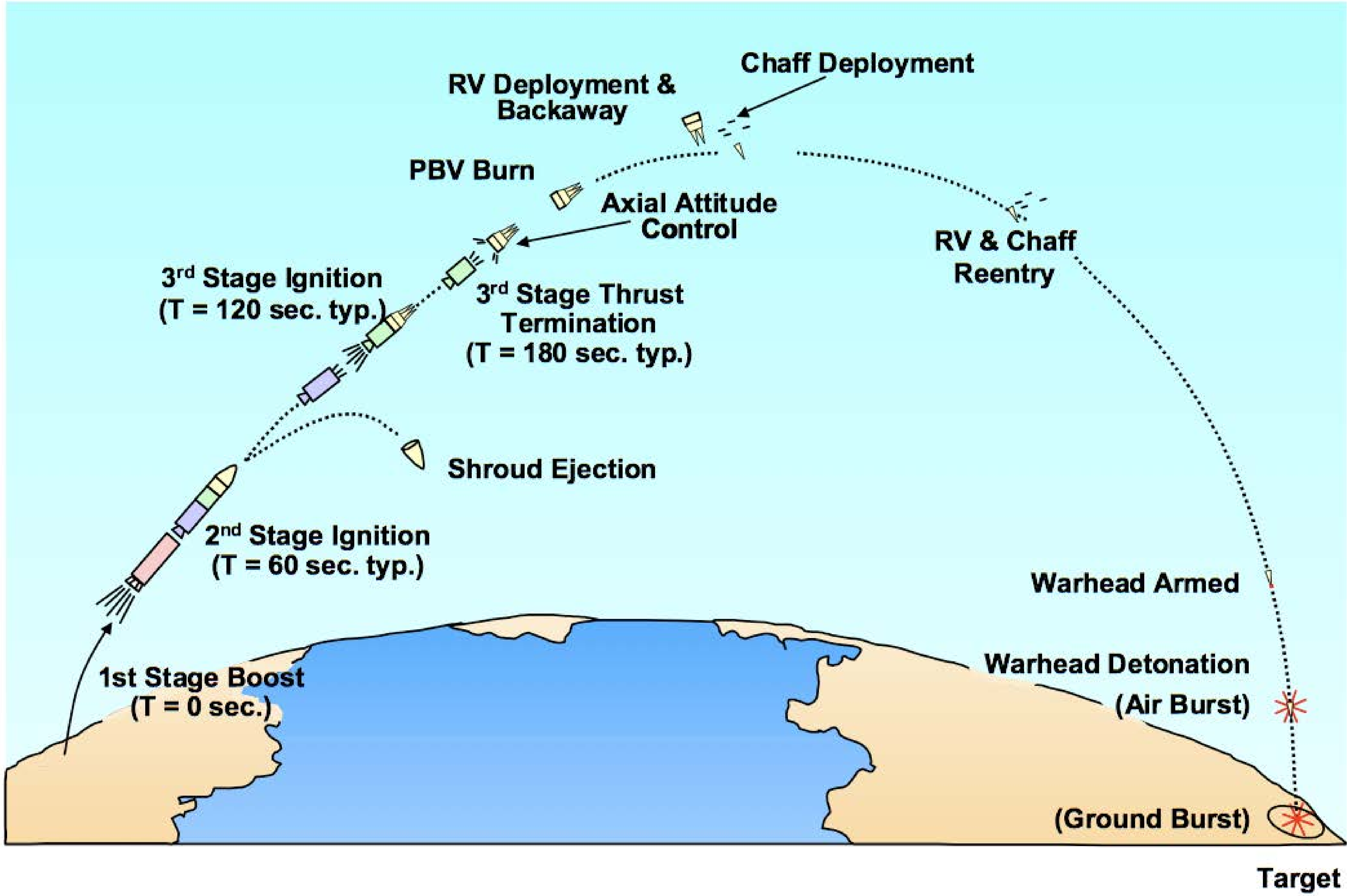
MX Peacekeeper missile tested at Kwajalein Atoll

Source:www.smdc.army.mil/kwaj/Media/Photo/missions.htm

Minuteman ICBM (Schematic)



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

Examples of US and Russian ICBMs

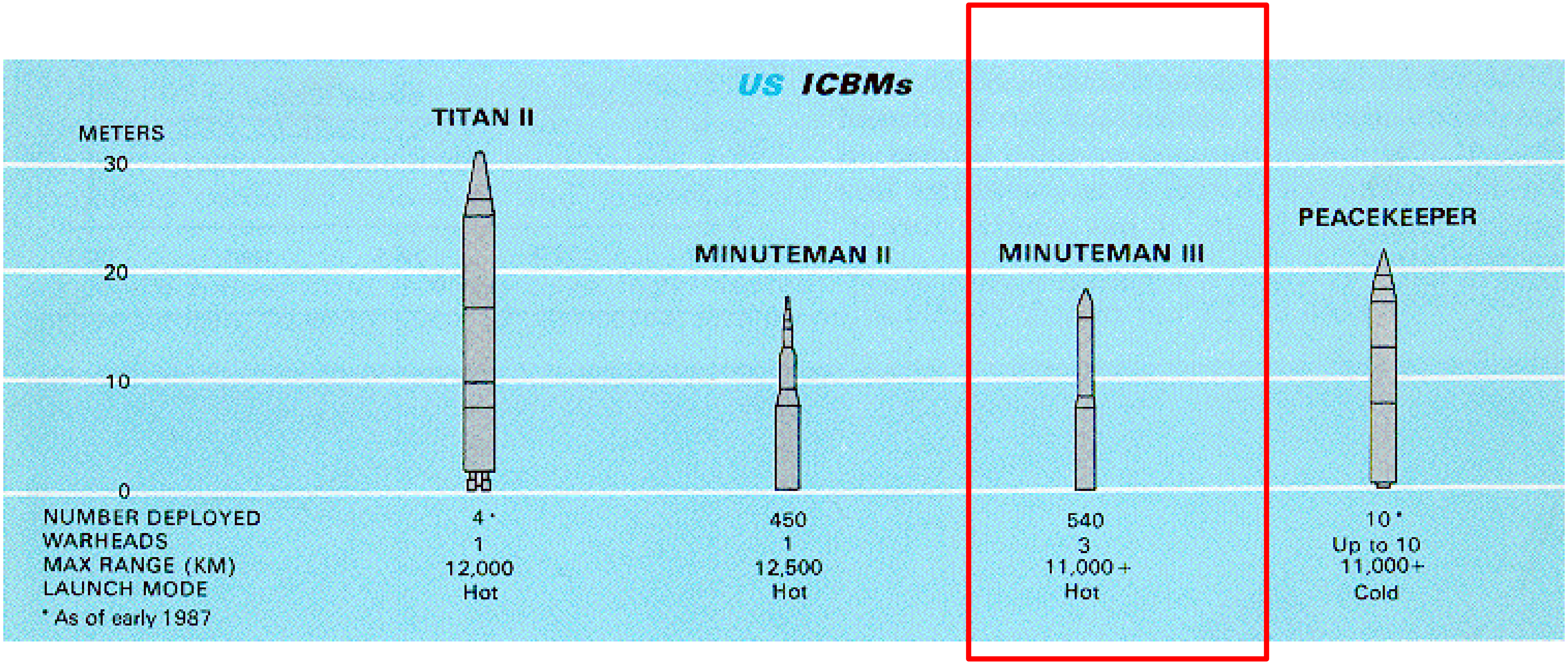
Recent US ICBMs —

- MMIII Solid-propellant, range ~ 12,000 km, 3 warheads (Minuteman)
- MX Solid-propellant, range ~ 12,000 km, 10 warheads (Peacekeeper, retired 2005)

