

Physics 280: Session 14

Plan for This Session

Questions

Midterm Exam, Thursday March 17th

- 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
- additional review session,
Sunday, March 13th, 3-5pm

News

Module 5: Nuclear Weapon Delivery Systems

U.N. Toughens Sanctions on North Korea in Response to Its Nuclear Program

By SOMINI SENGUPTA and CHOE SANG-HUN MARCH 2, 2016

UNITED NATIONS — Exasperated with North Korea’s defiant testing of nuclear bombs and ballistic missiles, the United Nations Security Council voted unanimously on Wednesday to severely toughen its penalties against the isolated country.

The development also reflected closer cooperation between the United States and China on a longstanding dispute. The 15-member Council approved a resolution, negotiated for weeks by American and Chinese officials, that called for inspecting all cargo going in and out of the country, banning all weapons trade and expanding the list of individuals facing sanctions.

Diplomats said the resolution contained the most stringent measures yet to undermine the North’s ability to raise money and secure technology and other resources for its nuclear weapons program. Much depends, however, on whether China — North Korea’s leading trade partner and diplomatic shield — will enforce it. Samantha Power, the American ambassador to the United Nations, called the resolution “comprehensive, robust and unyielding,” and said enforcement must be as well.

On Thursday morning, hours after the resolution passed, North Korea launched what appeared to be several short-range missiles off its east coast, the South Korean Defense Ministry reported.

The Security Council measure is a narrow, diplomatic convergence between the United States and China. Beijing has repeatedly said it opposes Pyongyang's development of a nuclear weapons arsenal, and publicly rebuked the North on Wednesday for carrying out nuclear and rocket tests this year in "defiance" of international prohibitions.

China signaled that it saw the resolution as spurring peace talks soon, a goal that was welcomed by nonproliferation advocates. Darryl Kimball of the Arms Control Association said the resolution could be useful as leverage to persuade Pyongyang to return to the bargaining table. But he also criticized the Obama administration's policy of "insisting on denuclearization as a precondition for talks to halt and reverse North Korea's advancing nuclear and missile capabilities."

"In the next several weeks, it will be important for Washington and Beijing to communicate to Pyongyang that they are willing to formally resume negotiations," Mr. Kimball argued.

U.S. test-fires ICBMs to stress its power to Russia, North Korea

VANDENBERG AIR FORCE BASE, CALIF. | BY DAVID ALEXANDER



An unarmed Minuteman III intercontinental ballistic missile launches during an operational test from Vandenberg Air Force Base, California at 11:01 p.m. on February 25, 2016.

1 of 2

The U.S. military test-fired its second intercontinental ballistic missile in a week on Thursday night, seeking to demonstrate its nuclear arms capacity at a time of rising strategic tensions with Russia and North Korea.

The unarmed Minuteman III missile roared out of a silo at Vandenberg Air Force Base in California late at night, raced across the sky at speeds of up to 15,000 mph (24,000 kph) and landed a half hour later in a target area 4,200 miles (6,500 km) away near Kwajalein Atoll in the Marshall Islands of the South Pacific.

Deputy Defense Secretary Robert Work, who witnessed the launch, said the U.S. tests, conducted at least 15 times since January 2011, send a message to strategic rivals like Russia, China and North Korea that Washington has an effective nuclear arsenal.

"That's exactly why we do this," Work told reporters before the launch.

"We and the Russians and the Chinese routinely do test shots to prove that the operational missiles that we have are reliable. And that is a signal ... that we are prepared to use nuclear weapons in defense of our country if necessary."

Demonstrating the reliability of the nuclear force has taken on additional importance recently because the U.S. arsenal is near the end of its useful life and a spate of scandals in the nuclear force two years ago raised readiness questions.

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

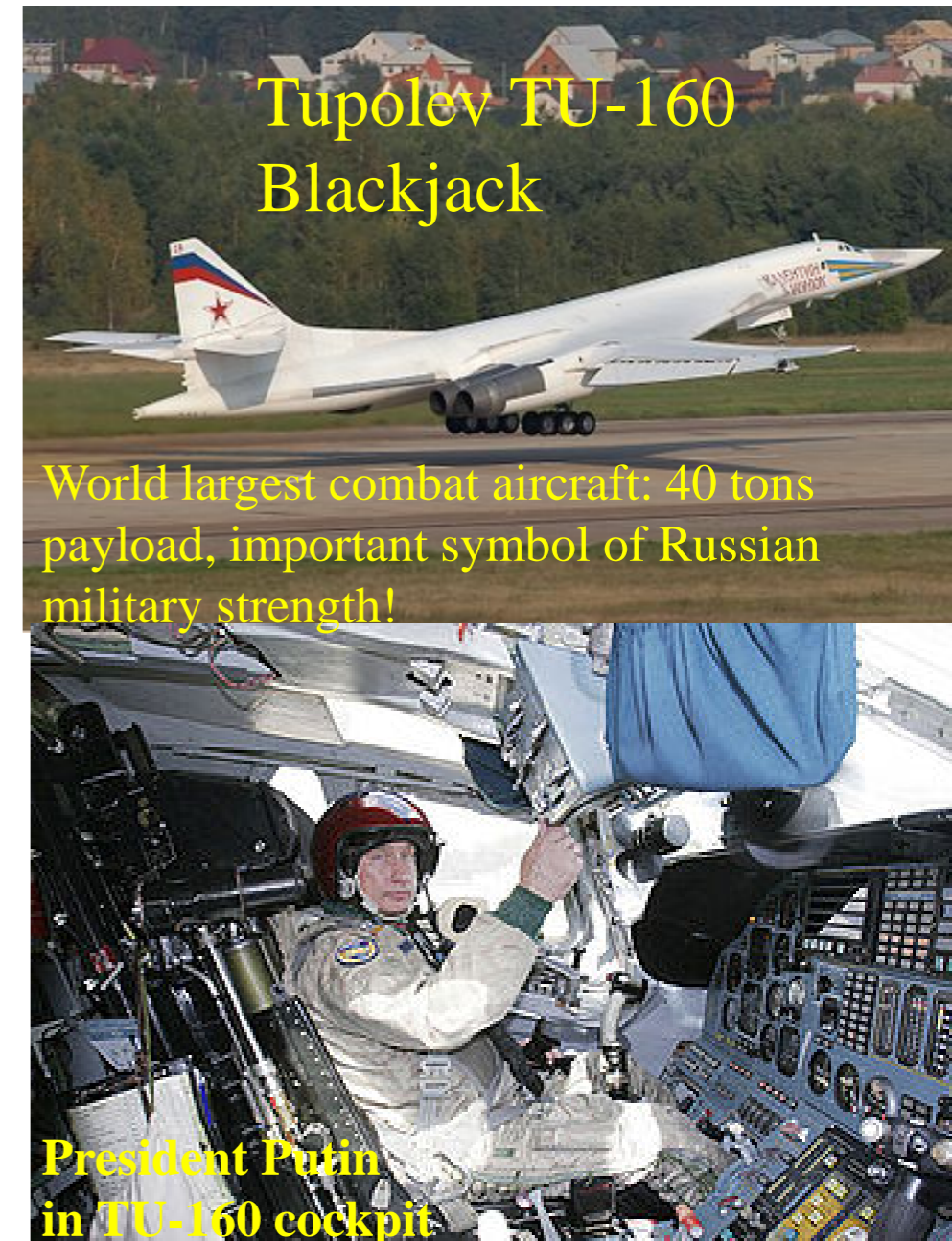
Air-Breathing Vehicles

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 an overall 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 organize the roles for 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.)

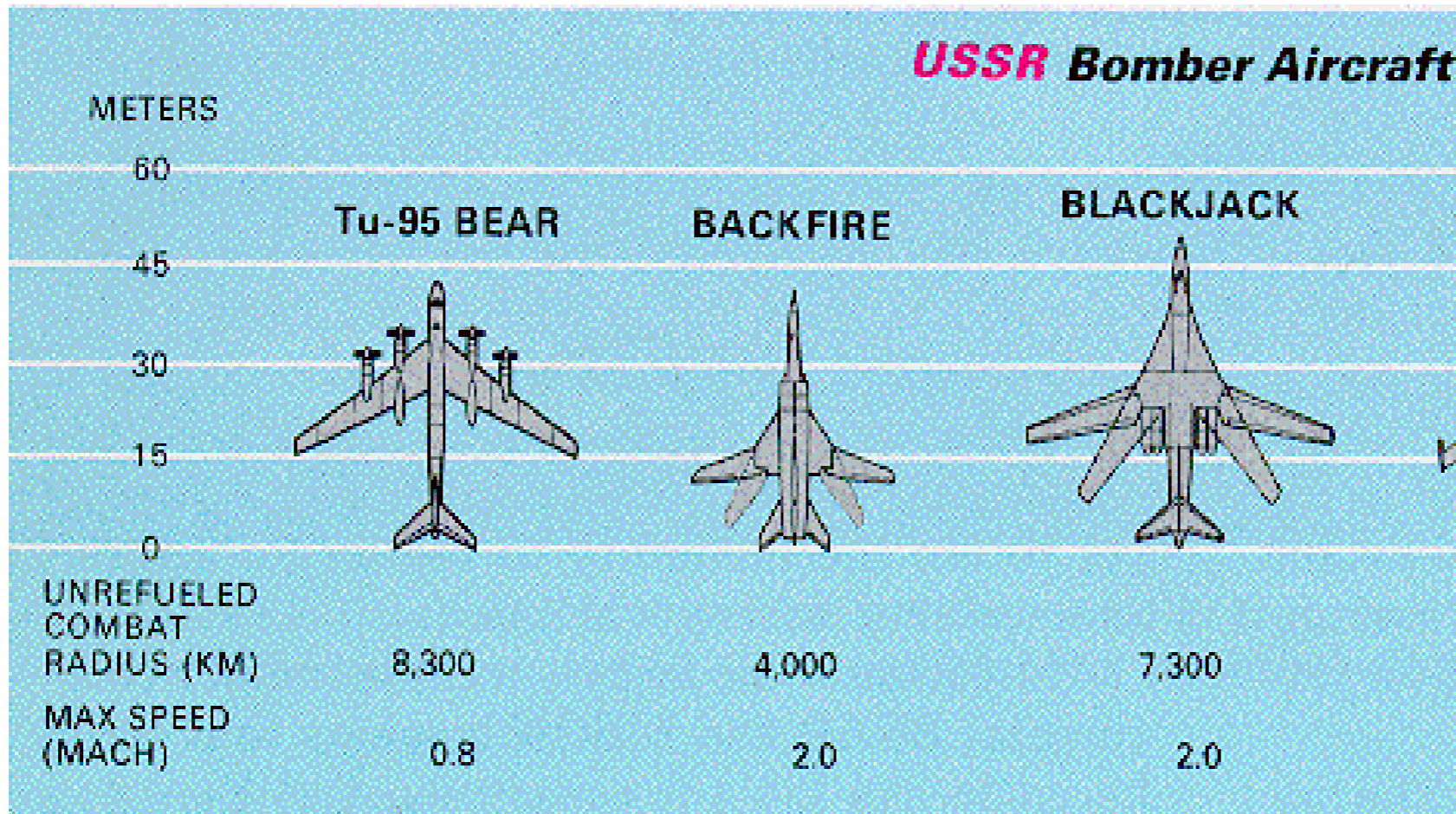
Systems in the Triad —

- 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

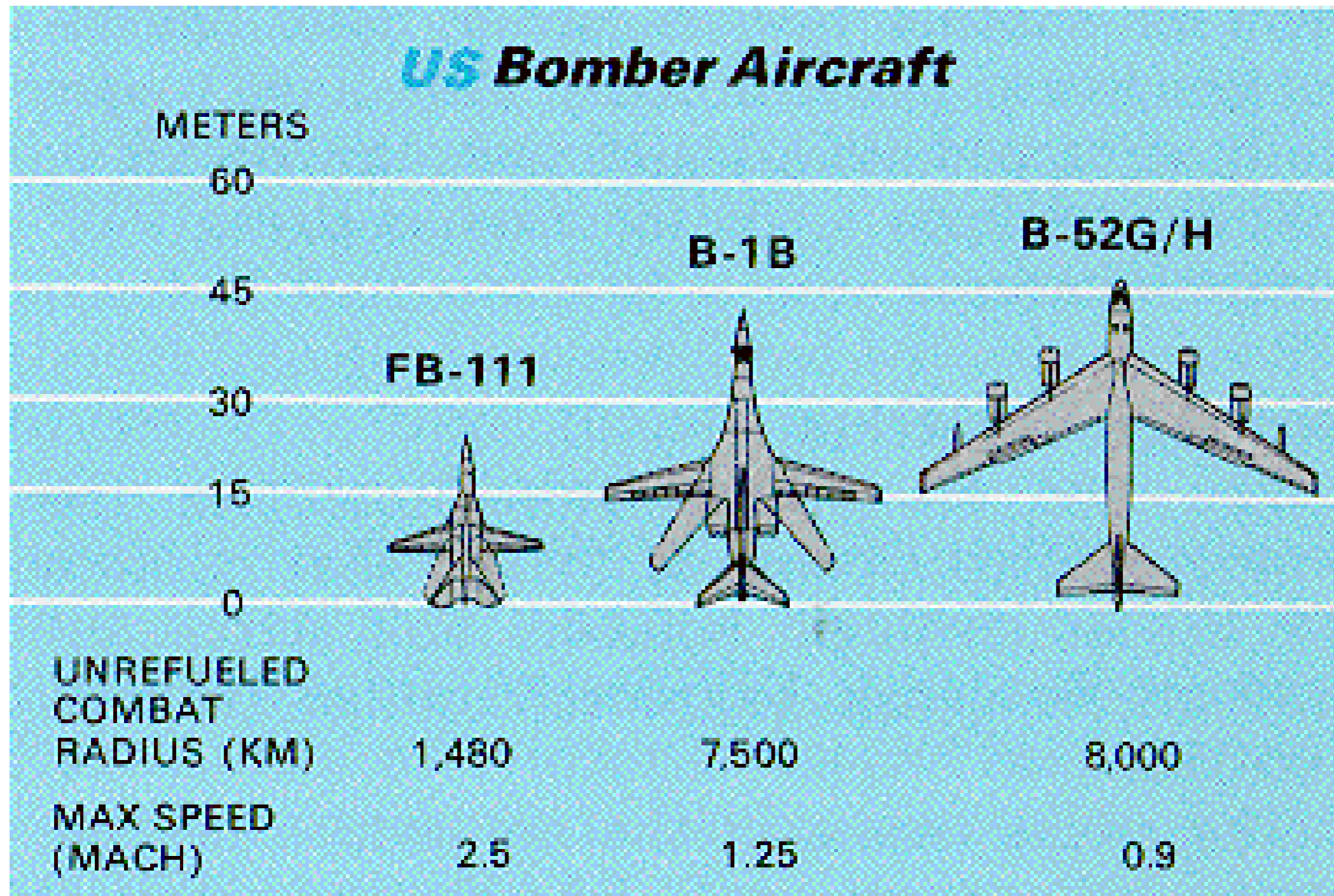


Tu-95
65

Tu-22
160

Tu-160
16

Examples of Intercontinental Bombers – 2



B-1
65

B-52
75

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

of B-2s 20



Currently Deployed U.S. and Russian Bombers

Current US bombers —

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

Russian bombers* —

- Bear carrying bombs
- Blackjacks carrying bombs

*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

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Module 5: Nuclear Delivery Systems

