Physics/Global Studies 280: Session 14

Plan for This Session

Questions

News

Module 5: Nuclear Weapon Delivery Systems

Report to Congress on Columbia-class Nuclear Ballistic Missile Submarine Program

March News 2020 Navy Naval Maritime Defense Industry (/index.php/news/defence-news/2020/march.html)

POSTED ON THURSDAY, 05 MARCH 2020 12:07

Congressional Research Service report, Navy Columbia(SSBN-826) Class Ballistic Missile Submarine Program: Background and Issues for Congress.

The Blue crew of the ballistic-missile submarine USS Henry M. Jackson (SSBN 730) (Picture source: US Navy)

Report to Congress on Columbia-class Nuclear Ballistic Missile Submarine Program

The Columbia (SSBN-826) class program is a program to design and build a class of 12 new ballistic missile submarines (SSBNs) to replace the Navy's current force of 14 aging Ohio-class SSBNs. The Navy has identified the Columbia-class program as the Navy's top priority program. The Navy wants to procure the first Columbia-class boat in FY2021. Research and development work on the program has been underway for several years, and advance procurement (AP) funding for the first boat began in FY2017. The Navy's proposed FY2021 budget requests $2,891.5 million in procurement funding, $1,123.2 million in advance procurement (AP) funding, and $397.3 million in research and development funding for the program.

The Navy's FY2021 budget submission estimates the total procurement cost of the 12-ship class at $109.8 billion in then-year dollars. A May 2019 Government Accountability Office (GAO) report assessing selected major DOD weapon acquisition programs stated that the estimated total acquisition (development plus procurement) cost of the Columbia-class program as of June 2018 was $103,035.2 million (about $103.0 billion) in constant FY2019 dollars, including $13,103.0 million (about $13.1 billion) in research and development costs and $89,932.2 million (about $89.9 billion) in procurement costs.

Issues for Congress for the Columbia-class program include the following:

- Whether the Navy has accurately priced the work it is proposing to do in the Columbia-class program in FY2021;

- The potential impact of the Columbia-class program on funding that will be available for other Navy programs, including other shipbuilding programs;

- The potential industrial-base challenges of building both Columbia-class boats and Virginia-class attack submarines (SSNs) at the same time.

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

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

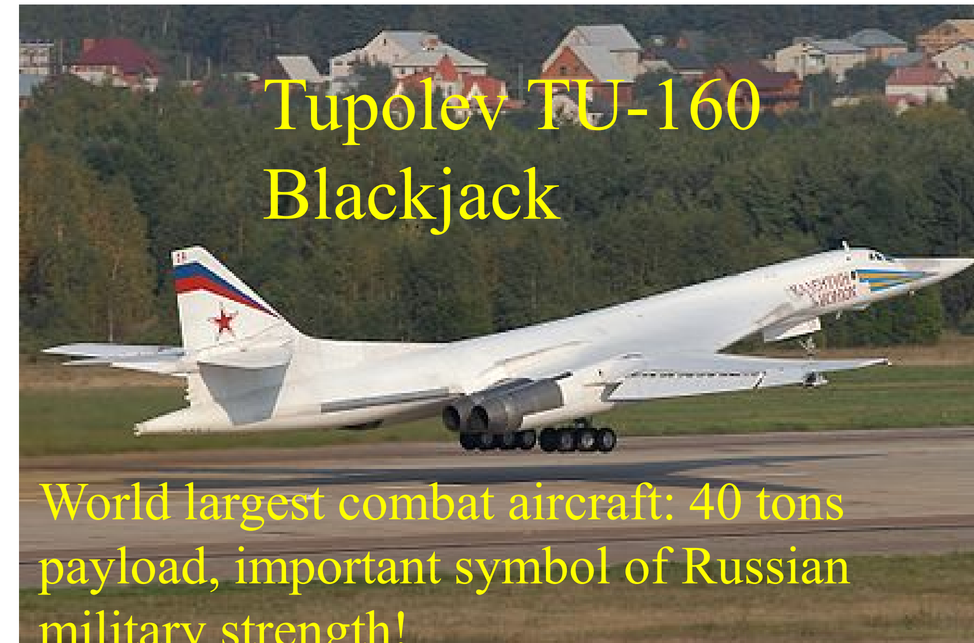
Air-Breathing Vehicles

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

Robert McNamara as President 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:

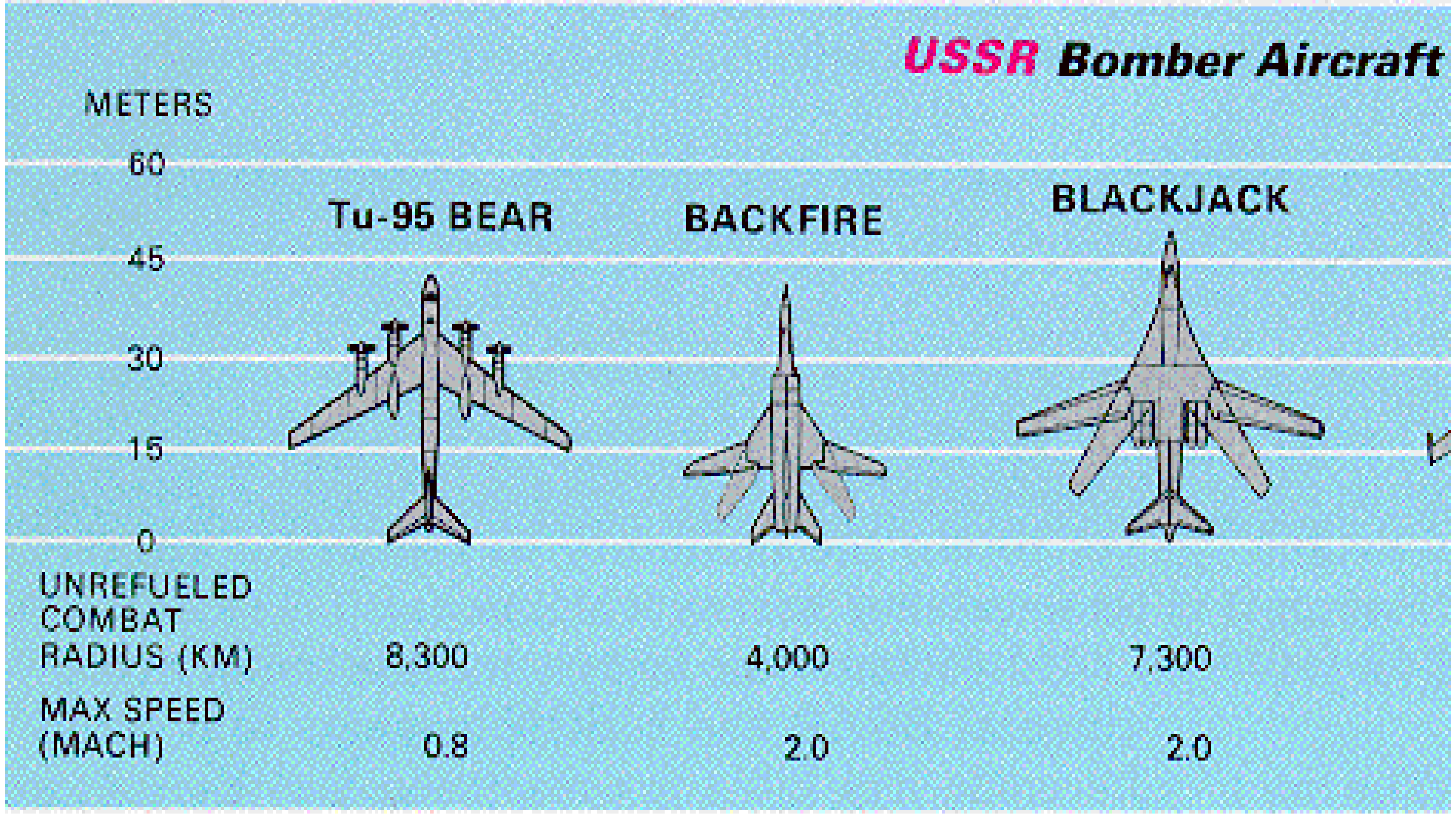
- Systems with intercontinental range (U.S. def.)
- Systems able to strike directly the homeland of the adversary (Soviet def.)