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



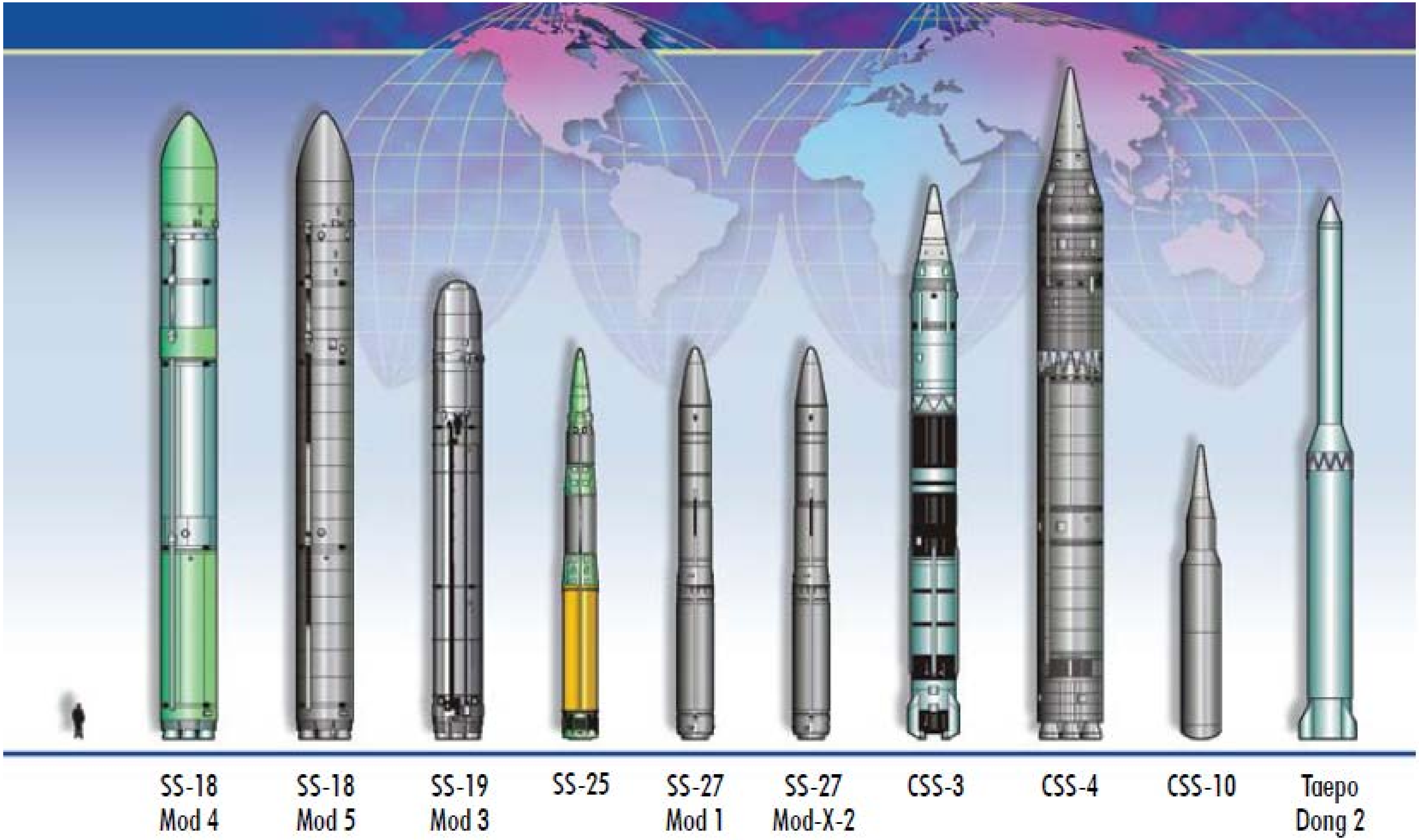
current land based
US ICMB

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
Russia						
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
China						
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
North Korea						
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

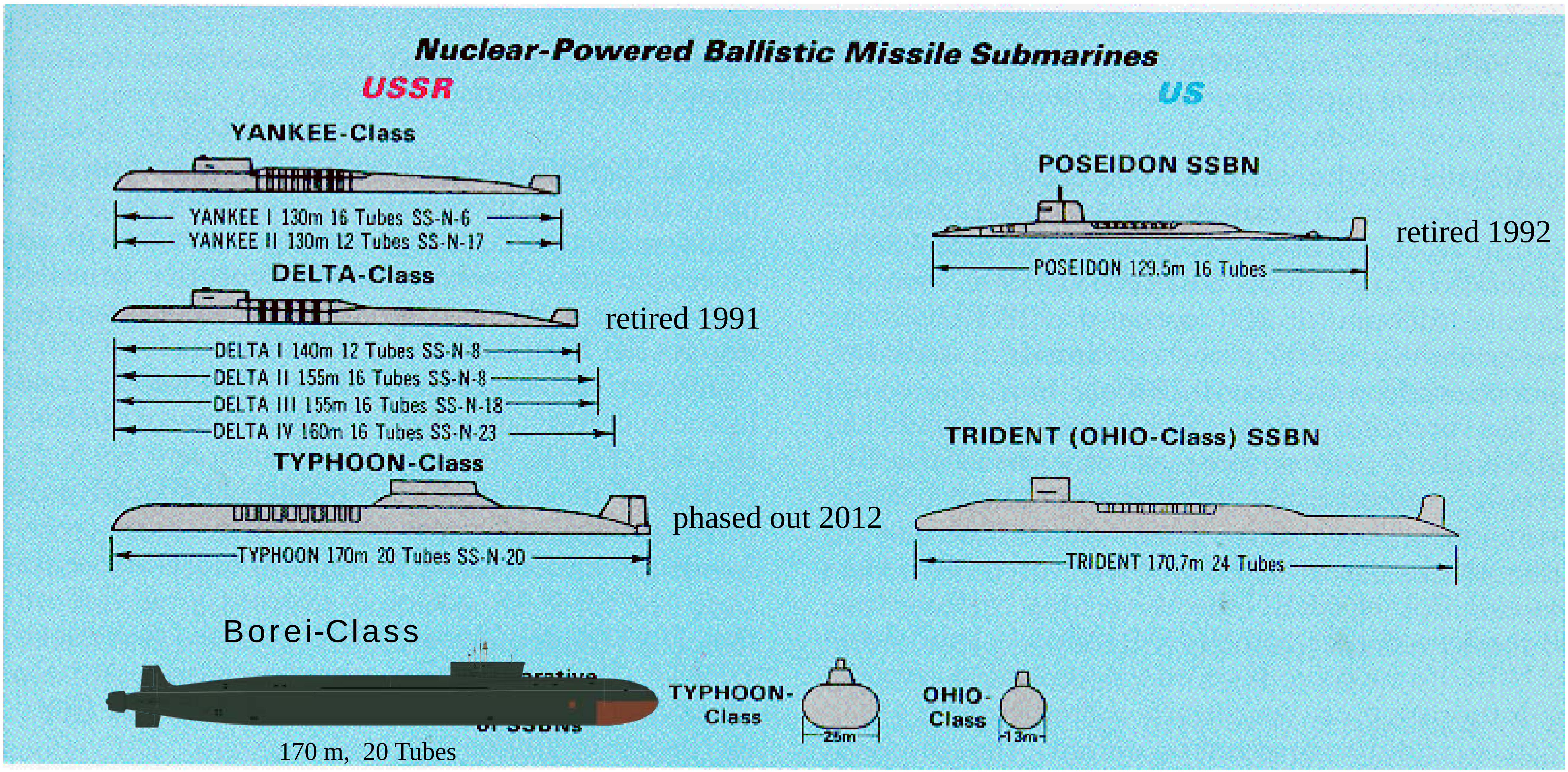
Russian, Chinese (and North Korean) ICBMs – 3