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

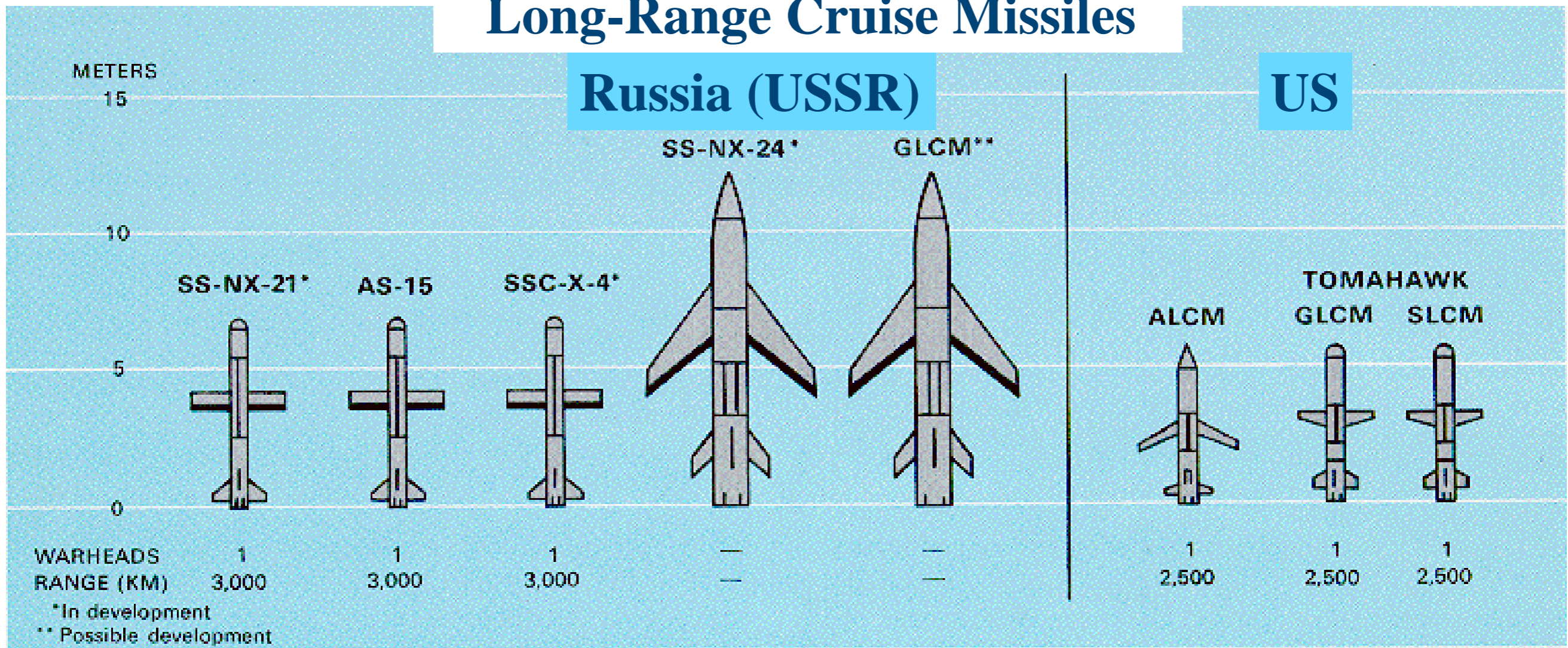
Introduction to Cruise Missiles – 2 (Important)

Key properties —

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

Long-Range Cruise Missiles – 1

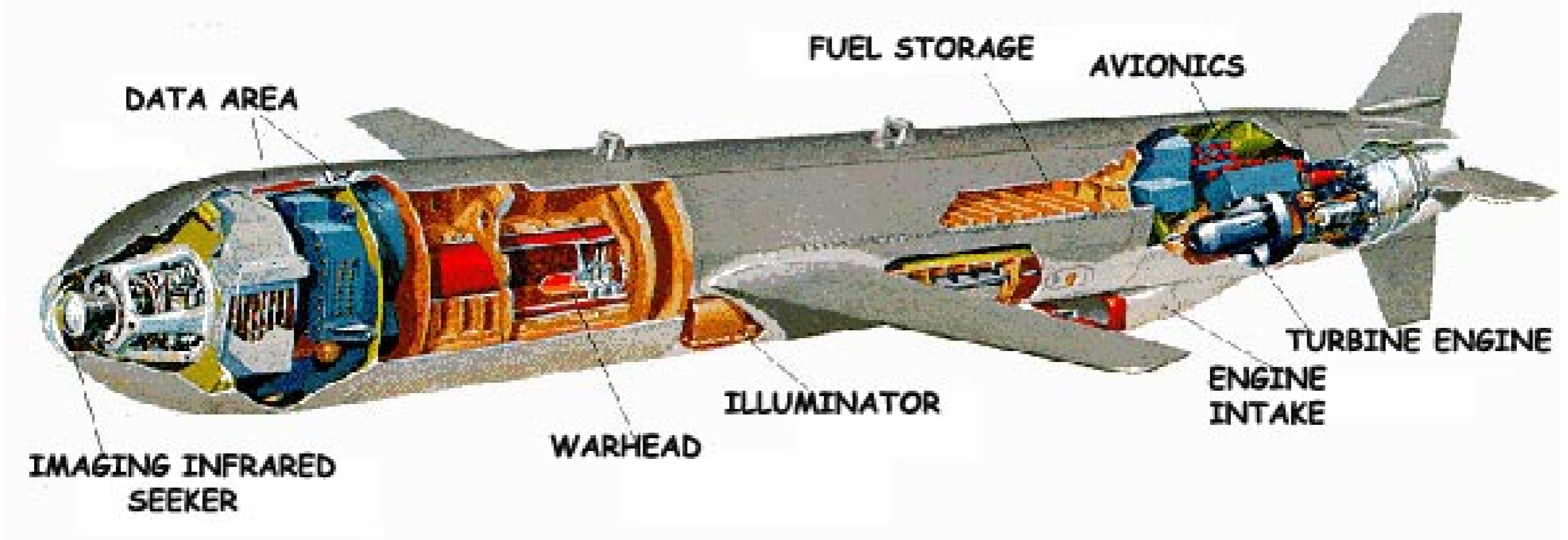
Long-Range Cruise Missiles



range : 1000 – 2000 miles

pay loads : 500 – 1200 lbs

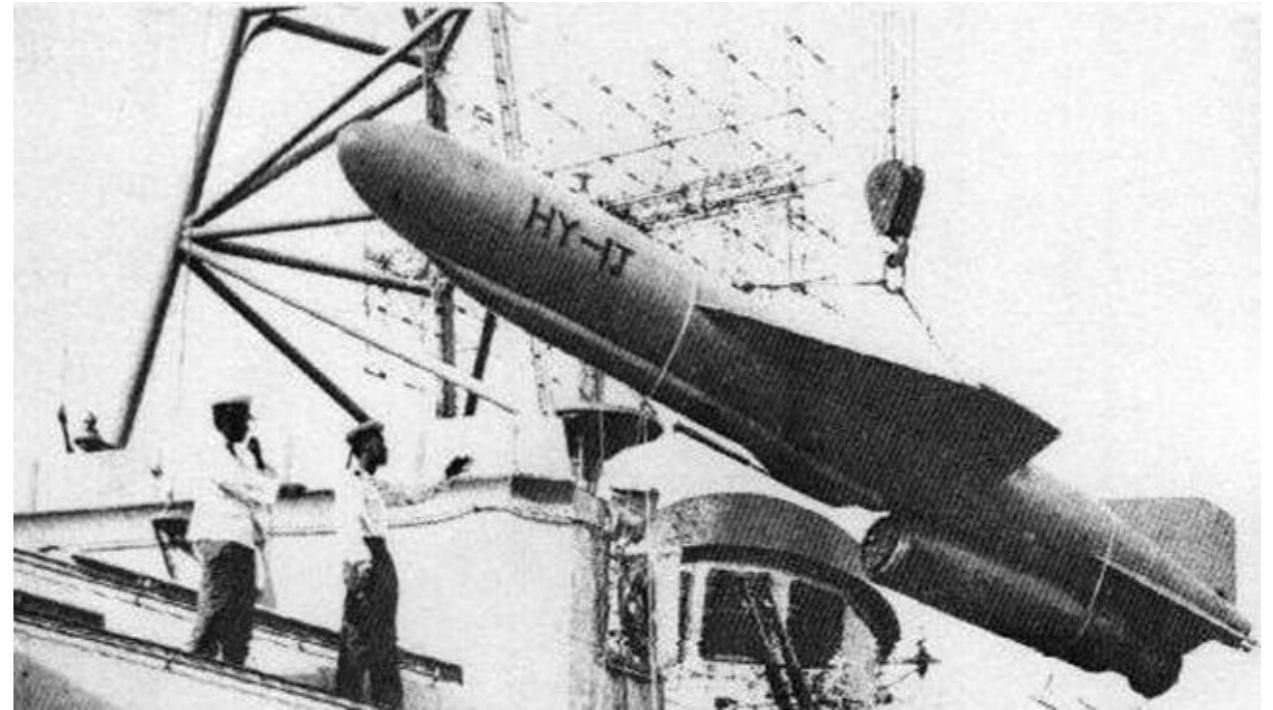
Long-Range Cruise Missiles – 2



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

Launching Cruise Missiles – 1



Launching Cruise Missiles – 2



Cruise-Missile Guidance – 1



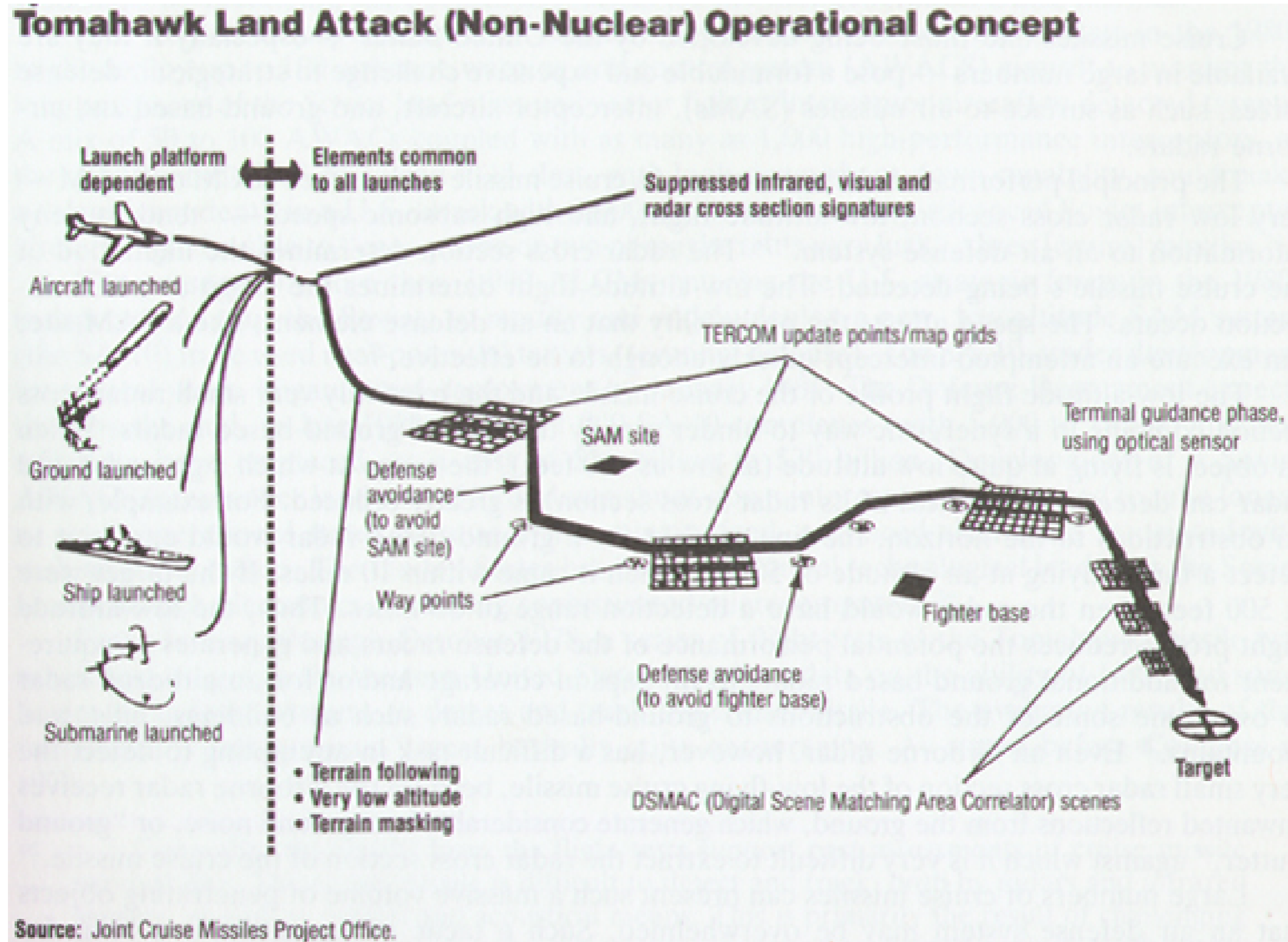
TERCOM: Terrain Contour Matching

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

Module 5: Nuclear Delivery Methods

Part 4: Ballistic Missiles

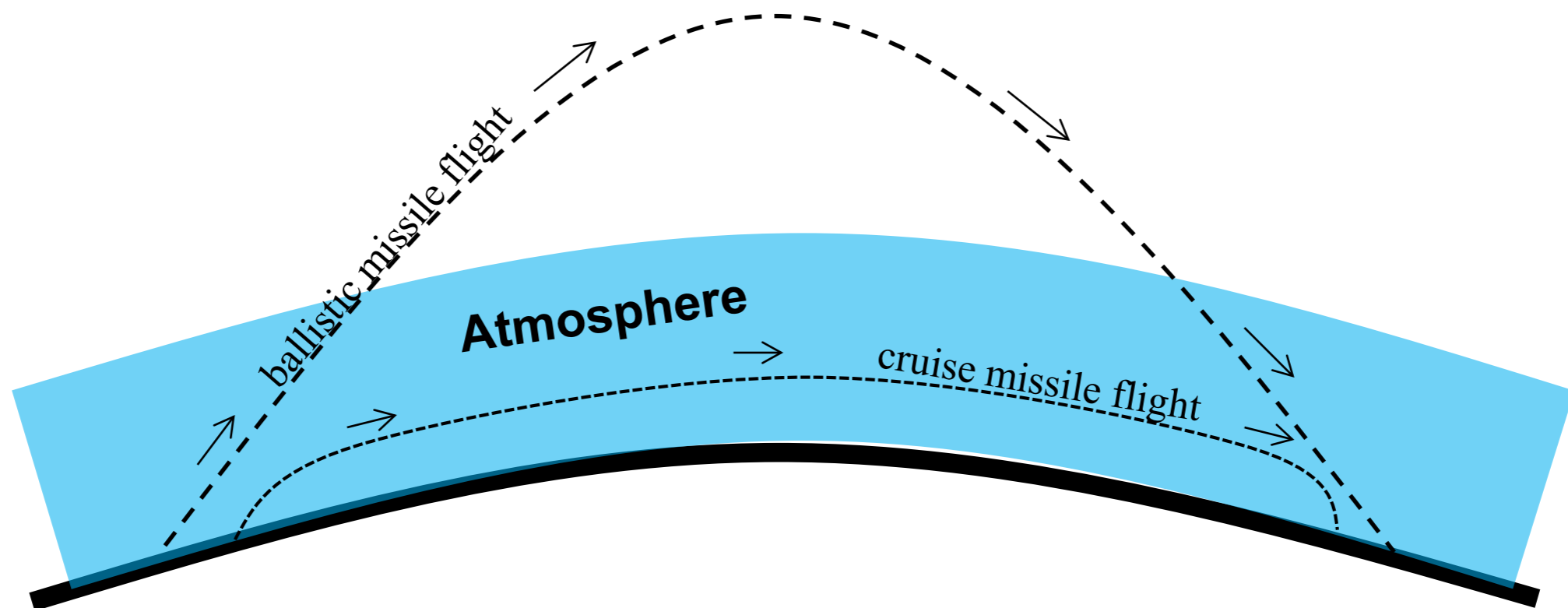
Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

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

Physics 280: Session 15

Plan for This Session

News

Module 5: Nuclear Weapon Delivery Systems

News: North Korea's Response to Joint US South Korean Military Exercise

theguardian

Russia warns North Korea over threats of nuclear strike

One of Pyongyang's few remaining allies says country is in danger of creating legal grounds for international military intervention.