Systems in the Triad —

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

Part 2: Aircraft

Examples of Intercontinental Bombers – 1



Tu-95	Tu-22	Tu-160
65	160	16

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

# of B-2s 20

Currently Deployed U.S. and Russian Bombers

Current US bombers —

- B-52 carrying bombs, or cruise missiles
- B1 carry conventional armament
- 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

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:

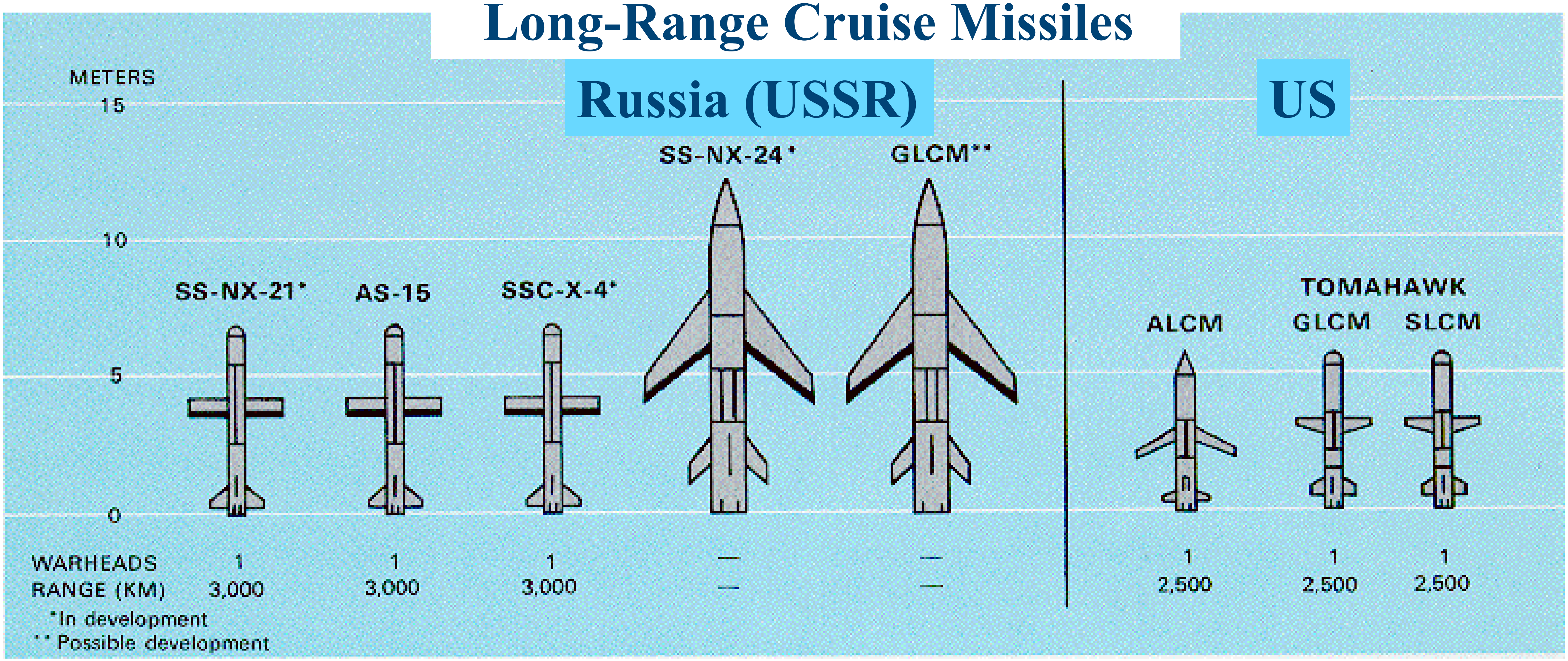
- Smaller and lighter nuclear warheads
- Efficient turbofan engines
- Highly capable miniaturized computers
- GPS, TERCOM (Terrain Contour Matching), and terminal guidance
- “Stealth” airframe technology

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)