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

US and Russian SSBNs



US Trident SSBN (14 SSBNs, 4 SSGNs)

Trident Missile Tubes
With Covers Open

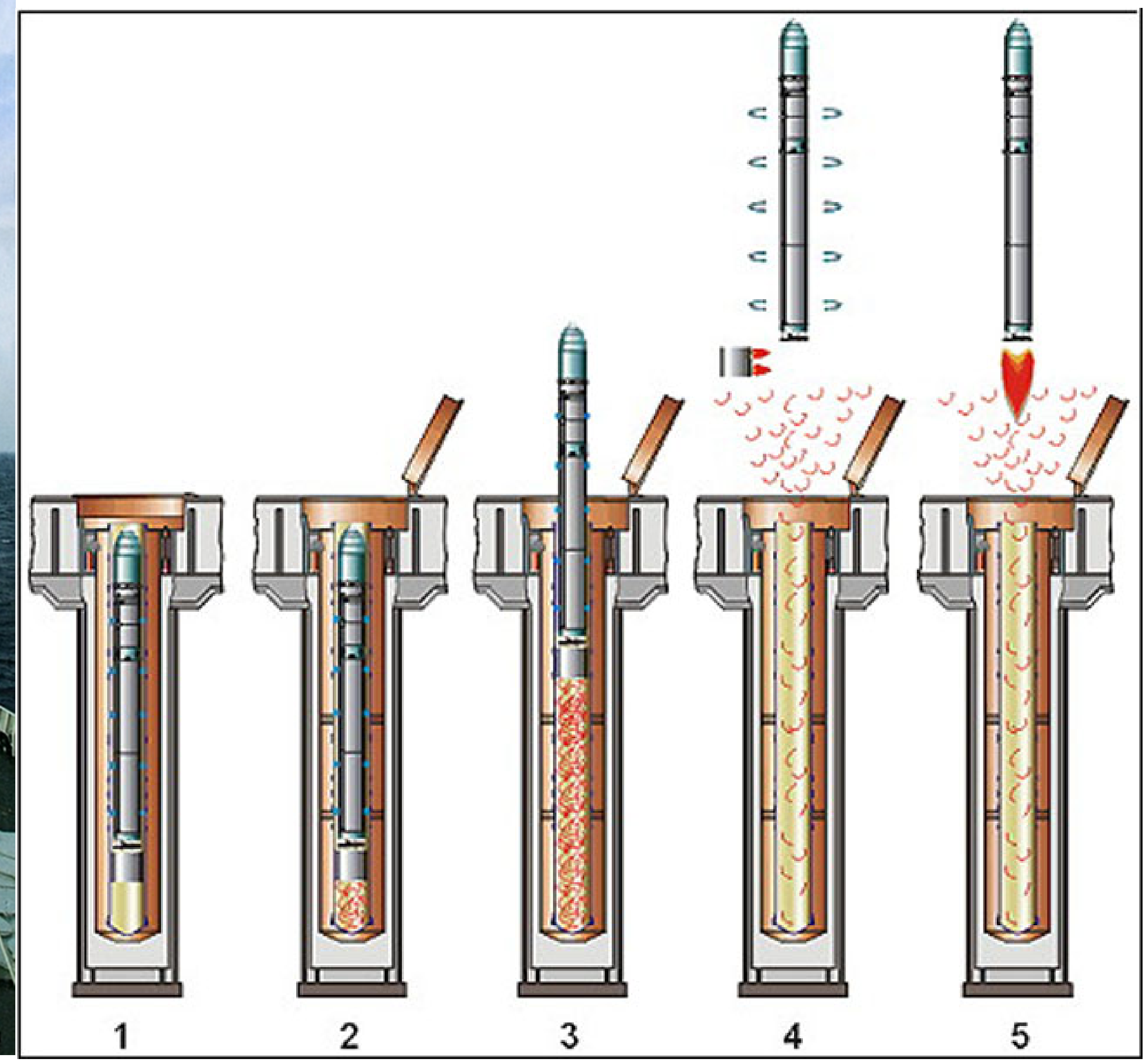
24 Trident C4 SLBMs
8 MIRVs with 100kt W76
➔ up to192 targets
SLBM range 7400 km

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

Cold Launch Mode

Missile is ejected with high pressure steam before rocket engines are started: “Cold Launch”