Chad O'Carroll for NK News, part of the North Korea network

Tuesday 8 March 2016 09.34 EST

Russia has warned North Korea that threats to deliver “preventive nuclear strikes” could create a legal basis for the use of military force against the country, suggesting that even Pyongyang's few remaining friends are growing concerned about its increasingly confrontational stance.

The Russian foreign ministry statement, which follows a North Korean threat to “annihilate” the US and South Korea, also criticises Washington and Seoul for launching the largest joint military drills yet to be held on the peninsula.

“Pyongyang should be aware of the fact that in this way the DPRK will become fully opposed to the international community and will create international legal grounds for using military force against itself in accordance with the right of a state to self-defense enshrined in the United Nations Charter,” continued the statement, translated by Itar Tass news agency.

Washington and Seoul launched their annual joint military exercises on the peninsula on Monday, stepping up the manoeuvres in response to North Korea's fourth nuclear test in January and rocket launch in February.

News: UK Increases Funds for Trident Upgrade

Trident replacement programme to get £640m additional funding

By Karthick Arvinth

March 3, 2016 06:51 GMT

The controversial Trident nuclear deterrent programme is to receive an additional investment of £640m (\$900m), reports say, despite a Commons vote on the issue not expected until later this year. Defence Secretary Michael Fallon is expected to announce the move at a Scottish Conservative Party conference in Edinburgh on 4 March.

It will bring the total amount already spent on the Trident replacement programme to nearly £4bn. The decision is likely to trigger anger from the SNP, who oppose the presence of nuclear weapons in Scottish waters.

The total cost of the Trident replacement programme, which is scheduled to be completed in the early 2030s, is estimated at £31bn.

"Claims that our deterrent is not needed, is easily detected, provocative or too expensive are bunk," Fallon will say. "All of these arguments have one thing in common. They are a desperate attempt to find a fig leaf to cover up [Labour's] opposition to our nuclear deterrent."

"The simple truth is that Labour is ideologically committed to scrapping the deterrent. They need to be honest about the consequences. They would make the world more dangerous, not safer."

Labour leader Jeremy Corbyn proposed a compromise on the Trident programme earlier this year, in which the four Trident-missile carrying submarines remain part of Britain's underwater fleet but go to sea without nuclear warheads on board. Fallon rejected the proposal in January and likened it to going to a fight with imitation weapons.

International Business Times

Investment so far: £4 Billion
Total expected cost: £31 Billion

Opposition from Labor, SNP,
awaits vote.

News: Trident Release of Low Level Radiation in Accident

theguardian

Trident base workers exposed to radiation

Safety breach at Faslane in 2012 led to workers receiving low dose of radiation while repairing nuclear submarine

Press Association

Sunday 6 March 2016 08.59 EST

Twenty workers were exposed to radiation at the Faslane nuclear base in Scotland as a result of a safety breach, according to newly released documents.

The workers were inadvertently exposed to a low dose of ionising radiation as they were repairing a leaking tank on a Trident nuclear submarine at the same time as a nearby reactor was undergoing trials.

The Ministry of Defence said no one was harmed in the incident, which took place in August 2012.

News: Trident Release of Low Level Radiation in Accident

“There was a prolonged and repeated failure of the ship’s staff to understand and control the radiological hazard that they were creating,” it said.

Other documents obtained by the group reveal that in April 2012 a training team was allowed to visit a submarine and enter a radiation exclusion zone without being issued with dosimeters, which measure exposure to ionising radiation.

In February 2013, a sailor working on a submarine at the base left it with a sponge bung without having it checked for contamination.

A fourth incident in December 2013 involved an employee of Babcock, which manages the Faslane site, who removed some grills from an external tank and put his head inside, exposing himself to a small dose of radiation.

The SNP defence spokesman, Brendan O’Hara, said: “The MoD – once again – stands accused of a very poor approach to radiation safety at the Faslane base. When it comes to protecting our armed forces personnel, the contractors working at the base, as well as the wider community, nuclear safety must be paramount.

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

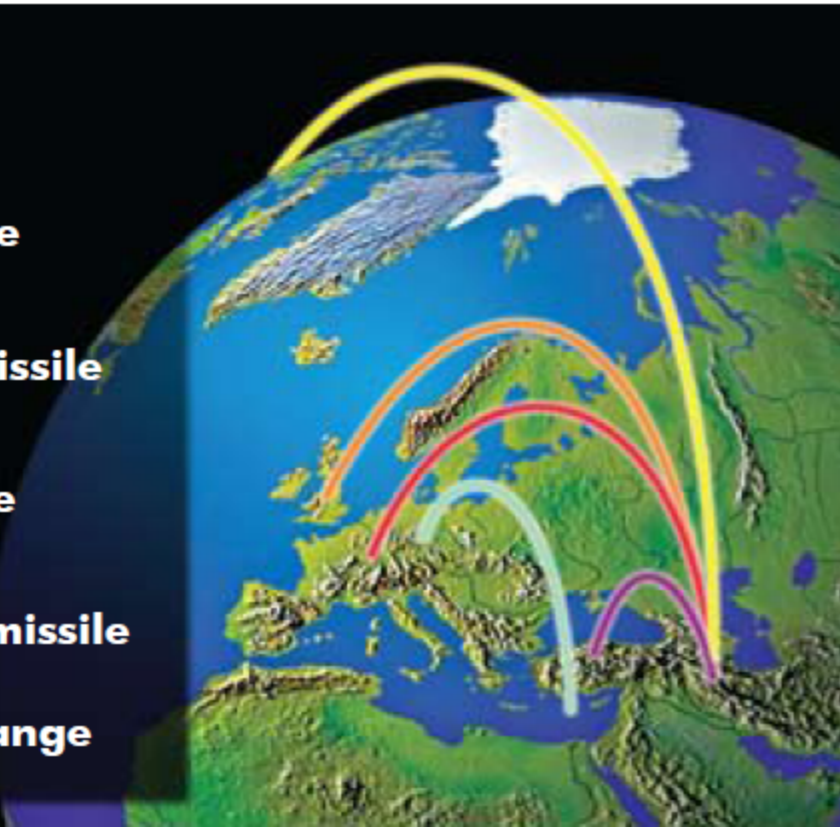
Intercontinental-range ballistic missiles (ICBMs, SLBMs) —

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

-  **SRBM Short-range ballistic missile**
<1,000 km (621 mi)
-  **MRBM Medium-range ballistic missile**
1,000-3,000 km (621-1,864 mi)
-  **IRBM Intermediate-range ballistic missile**
3,000-5,500 km (1,864-3,418 mi)
-  **ICBM Intercontinental ballistic missile**
>5,500 km (3,418 mi)
-  **SLBM Submarine-launched ballistic missile**
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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- Full-range ICBMs (FRICBMs): > 8,000 km
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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)