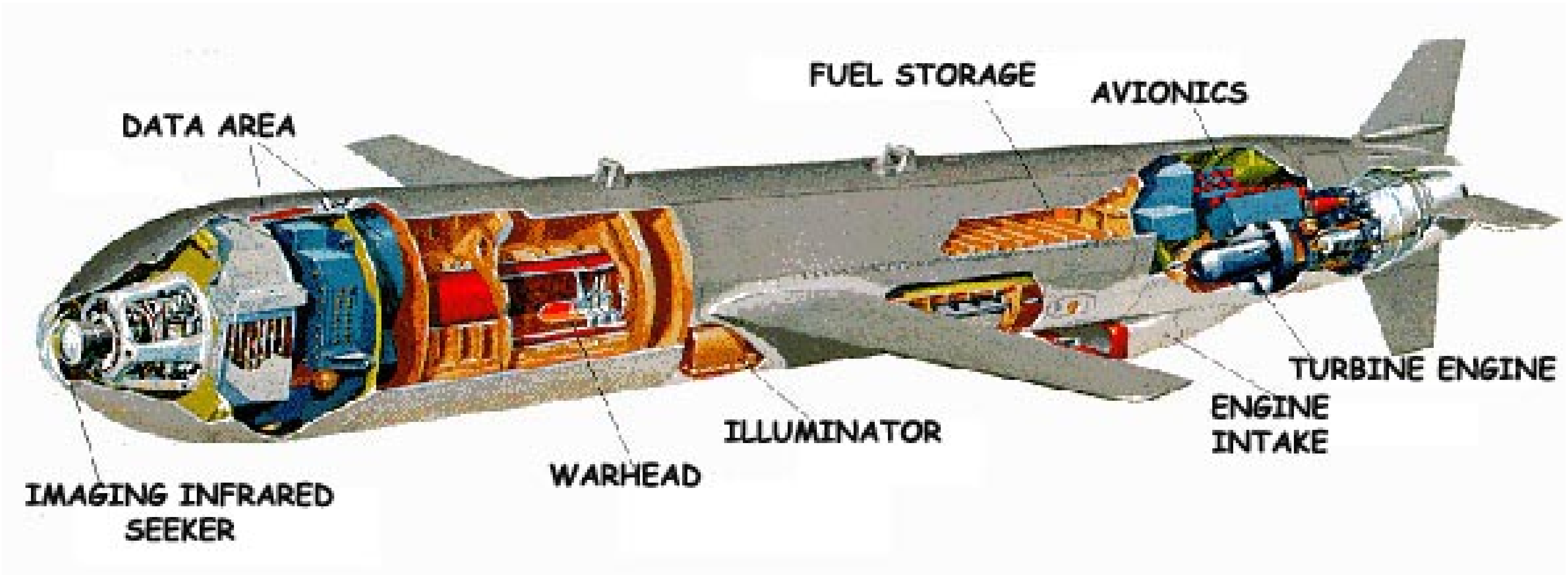
Long-Range Cruise Missiles – 1



range :1000 – 2000 miles

pay loads : 500 – 1200 lbs

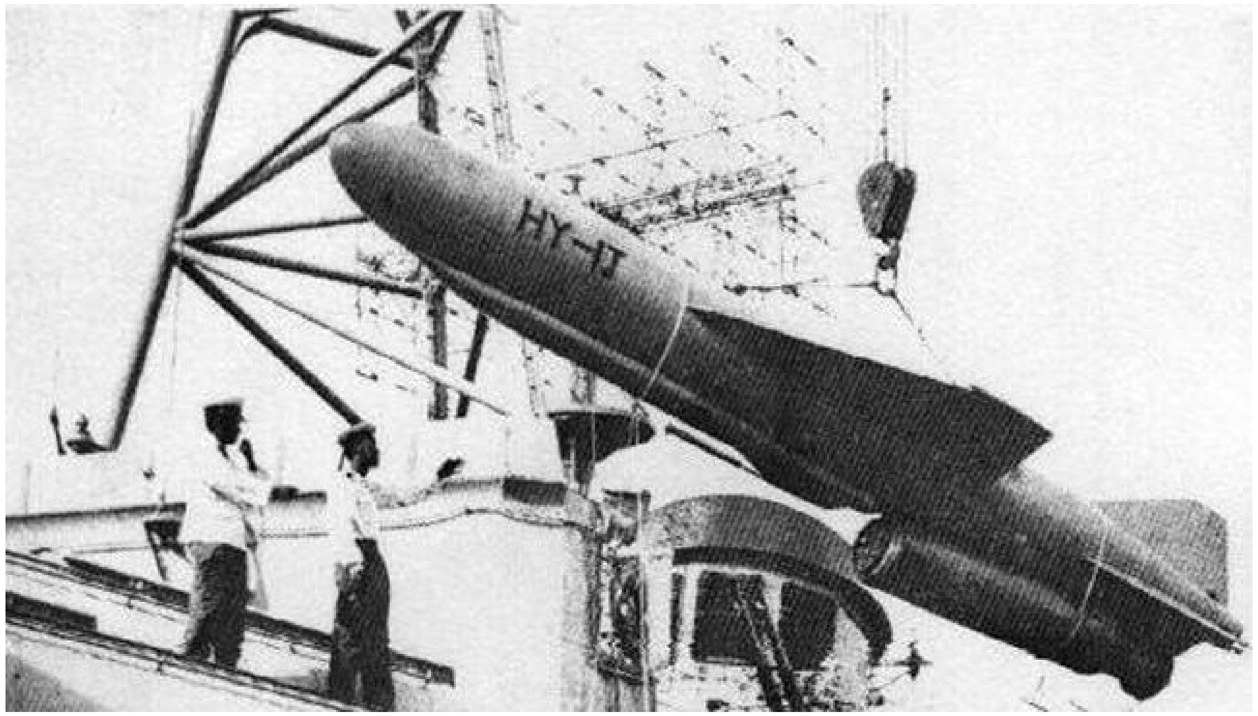
Long-Range Cruise Missiles – 2



Conventionally-Armed Tomahawk Cruise Missile

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

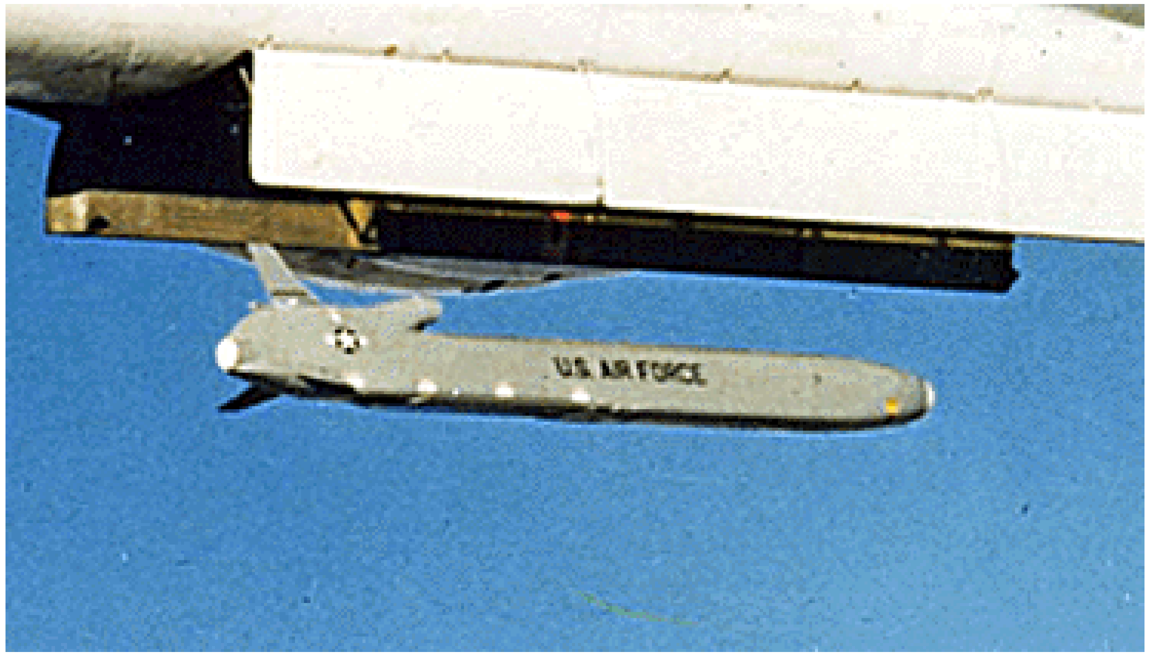
Chinese Silkworm Anti-Ship Cruise Missile



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

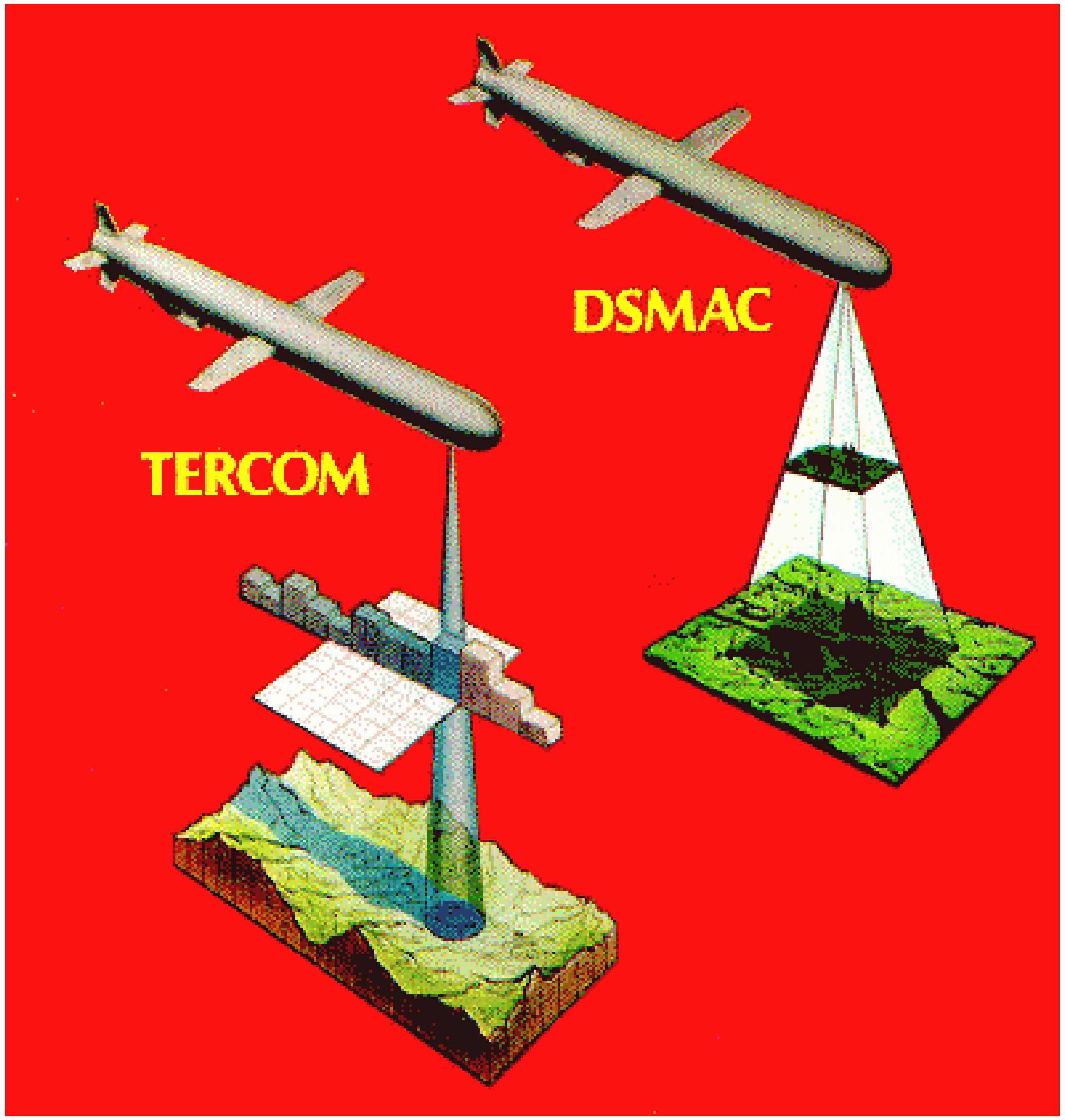
Velocity: 680 mph
payload: 660 lbs
range: 180 miles