US Trident SSBN

Submarine-Based Missiles

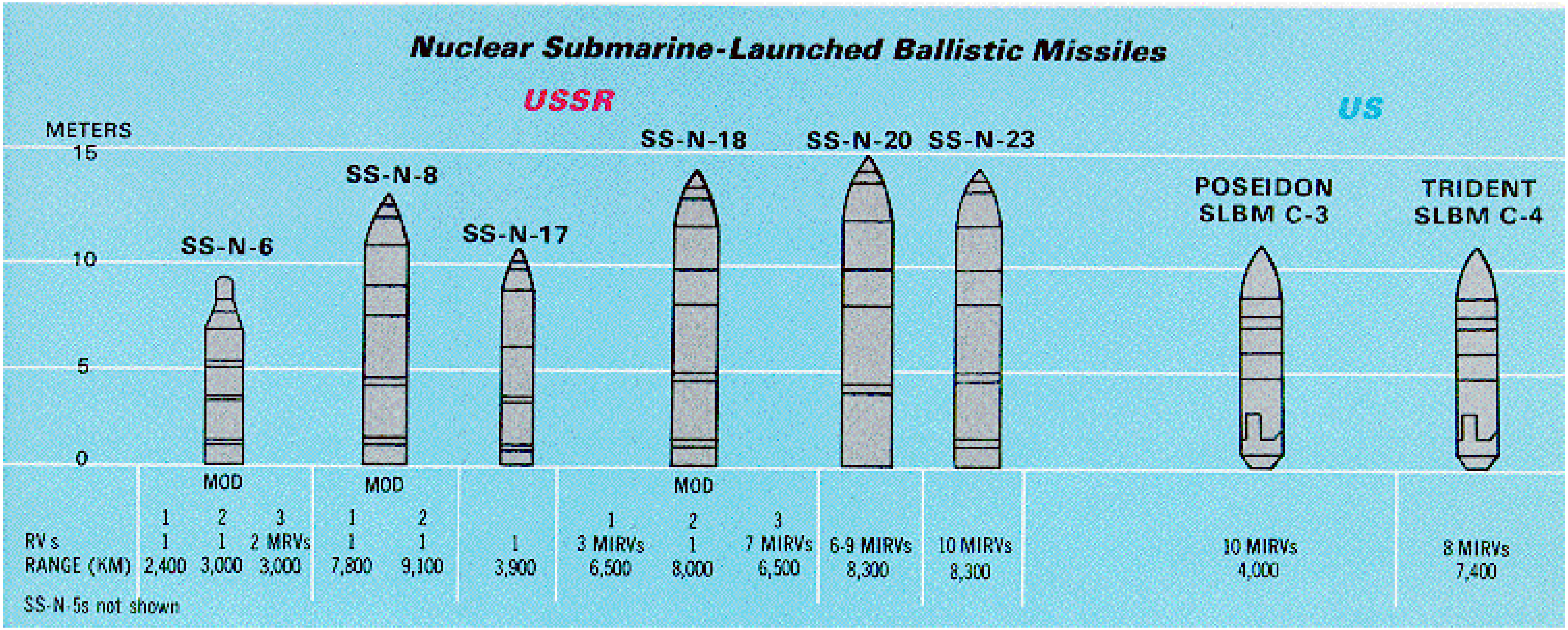
US SLBMs —

- 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)
- 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



Physics 280: Session 16

Plan for This Session

Questions

Midterm Review, Sunday, March 15th, , 6-8pm

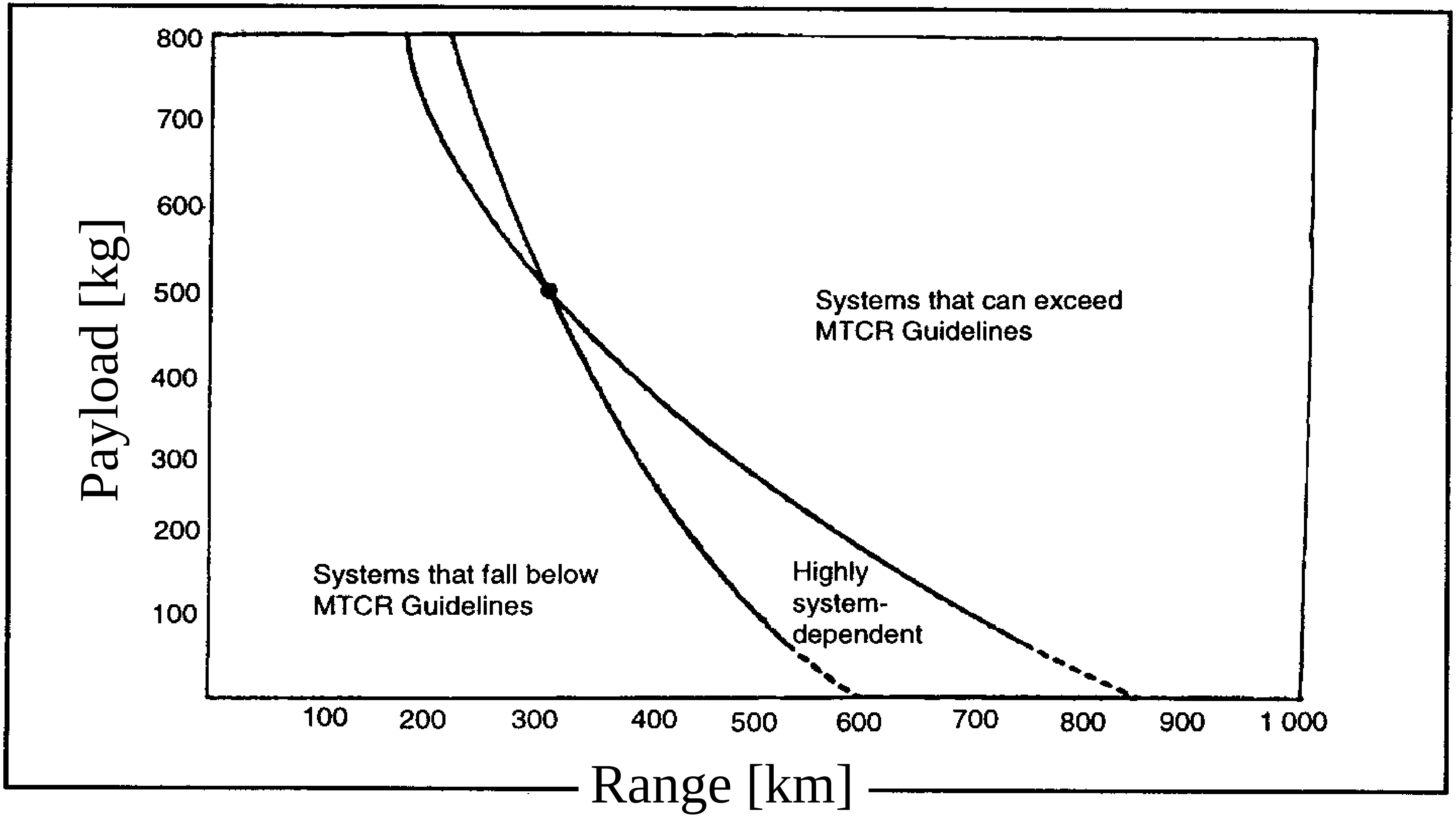
Midterm Exam, Thursday March 19th, , 2-3.20pm