PHASES OF BALLISTIC MISSILE TRAJECTORY



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

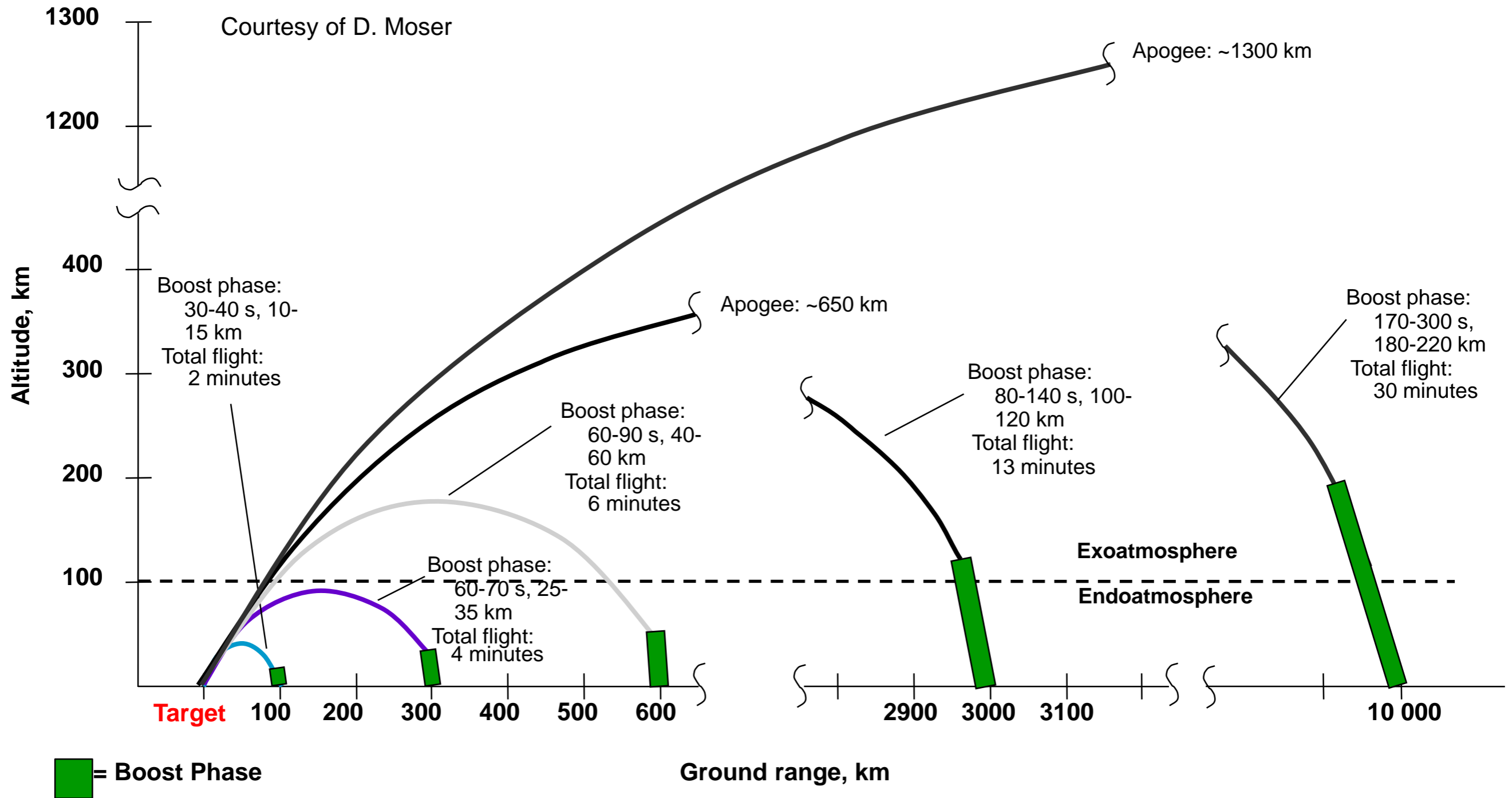
Stellar —

- Star trackers update inertial guidance system

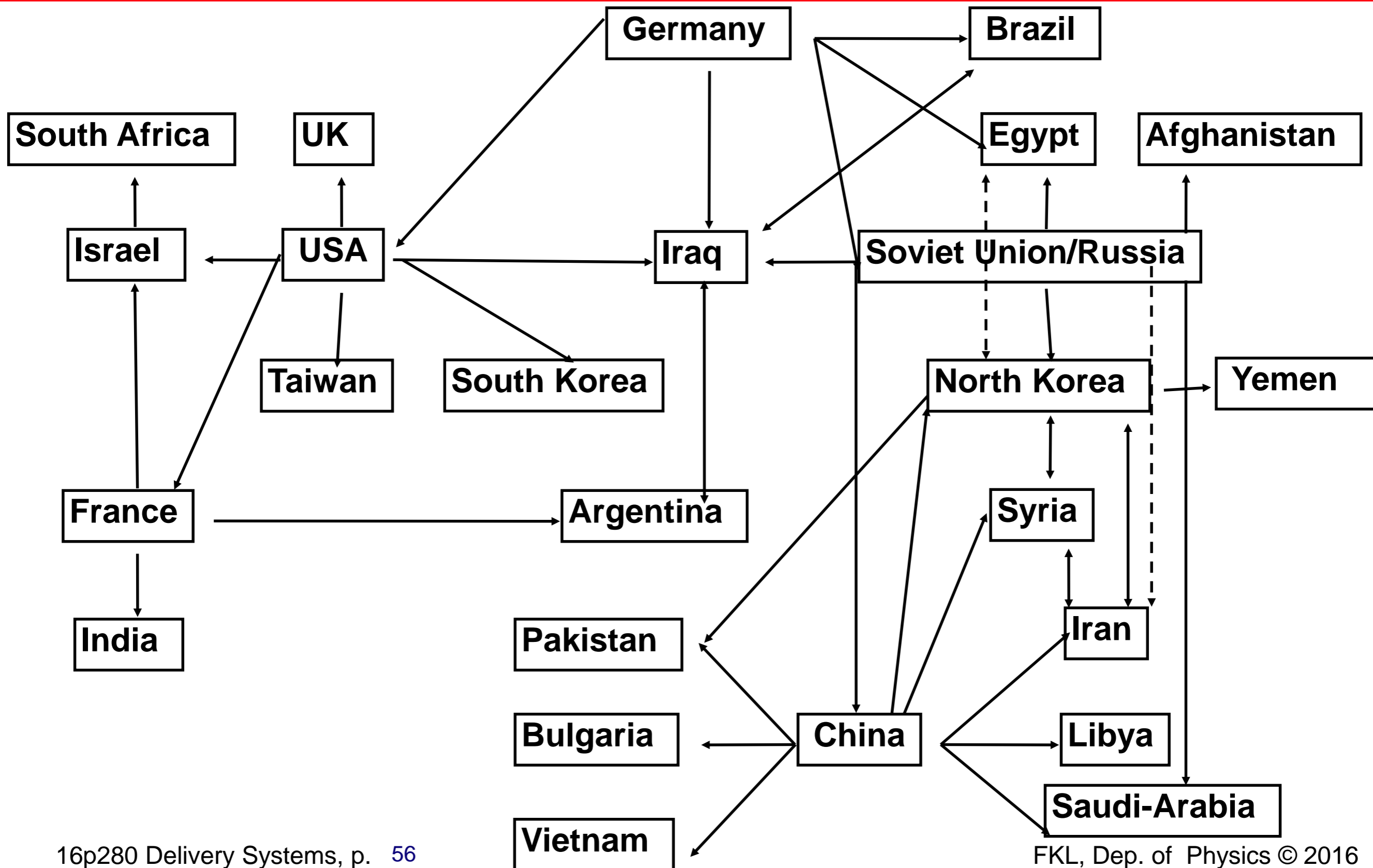
Satellite —

- 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

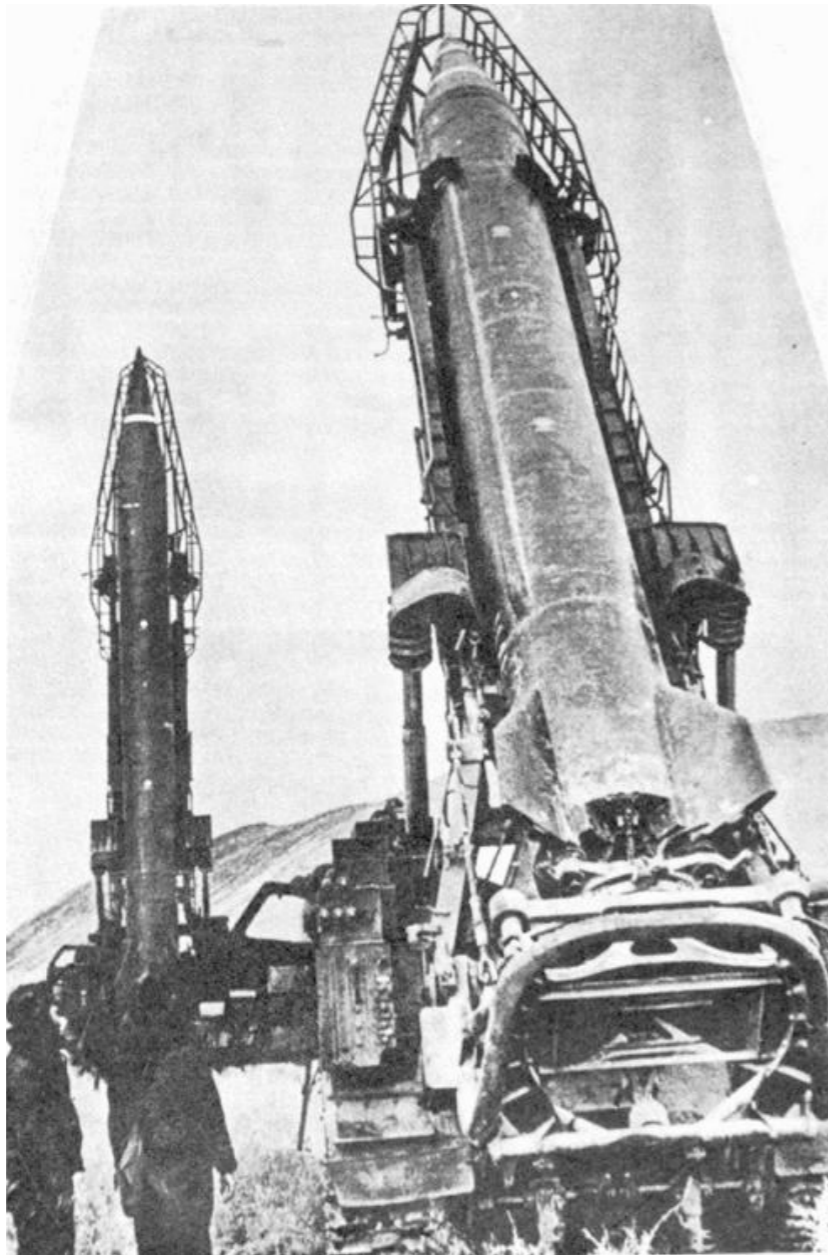
Trajectories and Phases of Flight of Missiles With Various Ranges



Proliferation of Ballistic Missile Technologies



Soviet Scud Missiles and Derivatives - 1

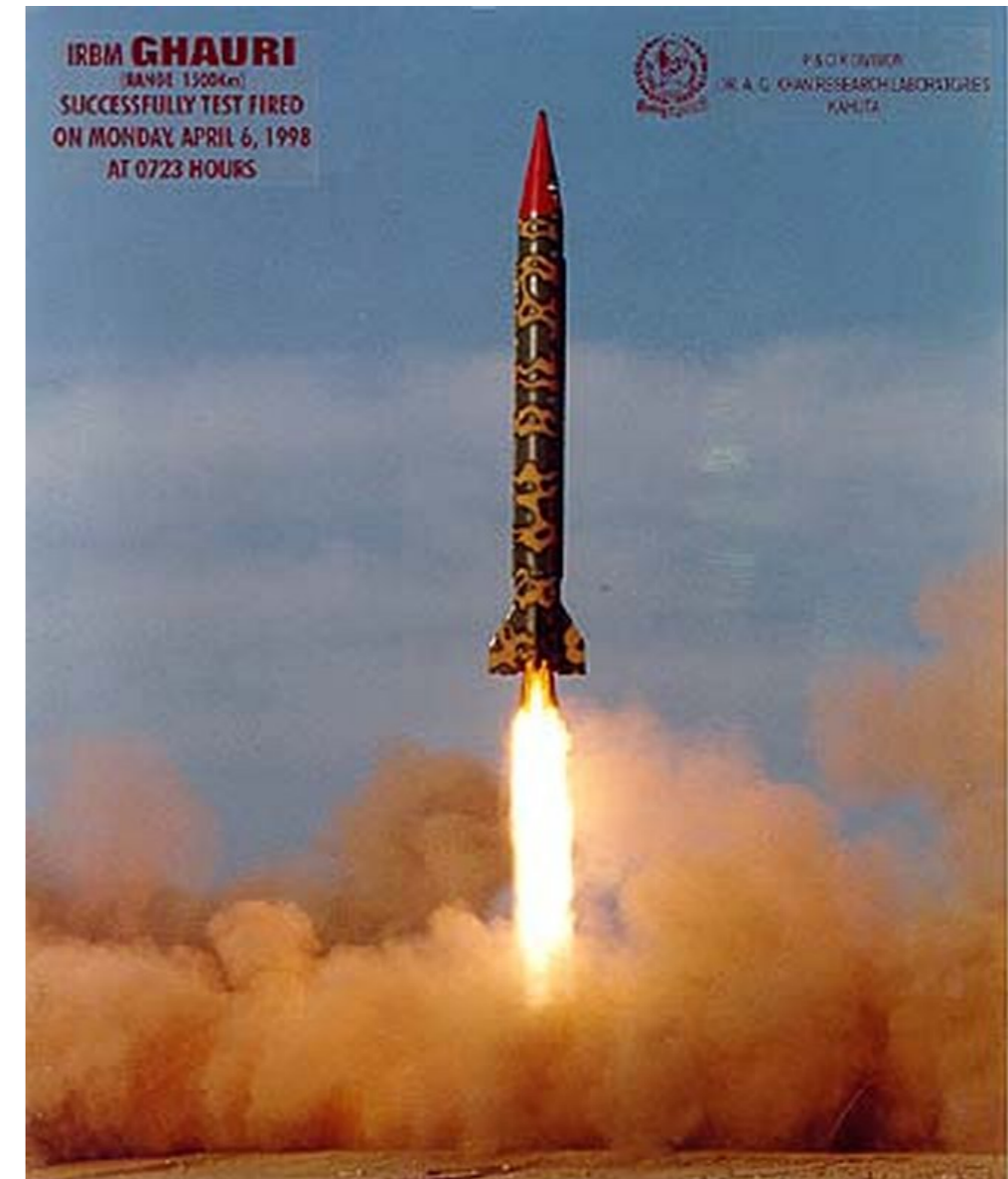


Soviet Scud-B Missile
(based on the German V2)
Range: 300 km



Iraqi Al-Hussein SRBM
Range: 600–650 km

Scud Missiles and Derivatives – 2

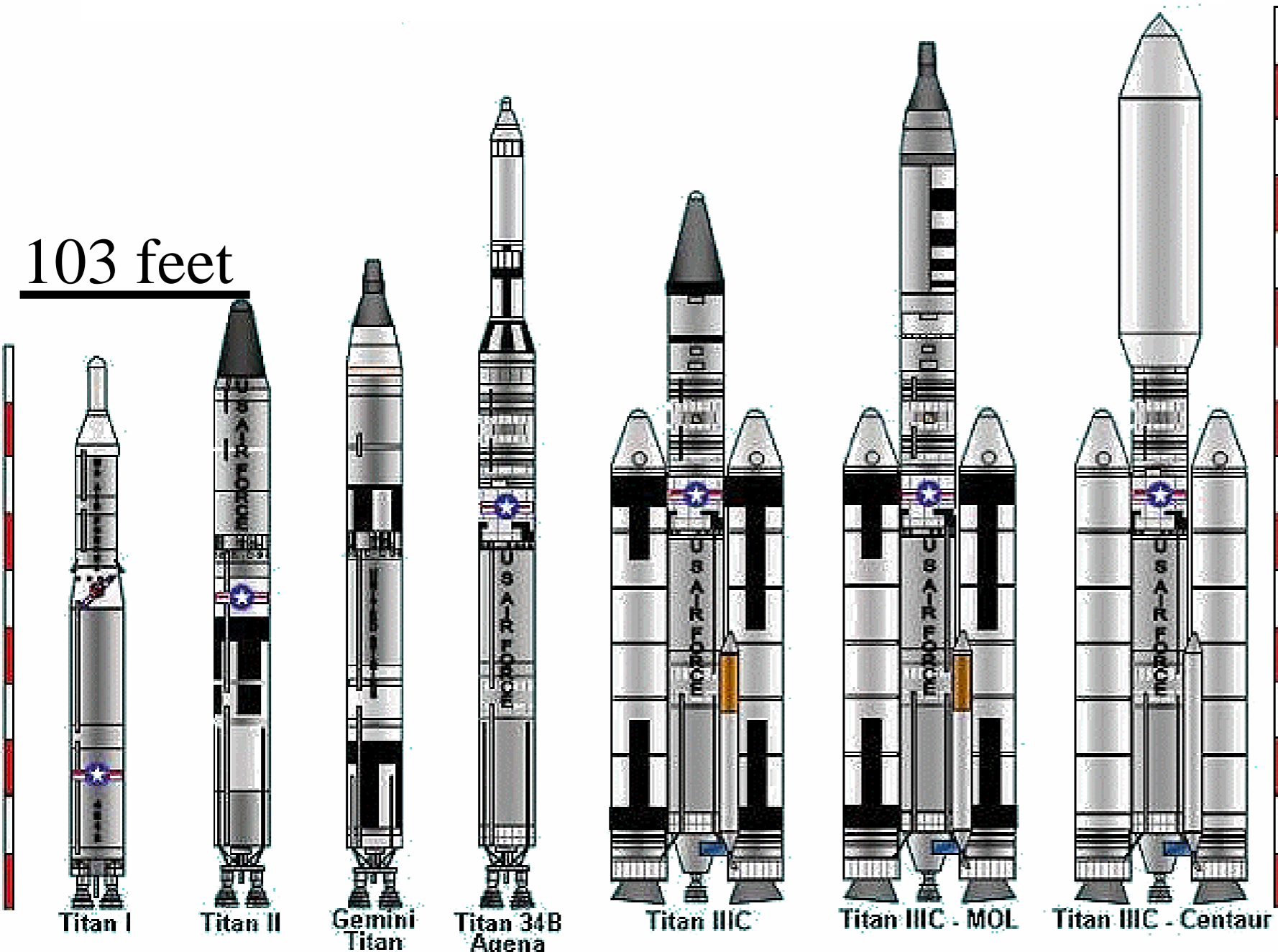


Pakistan's Ghauri MRBM and transporter (range 1,300 km).
It is almost identical to North Korea's No Dong MRBM, which is based on Scud technology that North Korea got from Egypt in the 1970s.