Launching Cruise Missiles – 1



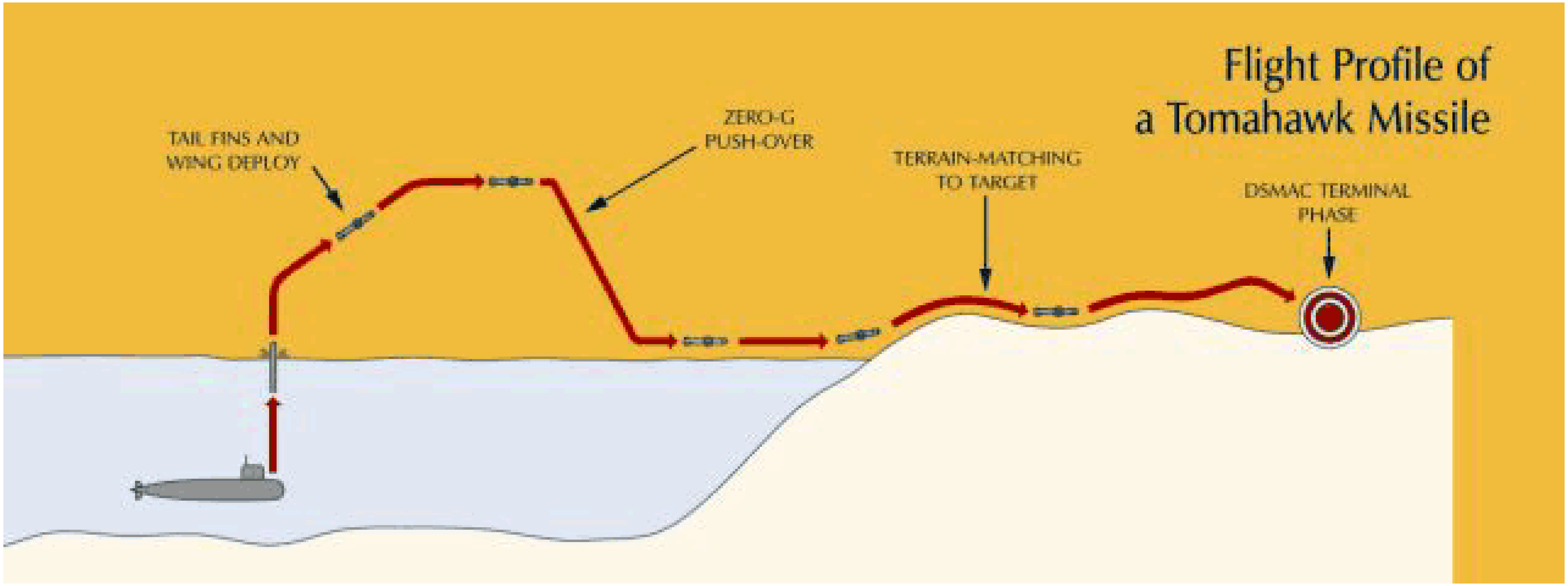
Launching Cruise Missiles – 2

Cruise-Missile Guidance – 1

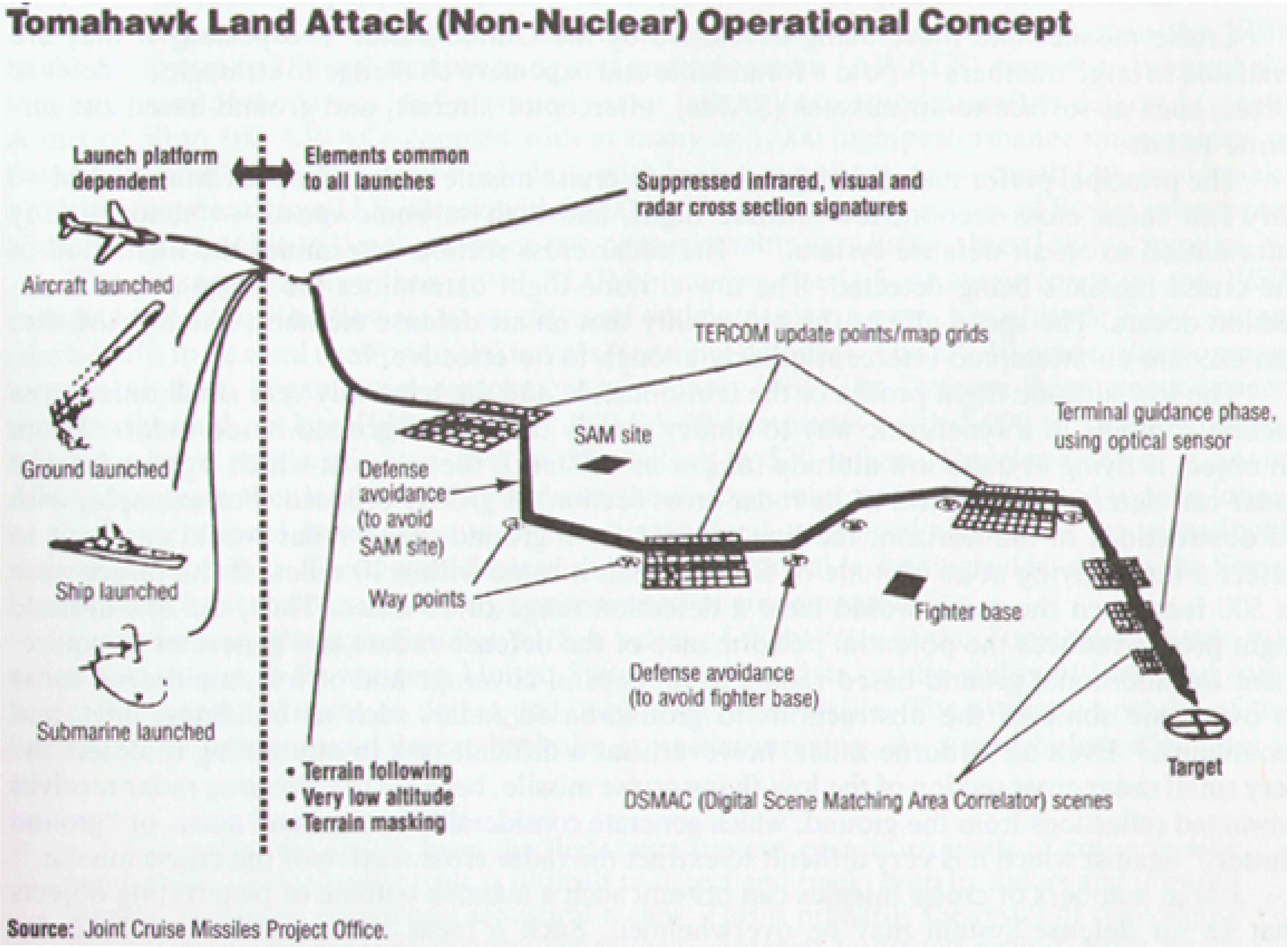


TERCOM: Terrain Contour Matching
DSMAC: Digital Scene Matching Area Correlation