News and discussion

Module 5: Nuclear Weapon Delivery Systems

Part 5: Technical and Operational Aspects

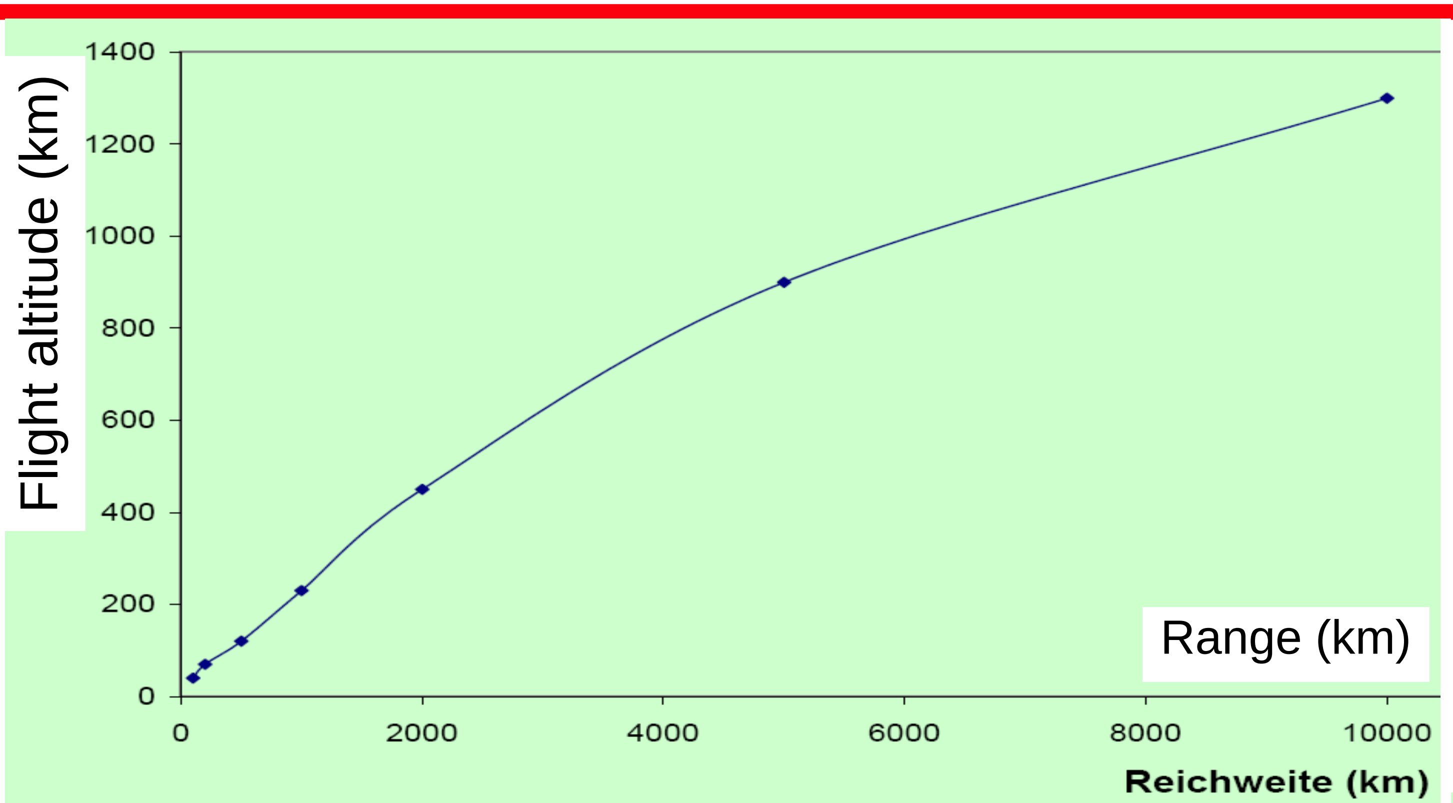
Range-Payload Tradeoff

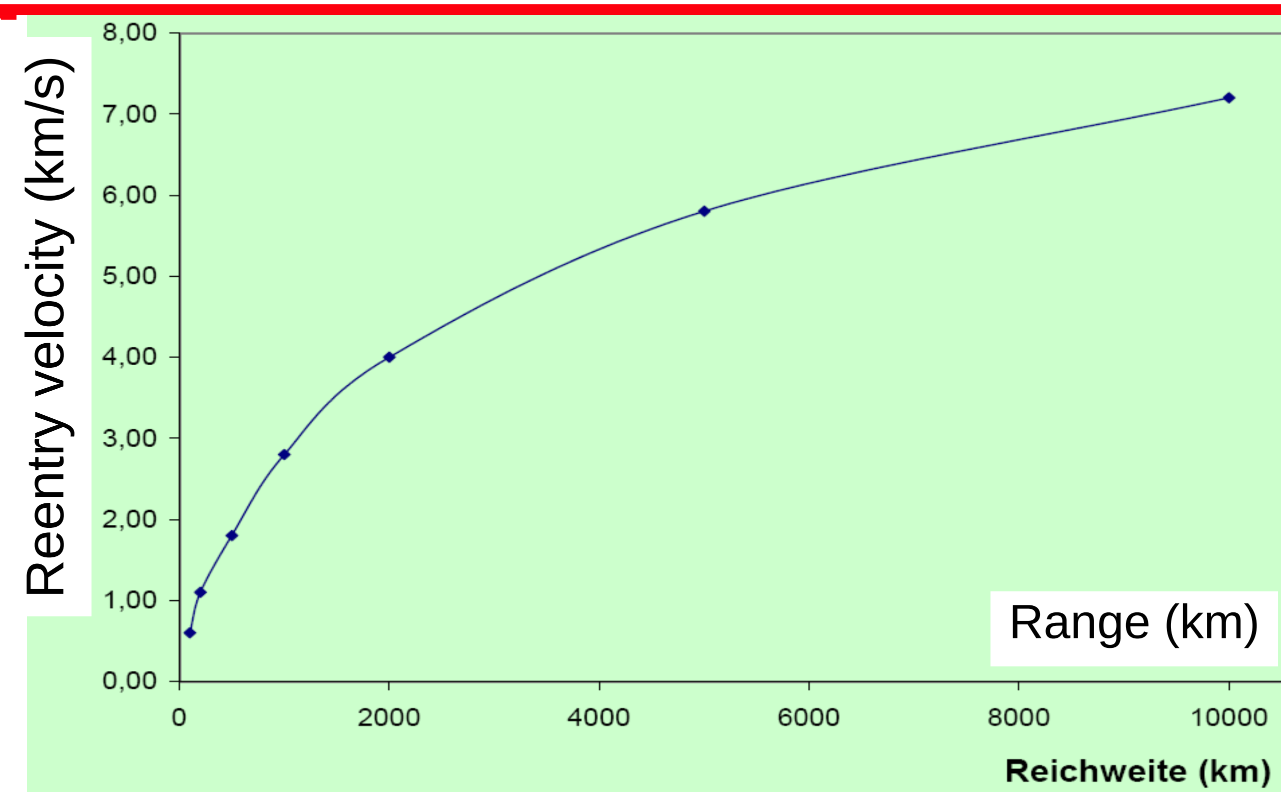