Titan Family of Missiles and Launch Vehicles

1959 – 2005 ICMB & civilian uses

103 feet



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

iClicker Question

iClicker Answer

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- B. Ship-launched ballistic missiles
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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

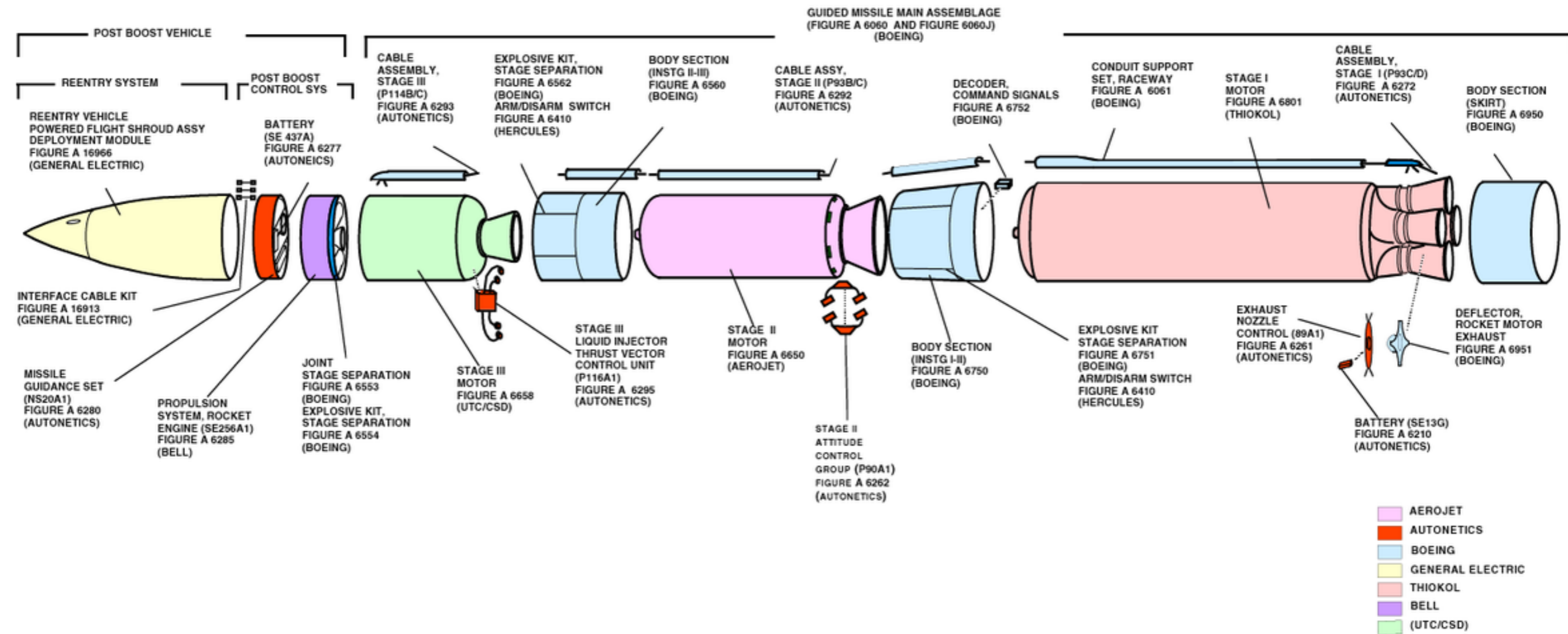
MIRV Technology



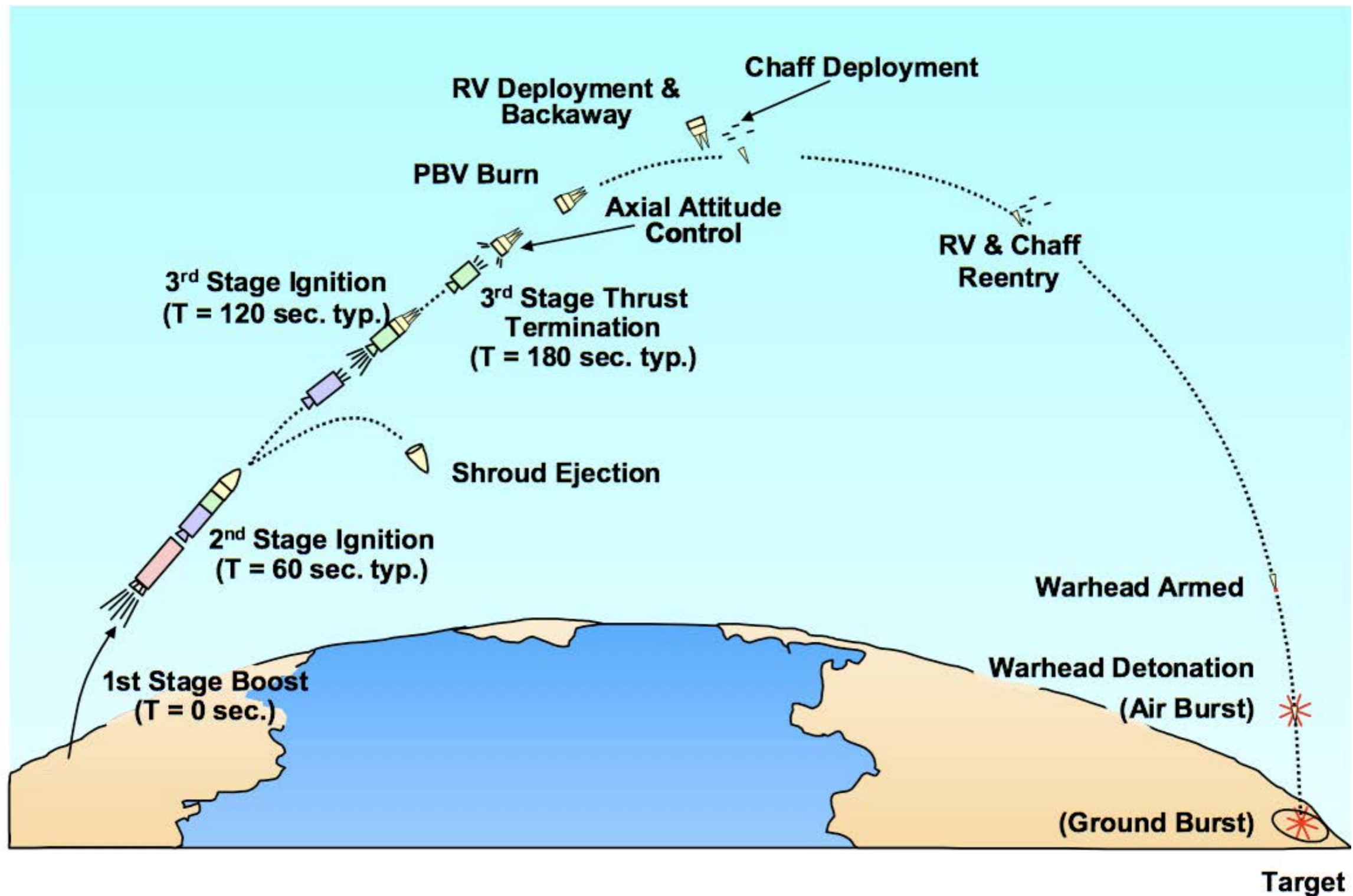
MX Peacekeeper missile tested at Kwajalein Atoll

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

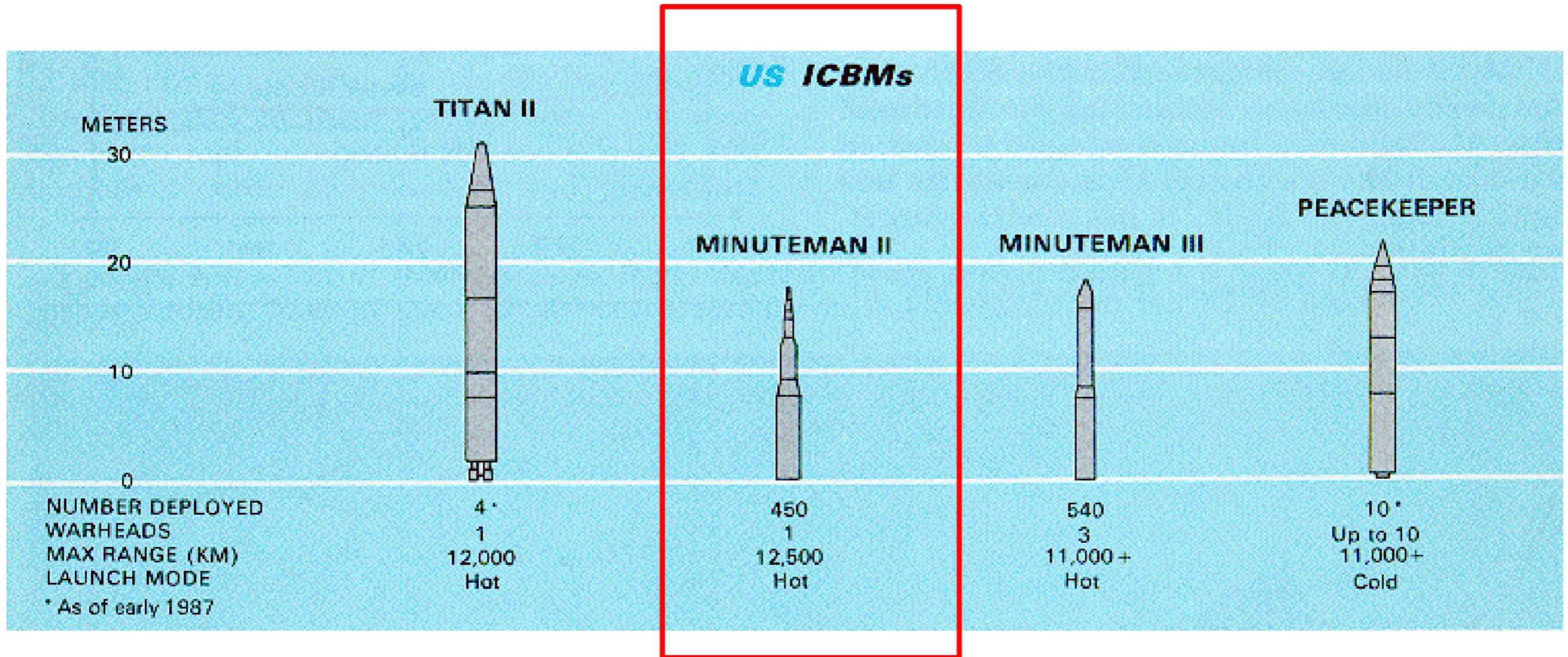
Recent US ICBMs —

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

Recent Russian ICBMs —

- SS-24 Solid-propellant, range > 9,000 km
- SS-25 Solid-propellant, range > 9,000 km
- SS-27 Solid-propellant, range > 9,000 km

US ICBMs – 1



current land based
US ICMB

US ICBMs – 2

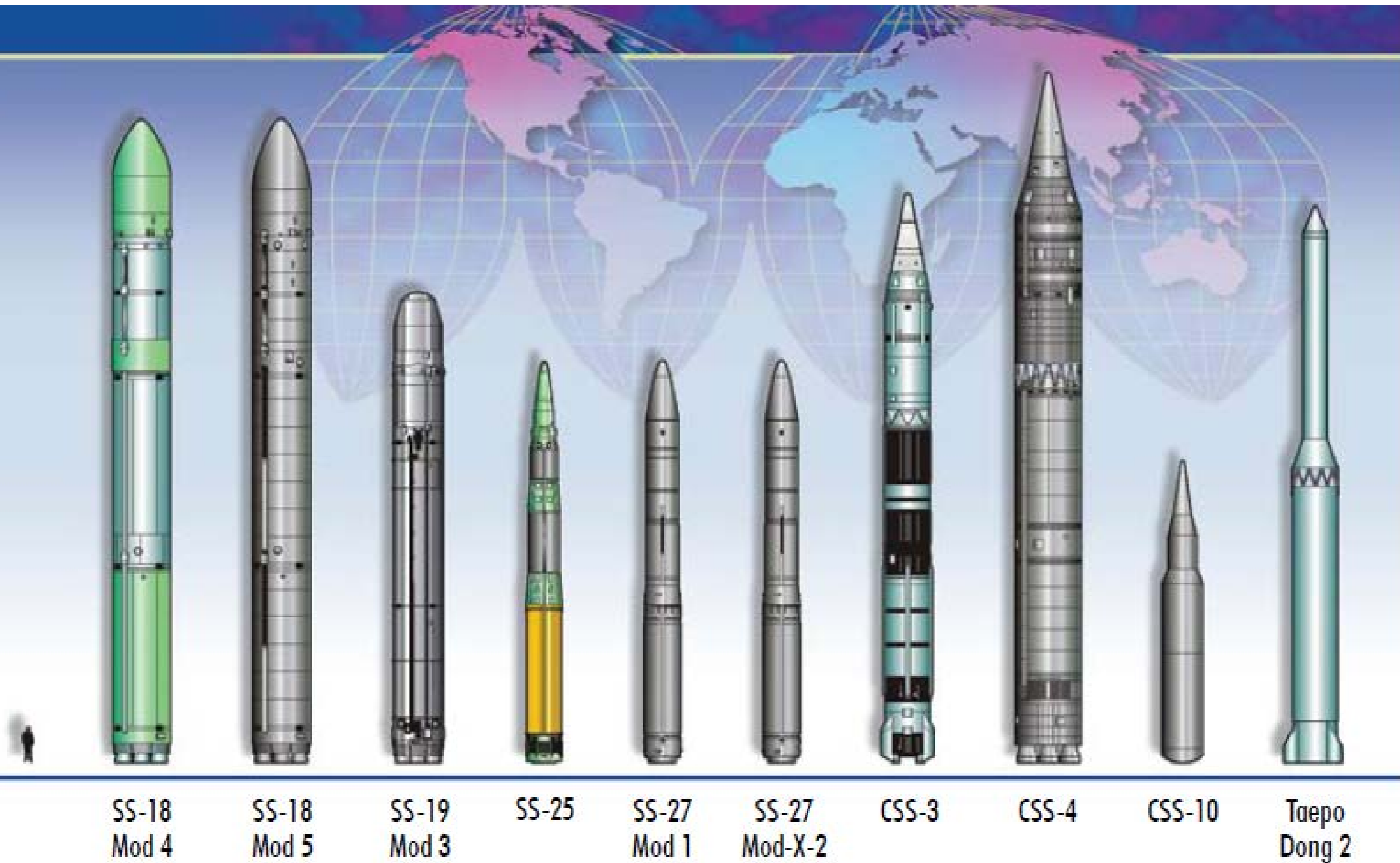


Launch of a Minuteman → [video!](#)