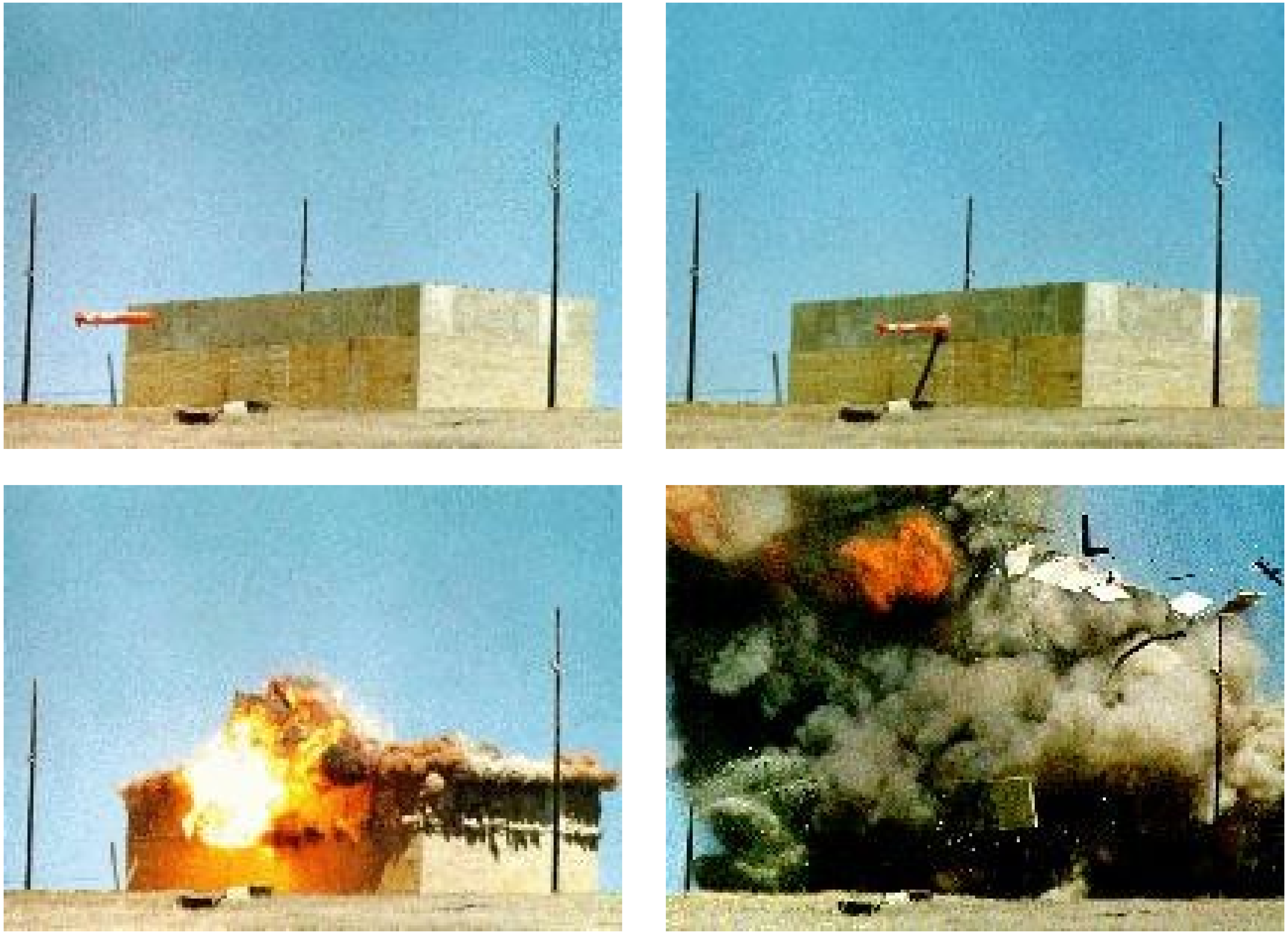
Cruise-Missile Guidance – 2



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

Part 4: Ballistic Missiles

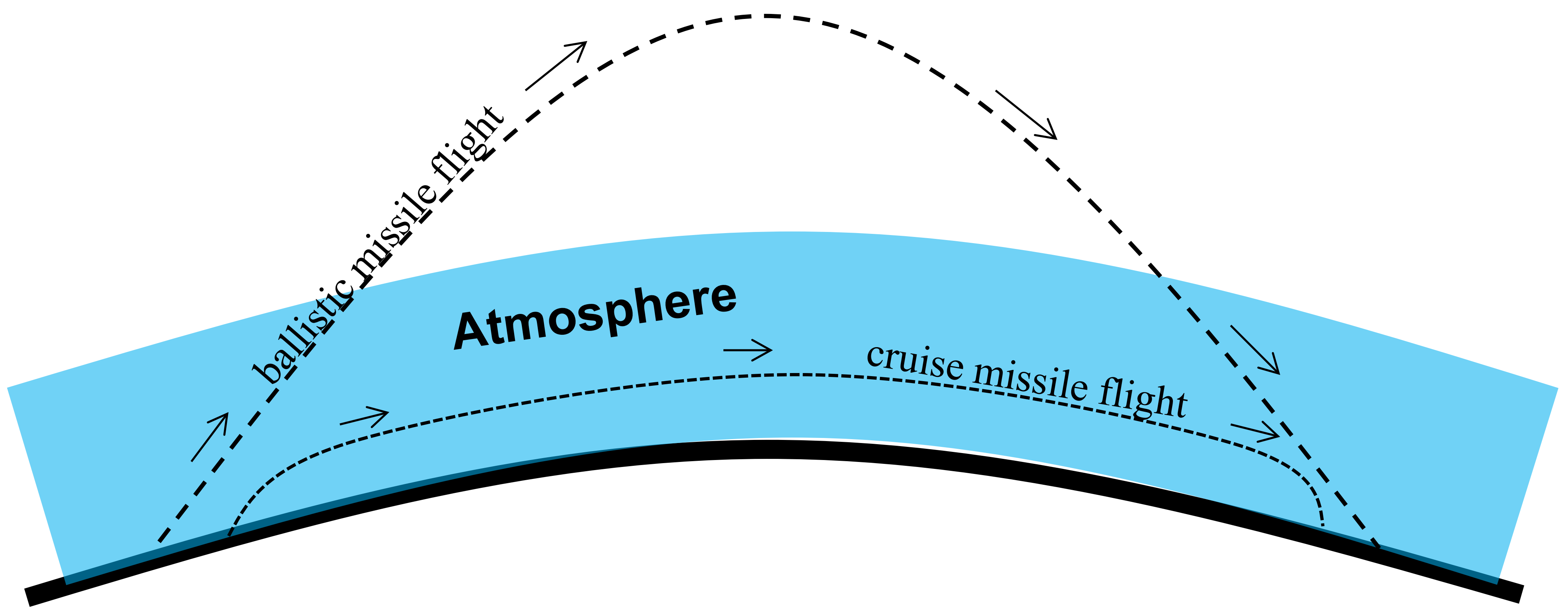
Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