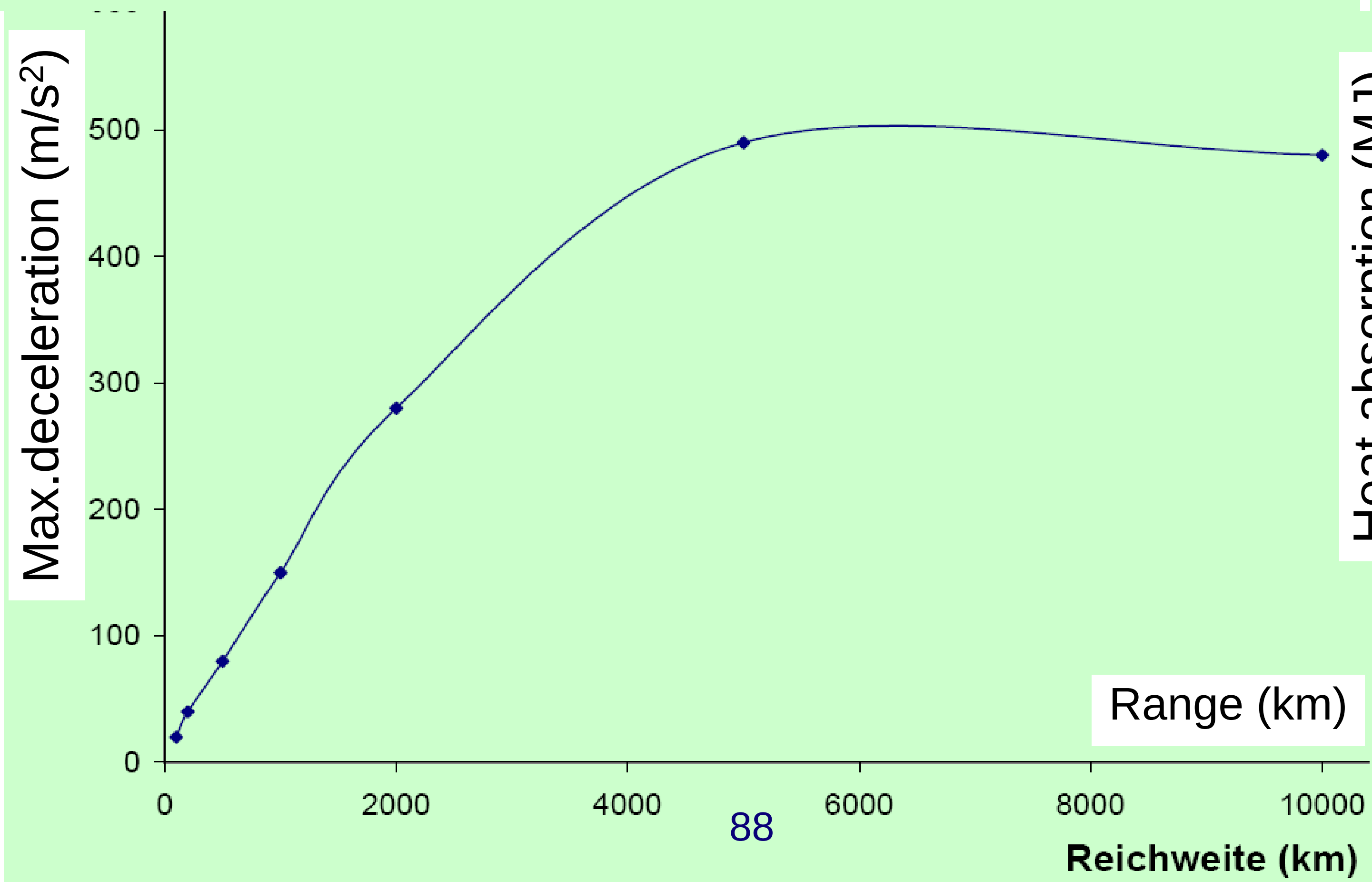
MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

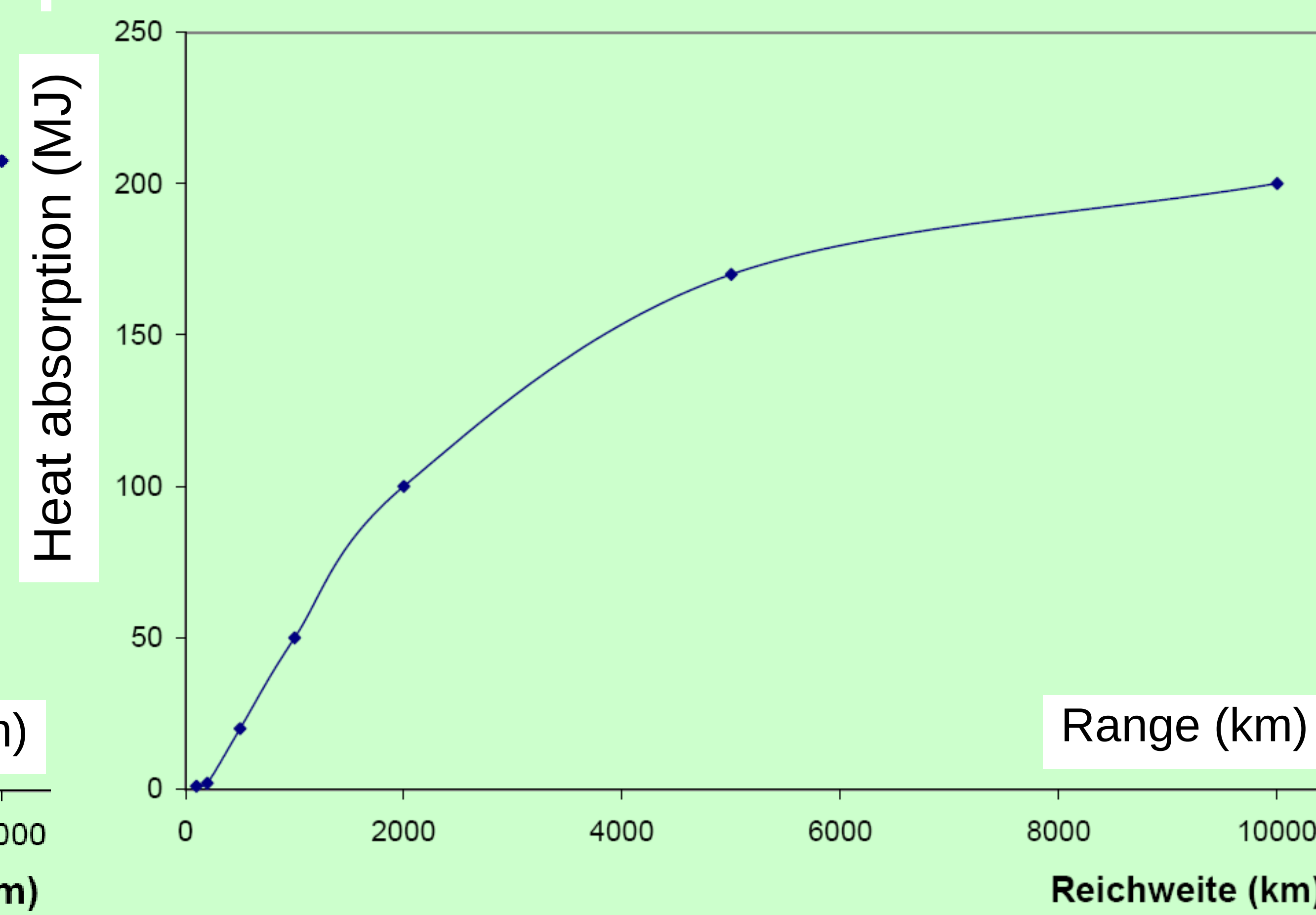
A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 157