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

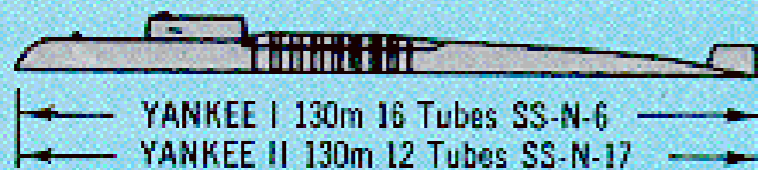
US and Russian SSBNs

Nuclear-Powered Ballistic Missile Submarines

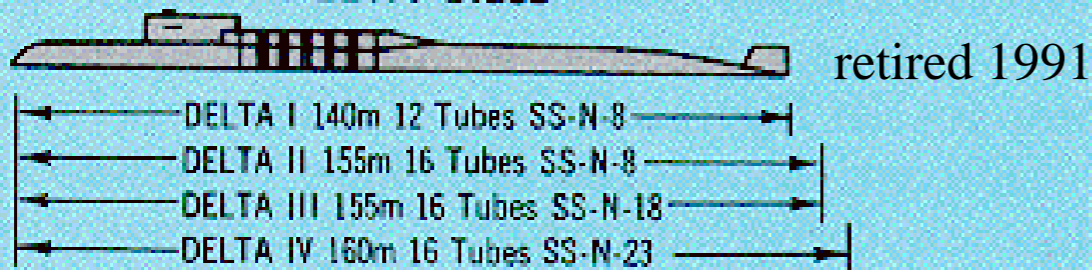
USSR

US

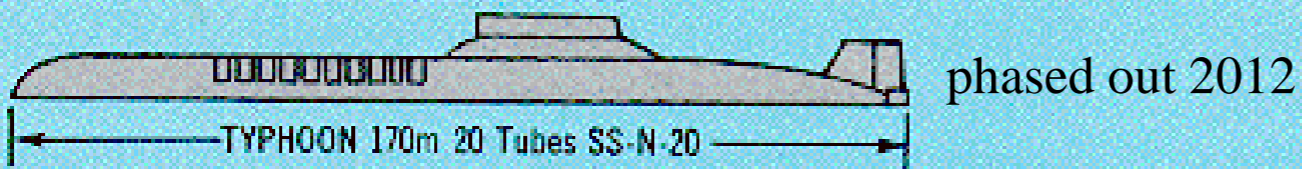
YANKEE-Class



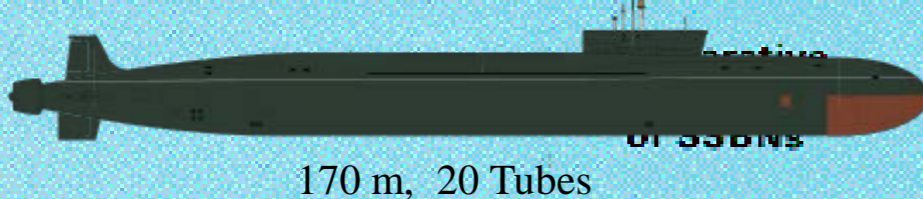
DELTA-Class



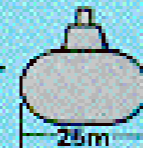
TYPHOON-Class



Borei-Class



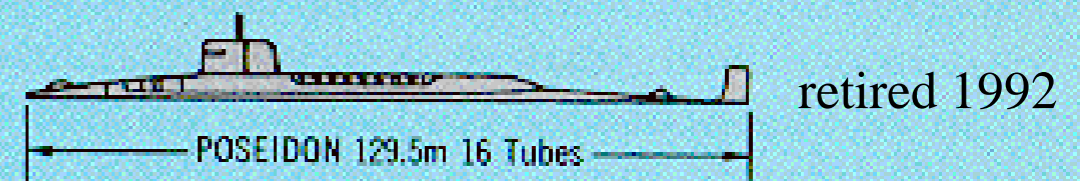
TYPHOON-Class



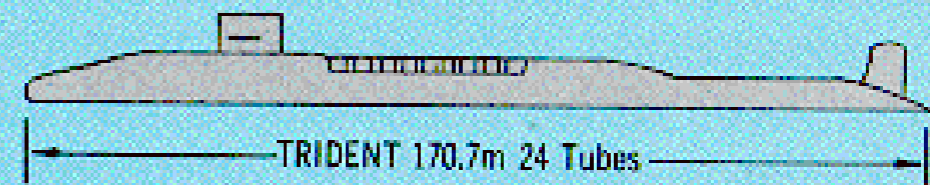
OHIO-Class



POSEIDON SSBN



TRIDENT (OHIO-Class) SSBN



Physics 280: Session 16

Plan for This Session

Questions

Midterm Review, Sunday, March 13th, Loomis 136, 3-5pm

Office Hours, Wednesday, March 16th, 404 Grainger, 12-6pm

Midterm Exam, Thursday March 17th, 1000 Lincoln Hall, 2-3.20pm

Module 5: Nuclear Weapon Delivery Systems



North Korea's Kim says country has miniaturized nuclear warheads

SEOUL | BY JACK KIM

North Korean leader Kim Jong Un said the country has miniaturized nuclear warheads to mount on ballistic missiles and ordered improvements in the power and precision of its arsenal, state media reported on Wednesday.

Kim has called for his military to be prepared to mount pre-emptive attacks against the United States and South Korea and stand ready to use nuclear weapons, stepping up belligerent rhetoric after coming under new U.N. and bilateral sanctions for its nuclear and rocket tests.



North Korean leader Kim Jong Un meets scientists and technicians in the field of researches into nuclear weapons in this undated photo released by North Korea's Korean Central News Agency (KCNA) in Pyongyang March 9, 2016.

REUTERS/KCNA

1 of 4

US Trident SSBN (14 SSBNs, 4 SSGNs)



Trident Missile Tubes
With Covers Open

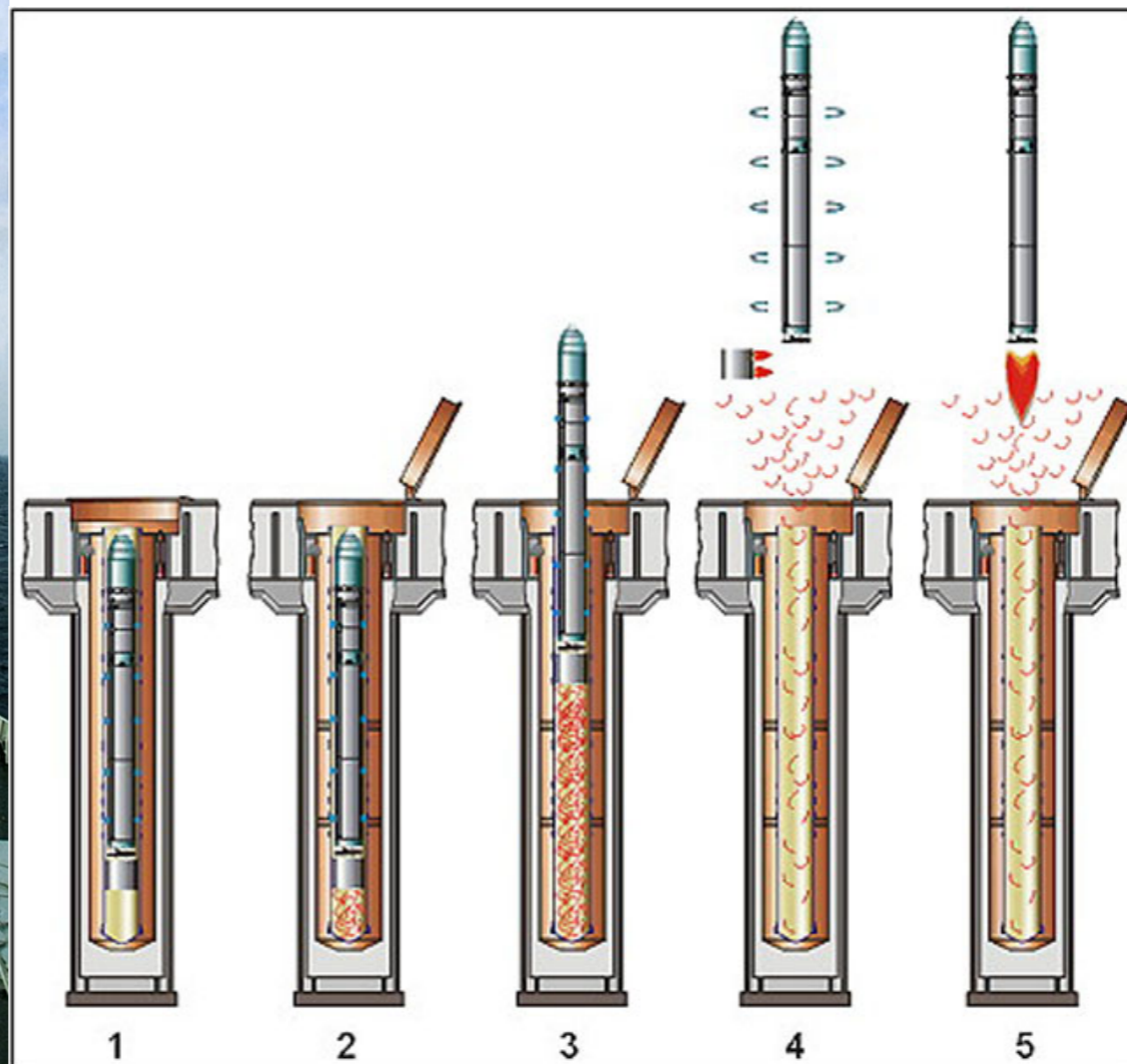
24 Trident C4 SLBMs
8 MIRVs with 100kt W76
→ up to 192 targets
SLBM range 7400 km

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

Cold Launch Mode

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



US Trident SSBN



Launch video

Submarine-Based Missiles

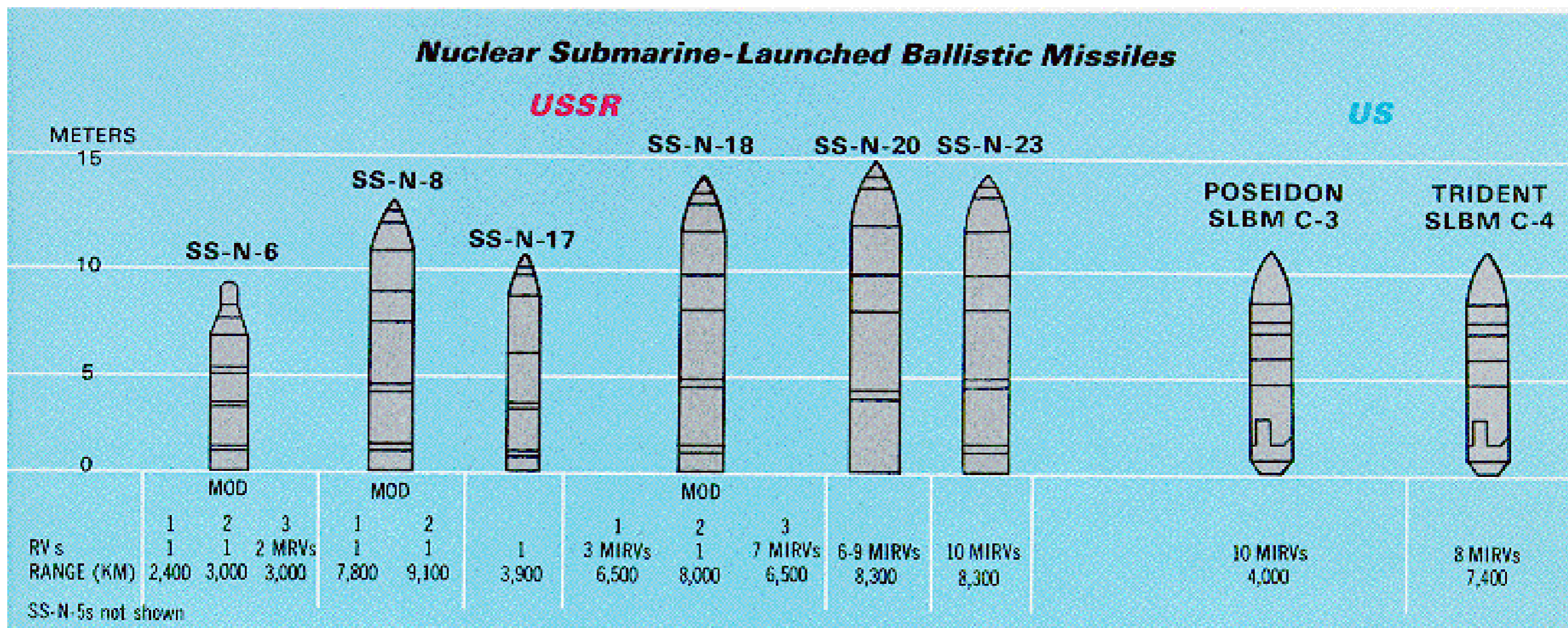
US SLBMs —

- 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)