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) —

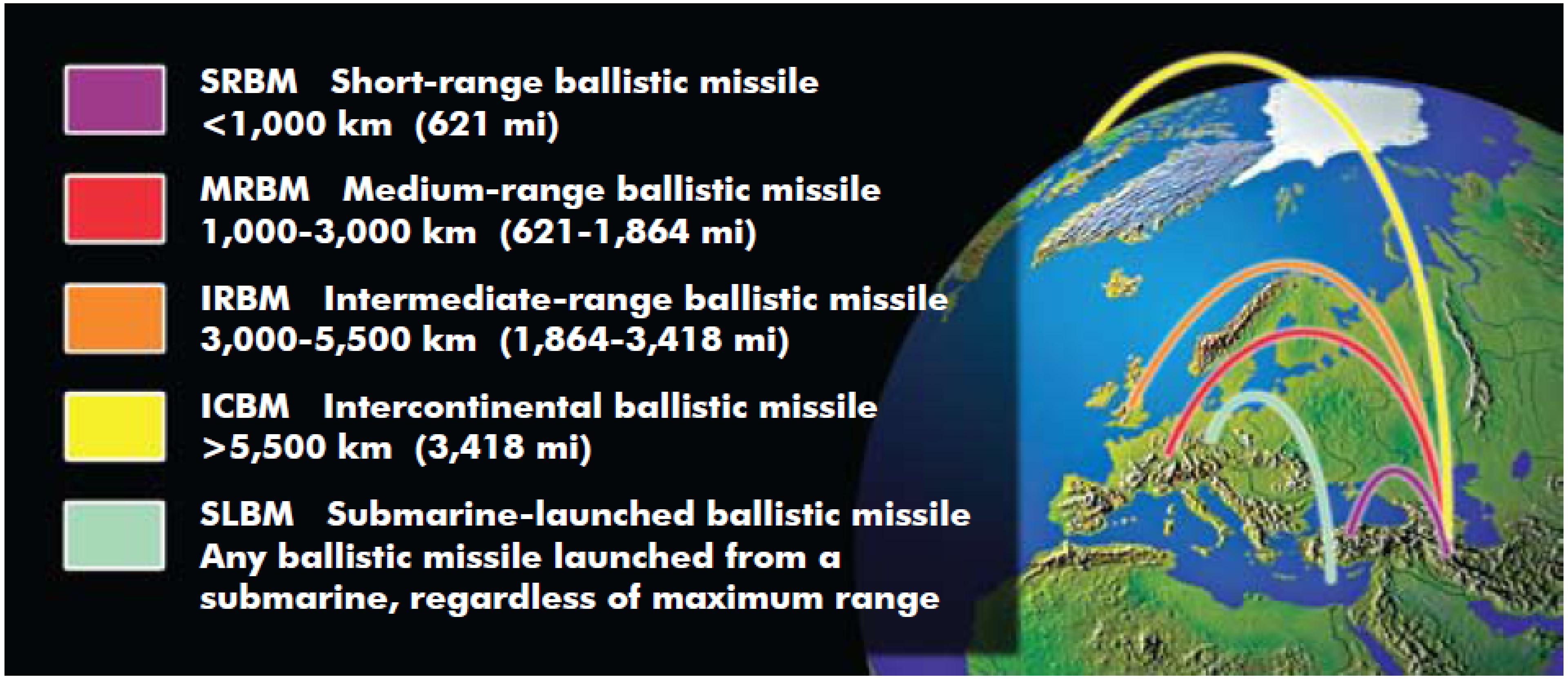
- Ranges between 3,000 km and 5,500 km

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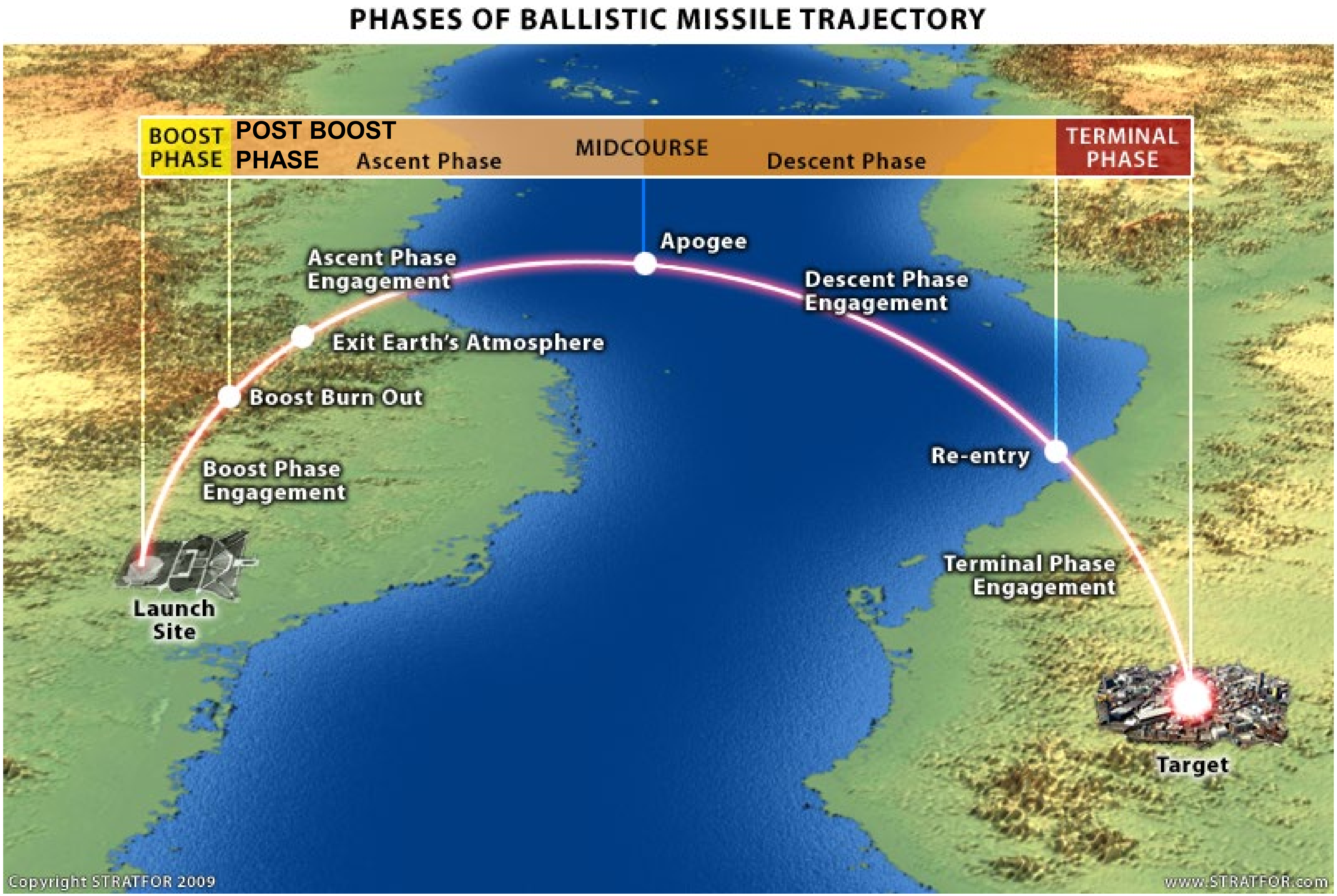
Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