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

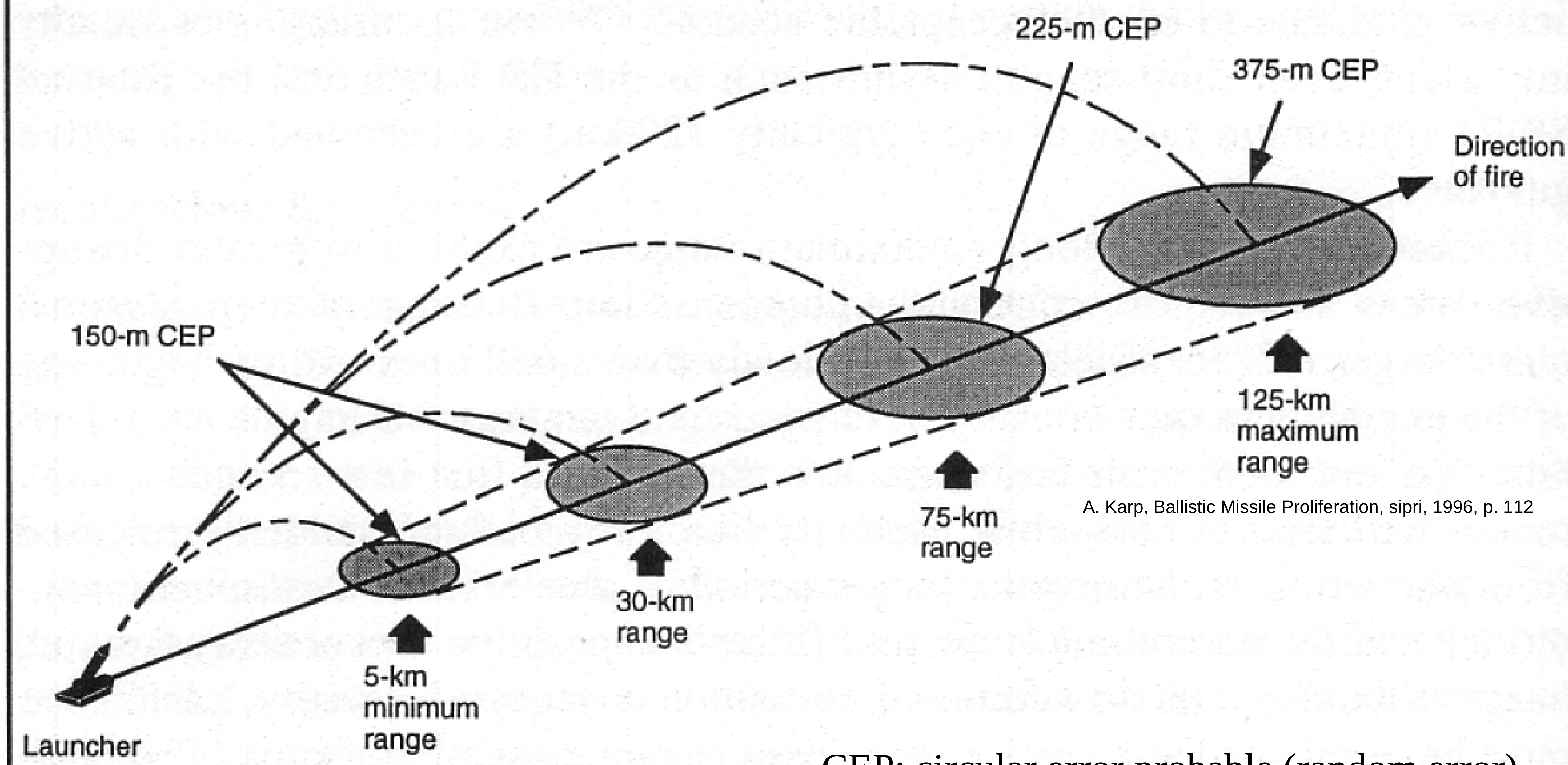








Missile Range–Accuracy Tradeoff



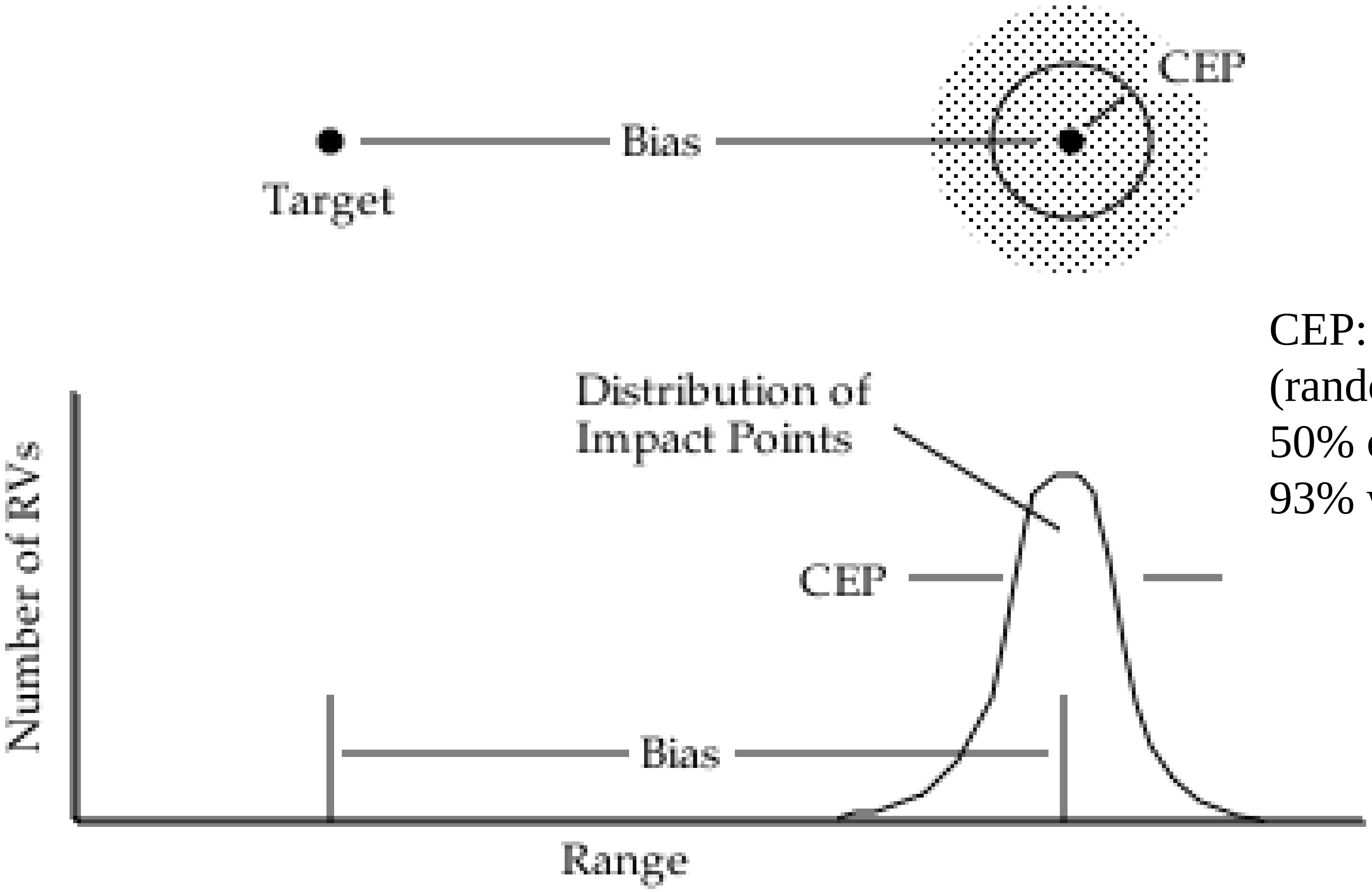
A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 112