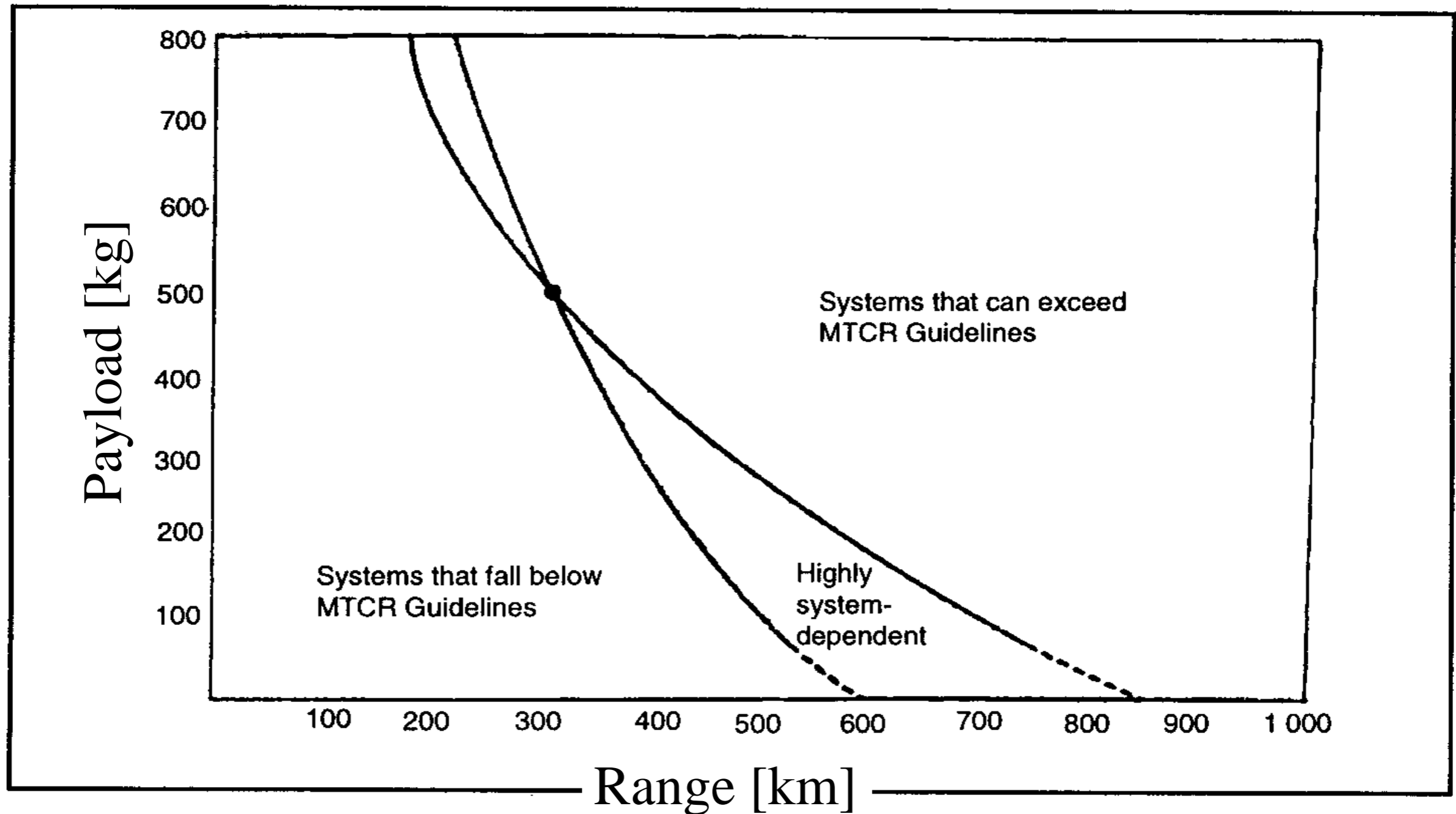
US and Russian SLBMs



Module 5: Nuclear Delivery Systems

Part 5: Technical and Operational Aspects

MTCR: Range-Payload Limits



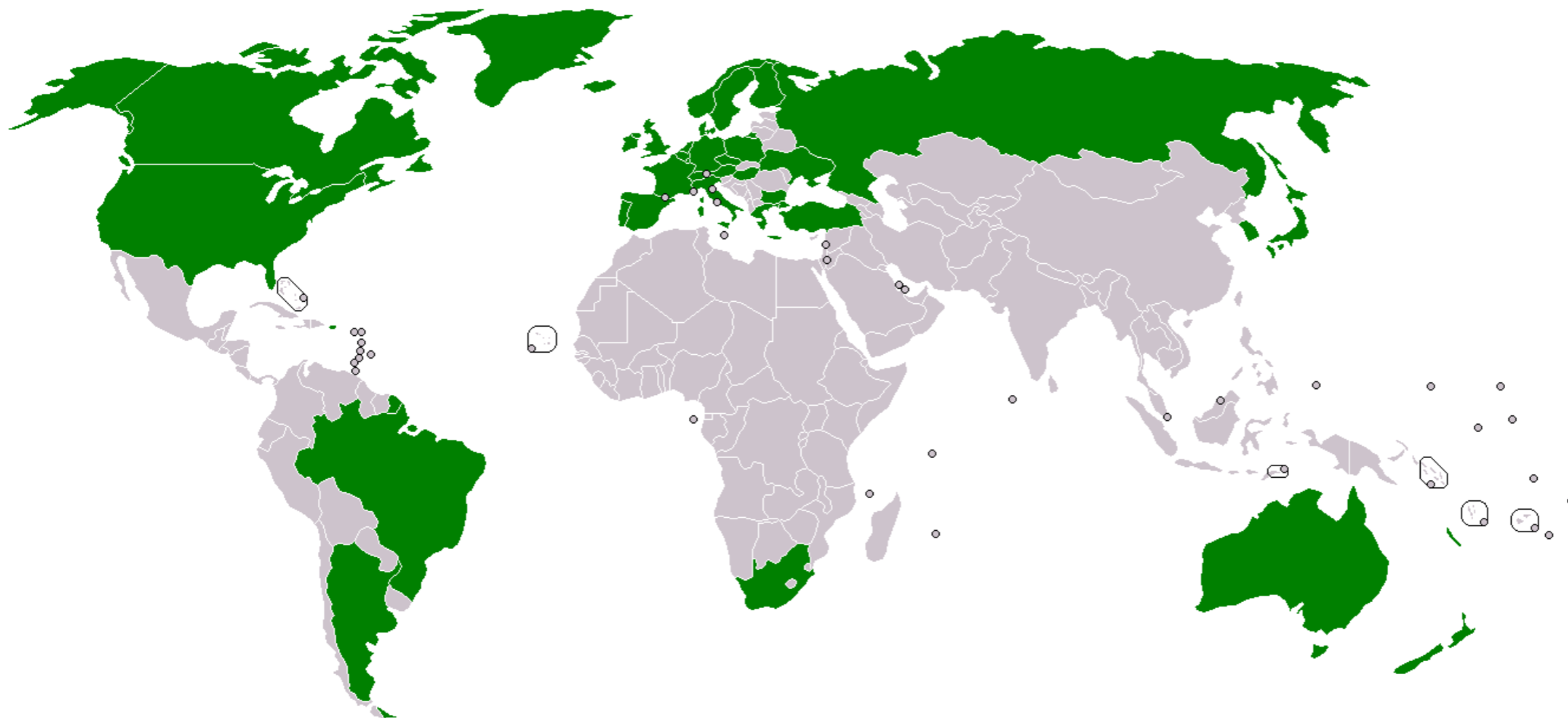
MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

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

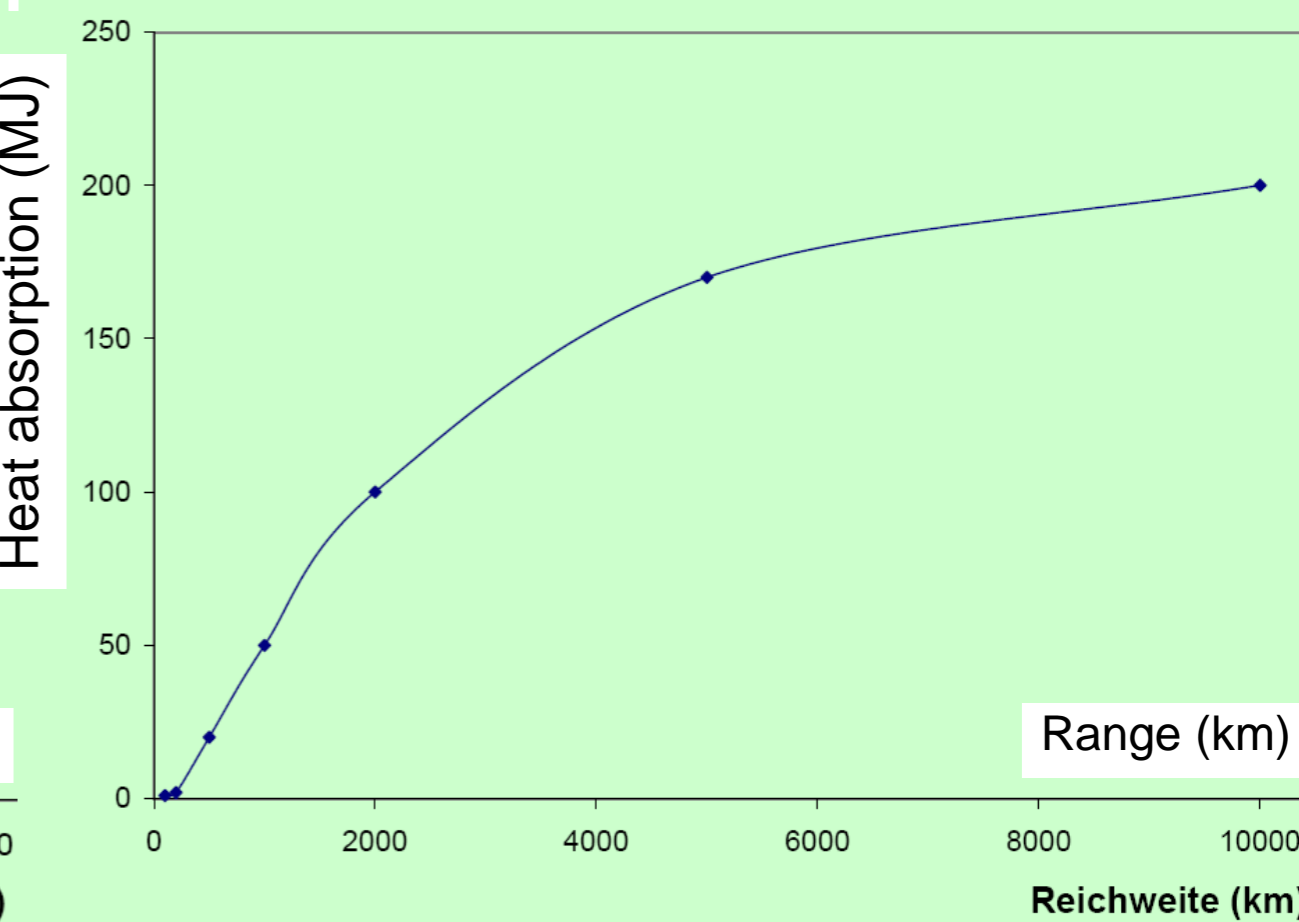
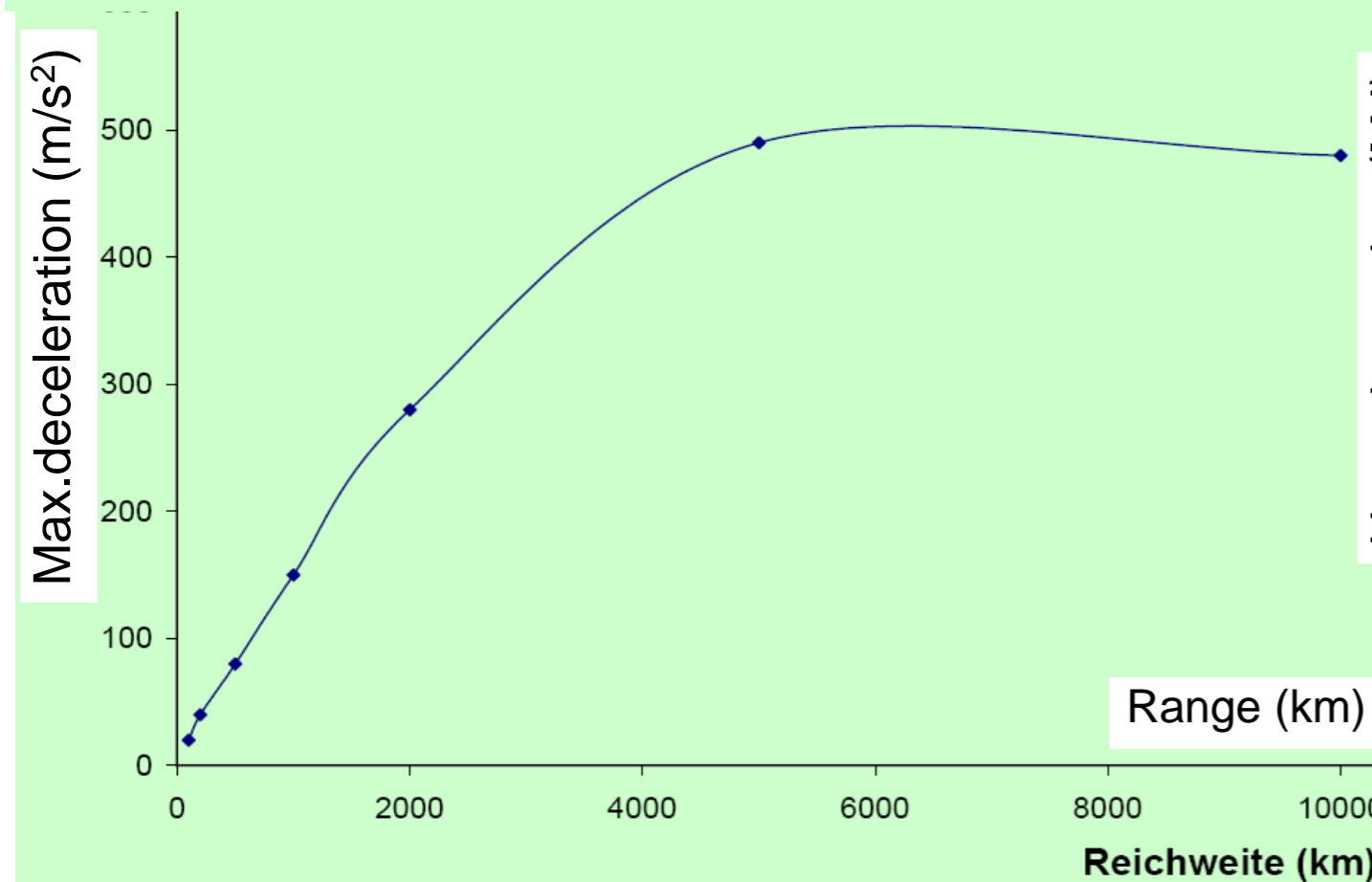
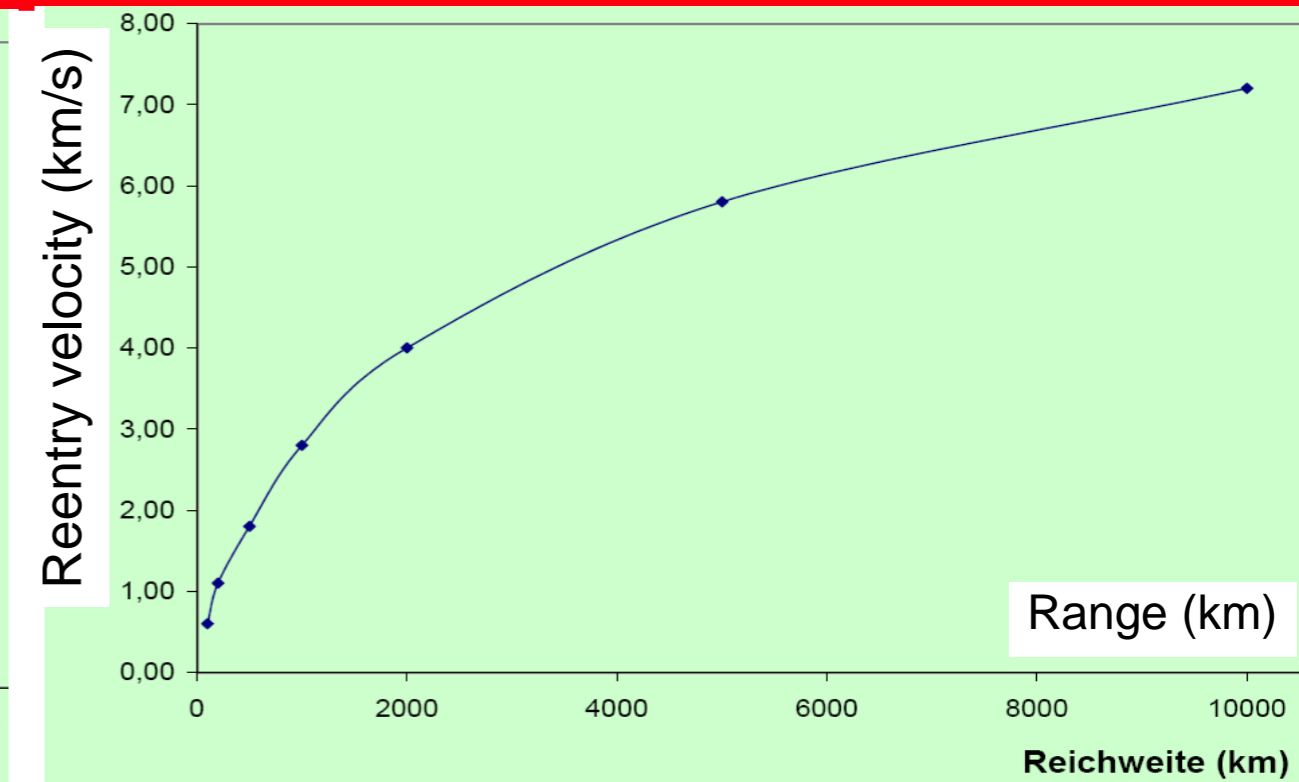
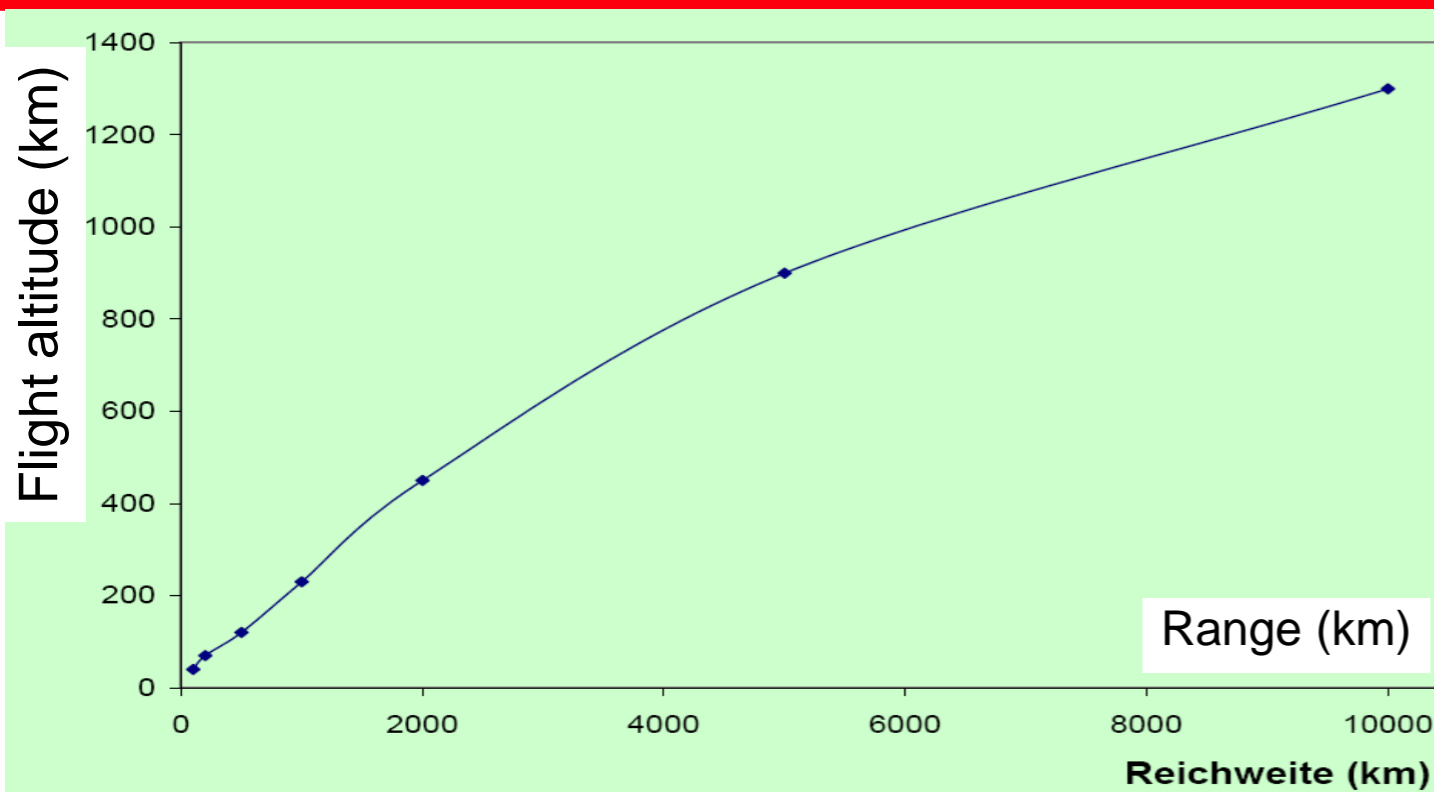
1987 Missile Technology Control Regime