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

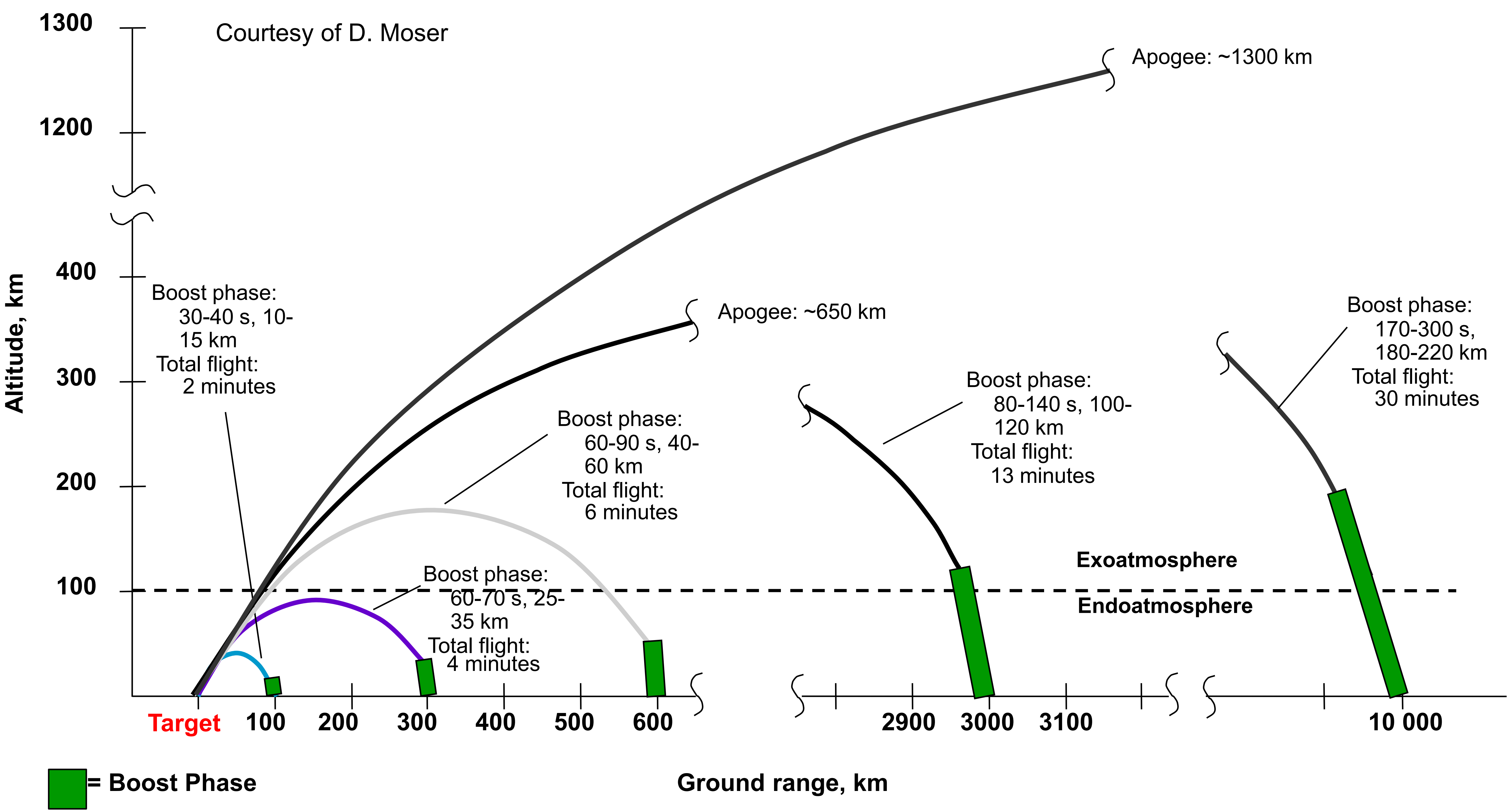
Stellar —

- Star trackers update inertial guidance system

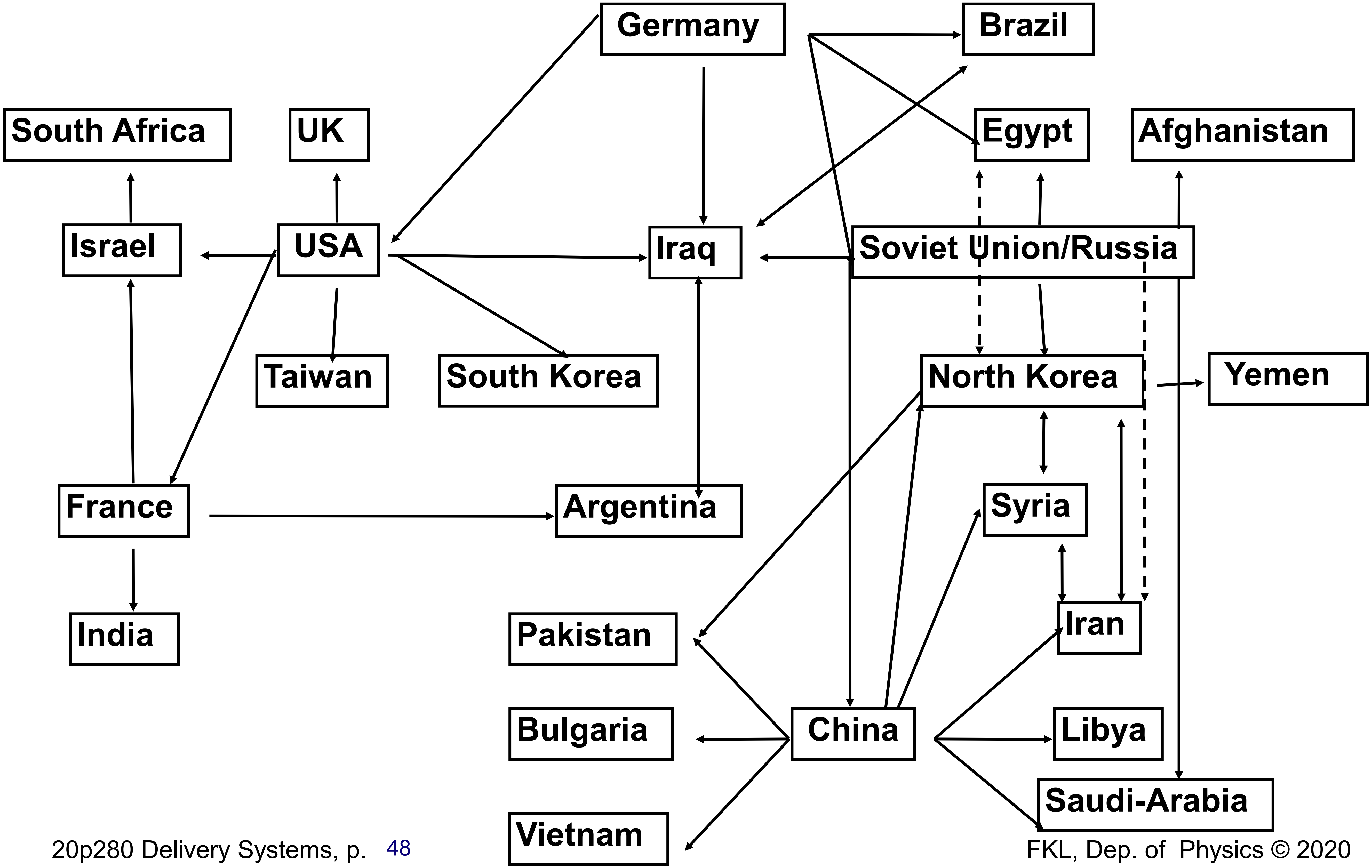
Satellite —

- 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

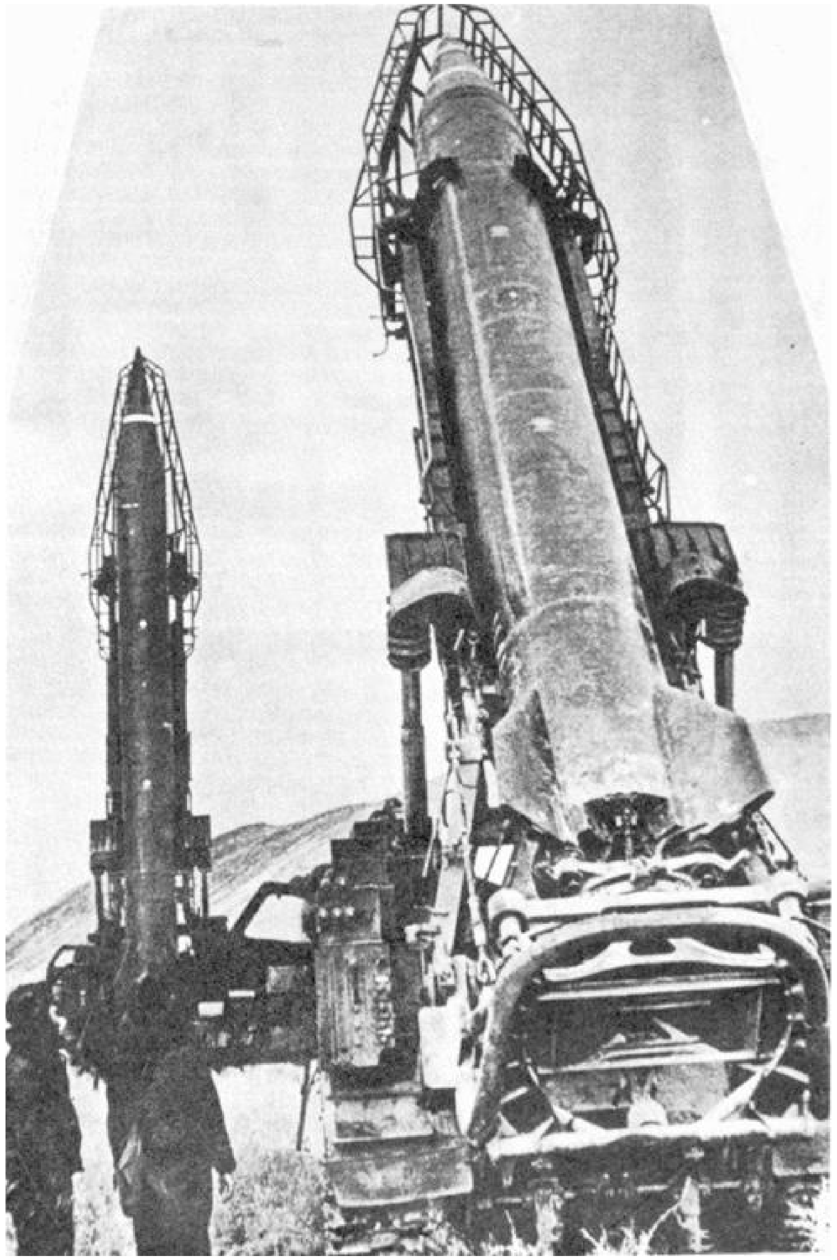
Trajectories and Phases of Flight of Missiles With Various Ranges