Lance missile

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

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

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)

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

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

ICBM Accuracy & Vulnerability

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

Vulnerable to attack

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

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)

Sources of Systematic Error

- Gravitational field variations
- Atmospheric drag variations

Gravitational Field Variations

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

Fundamental uncertainties

- Missile accuracy
- Warhead yield
- Silo hardness

Operational uncertainties

- 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

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

Operational considerations

- Vulnerability depends on
  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) before New START

- United States

2688	[SLBM warheads}
x 0.75	[fraction typically on-station]
x 0.90	[estimated reliability]
= 1,814	[effective number of warheads]

- Russia

2384	[SLBM warheads}
x 0.25	[fraction typically on-station]
x 0.70	[estimated reliability]
= 447	[effective number of warheads]

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

Part 5: Nuclear Command and Control

Nuclear Command and Control – 1

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^3I) assets
- Vulnerability of strategic C^3I assets to attack

Alert levels — (Defensive Readiness Condition)

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 2 Further Increase in force readiness
DEFCON 1 Maximum force readiness.

Nuclear Command and Control – 3

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

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

The Threat of Accidental Nuclear War
20 Dangerous Incidents

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, 1995: Russian False Alarm

Source: www.nuclearfiles.org/kinuclearweapons/anwindex.html

January, 1995: Russian False Alarm

On January 25, 1995, the Russian early warning radar's detected an unexpected missile launch near Spitzbergen. The estimated flight time to Moscow was 5 minutes. The Russian President, the Defense Minister and the Chief of Staff were informed. The early warning and the control and command center switched to combat mode. Within 5 minutes, the radar's determined that the missile's impact would be outside the Russian borders.

The missile was Norwegian, and was launched for scientific measurements. On January 16, Norway had notified 35 countries including Russia that the launch was planned. Information had apparently reached the Russian Defense Ministry, but failed to reach the on-duty personnel of the early warning system.

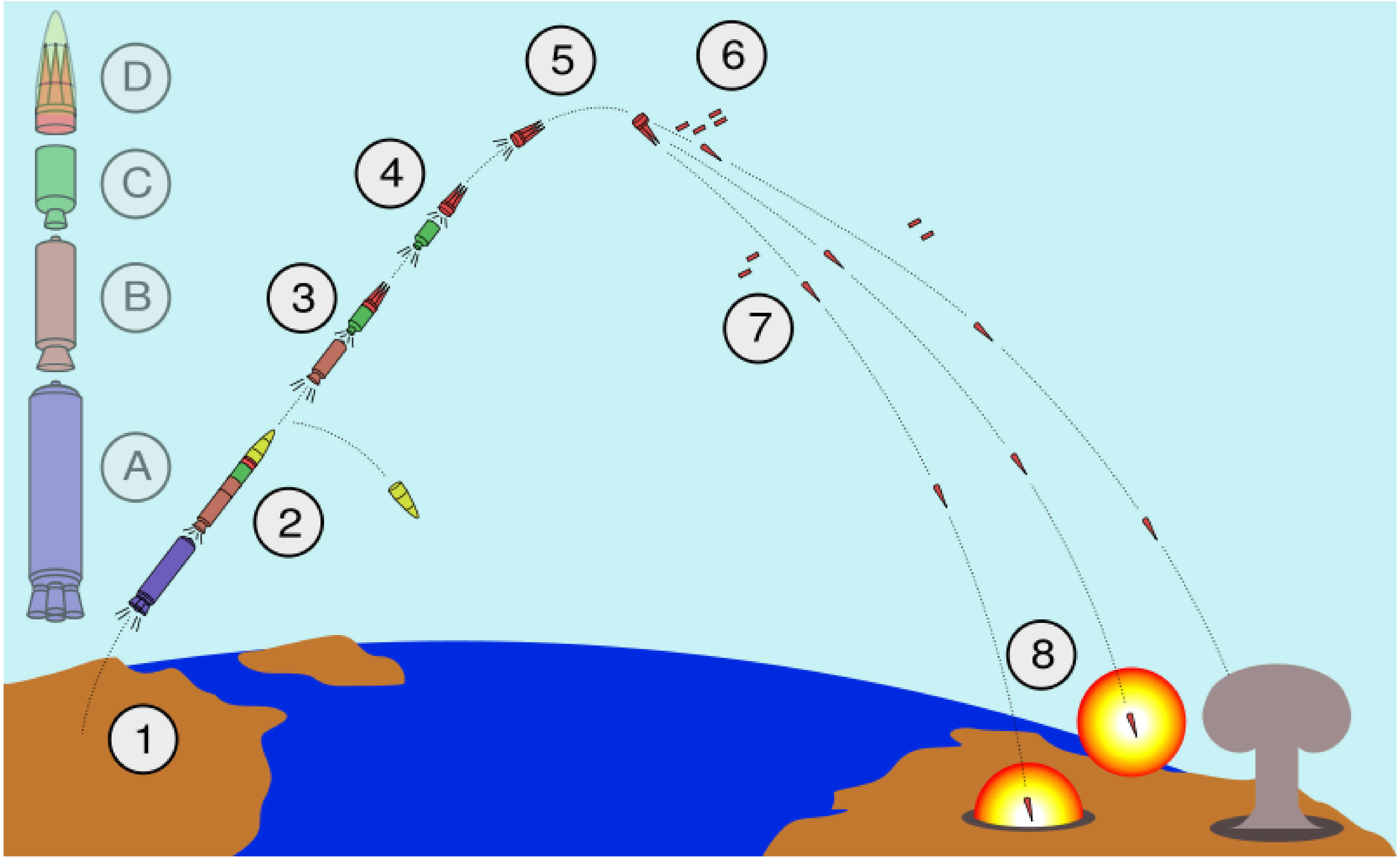
Possible Risk Reduction Measures

- 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

End of Module 5

Flight of a MIRV'd ICBM (Schematic)



Flight of a MIRV'd ICBM (Schematic)

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.

Schedule Midterm Review

Please click

A if "can't make time"

B if "can make time but inconvenient"

	A	B
(1) Saturday, March 15, 5-7pm		
(2) Saturday, March 15, 6-8pm		
(3) Saturday, March 15, 7-9pm		

	A	B
(4) Sunday, March 16, 5-7pm		
(5) Sunday, March 16, 6-8pm		
(6) Sunday, March 16, 7-9pm		

	A	B
(7) Tuesday, March 15, 5-7pm		
(8) Tuesday, March 15, 6-8pm		
(9) Tuesday, March 15, 7-9pm		