34 member countries (the leading missile producing countries have agreed to restrict missile exports).

China and Israel are not members but have agreed unilaterally to adhere to the provisions of the agreement.



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



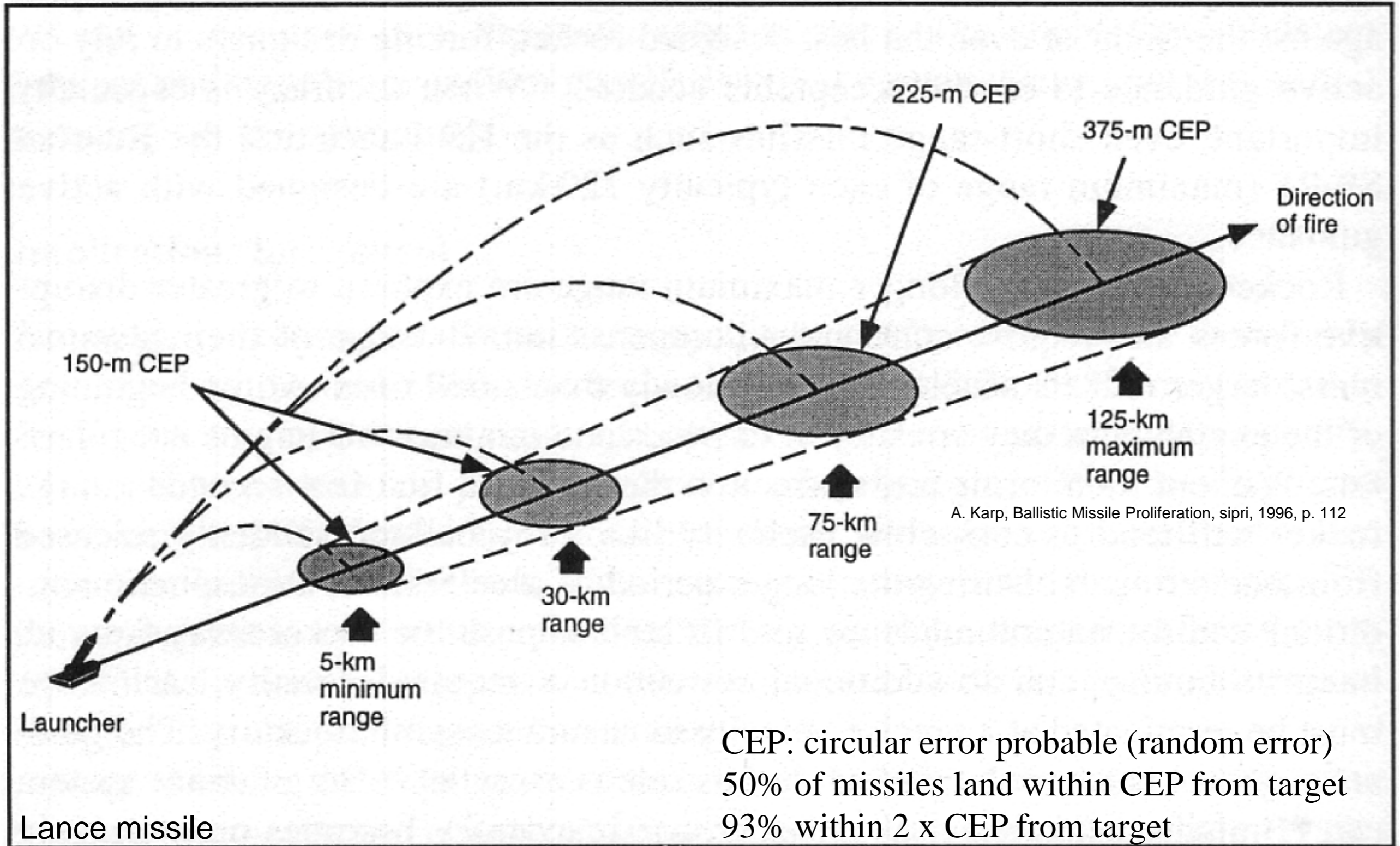
How Does this Translate into Challenges During Re-Entry into the Atmosphere?



Large frictional forces on re-entry lead to

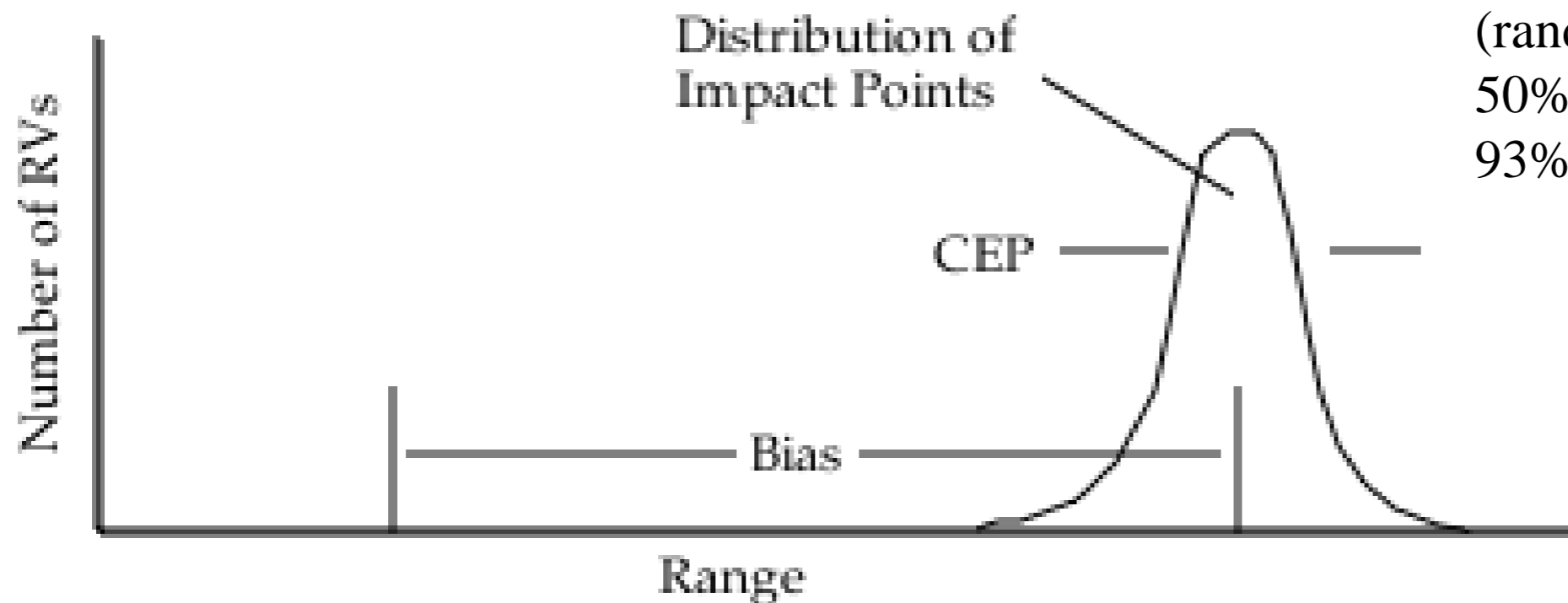
- ➔ deceleration up to $500 \text{ m/s}^2 = 51 \text{ g}$
~ car with 70mph into concrete wall
g-forces can be lethal if $> 25 \text{ g}$
- ➔ 200 MJ of energy is enough to heat
2 W76 warheads to the melting temperature
of iron $\sim 1540 \text{ C}$!

Missile Range–Accuracy Tradeoff



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 II	100 m
Russia	SS-18	450 m
	SS-27	350 m
	SS-27 Sickle B	200 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 an 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

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

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

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

- 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

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 (C³I) assets
- Vulnerability of strategic C³I 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) September, 1983: Russian False Alarm
- 21) November, 1983 Able Archer
- 21) January, 1995: Russian False Alarm (Norwegian research missile)

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.

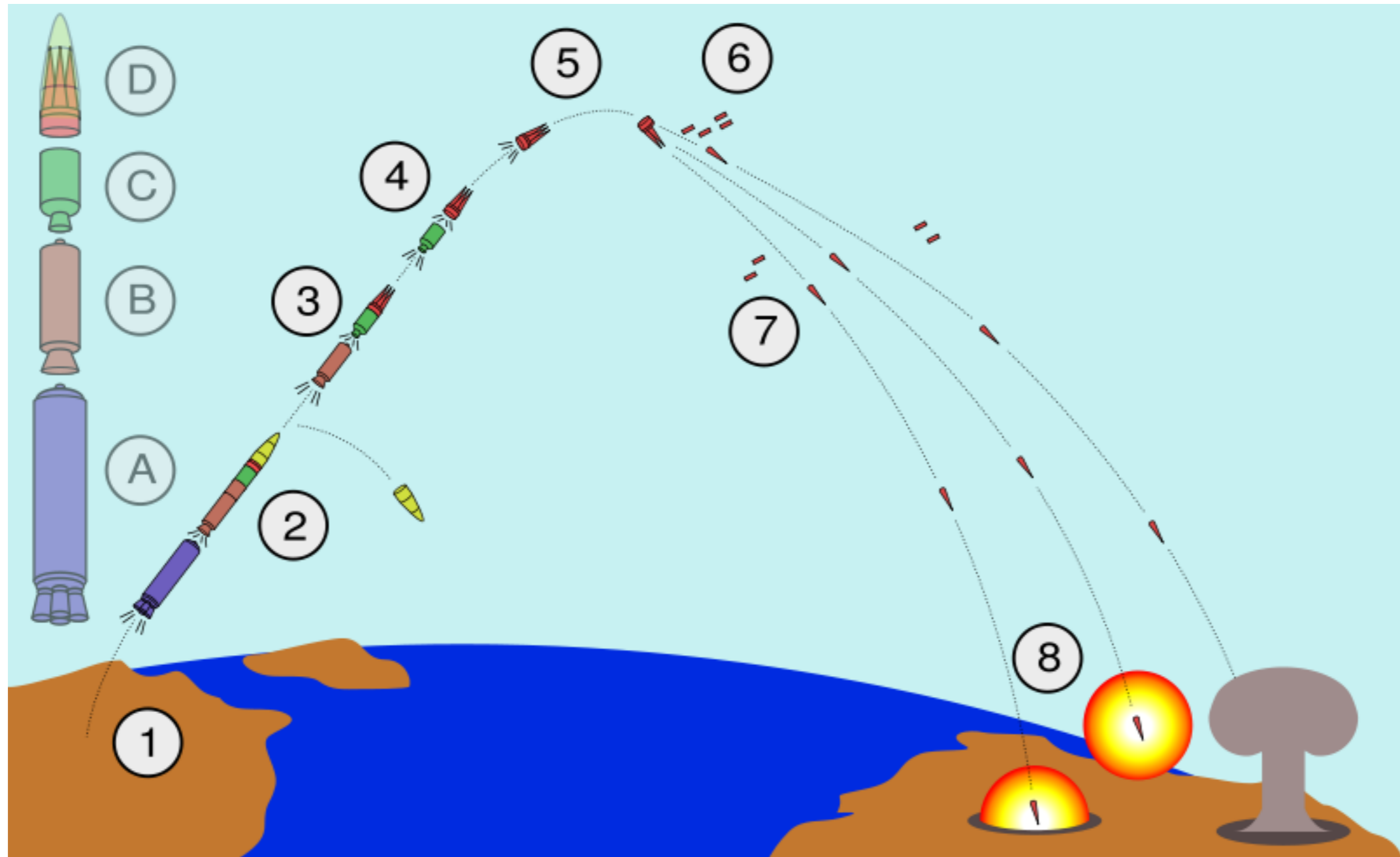
Possible Risk Reduction Measures

- 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.