Proliferation of Ballistic Missile Technologies



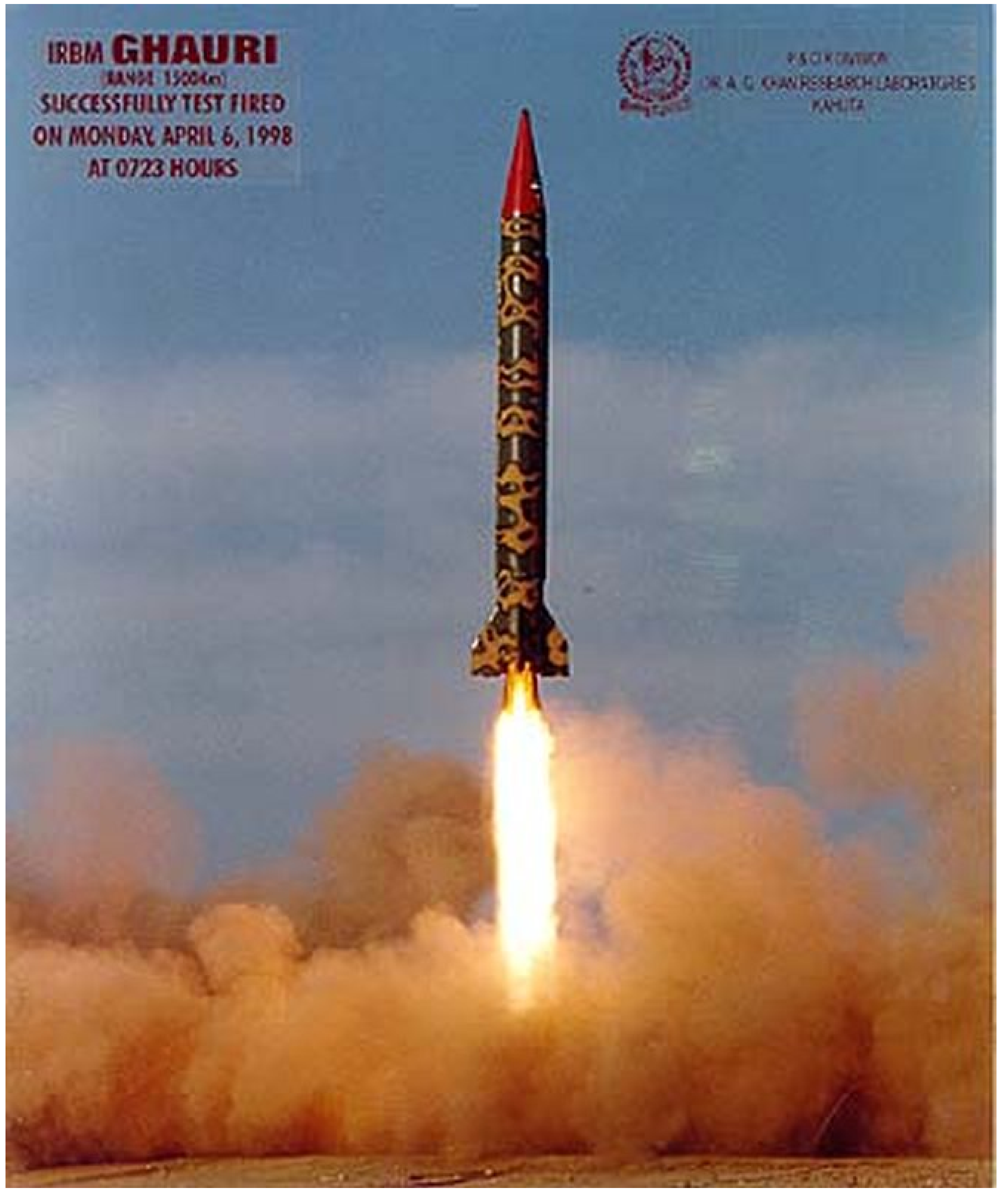
Soviet Scud Missiles and Derivatives - 1



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

Iraqi Al-Hussein SRBM
Range: 600–650 km

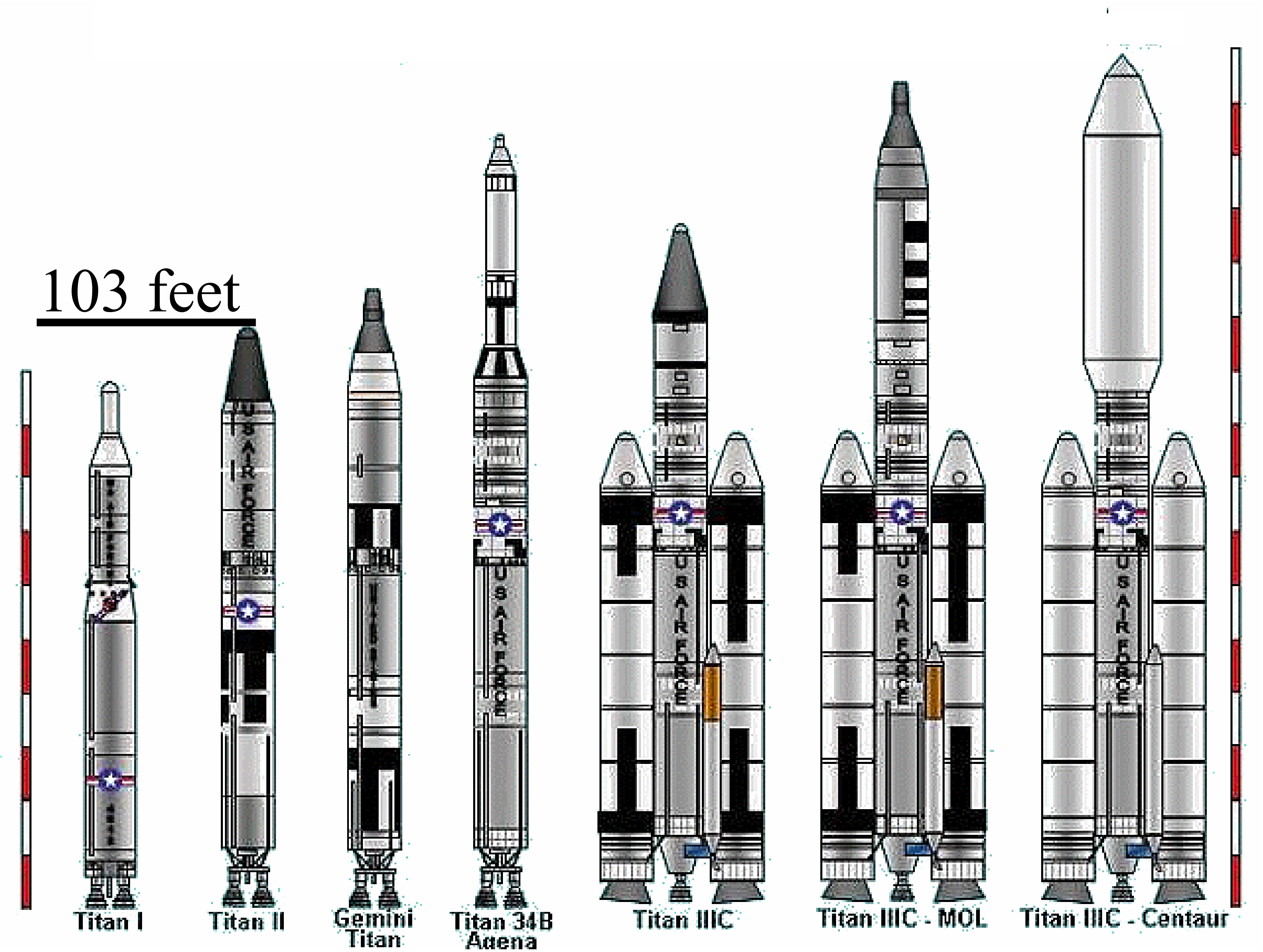
Scud Missiles and Derivatives – 2



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)

Plan for This Session

News

Midterm, Thursday, March 14th, 2.00-3.20 pm in 100 MSEB

(Material Science and Engineering Building)

- ➔ midterm will cover modules 1 to 5 + news
- ➔ old tests will be available on course web-page
- ➔ 50% of problems will be from old exam
- ➔ review session, Wednesday evening, March 13th

Module 5: Nuclear Weapon Delivery Systems

Movement at North Korea ICBM plant viewed as missile-related, South says

REUTERS

David Brunnstrom, Hyonhee Shin

WORLD NEWS MARCH 6, 2020 / 9:21 PM /

WASHINGTON/SEOUL (Reuters) - New activities have been detected at a North Korean intercontinental ballistic missiles plant, South Korean media said on Thursday, as U.S. President Donald Trump said he would be very disappointed if Pyongyang rebuilt a rocket site.

Movement of cargo vehicles was spotted recently around a factory at Sanumdong in Pyongyang, which produced North Korea's first intercontinental ballistic missiles (ICBMs) capable of reaching the United States, South Korea's JoongAng Ilbo and Donga Ilbo newspapers reported, citing lawmakers briefed by the National Intelligence Service on Tuesday. Spy chief Suh Hoon told the lawmakers he viewed the activity as missile related, the JoongAng Ilbo said. It quoted Suh as saying North Korea continued to run its uranium enrichment facility at the main Yongbyon nuclear complex after the first summit between Trump and its leader, Kim Jong Un, in June in Singapore.

The reports came after the leaders' second summit in the Vietnamese capital of Hanoi broke down last week over differences on the limits North Korea was ready to put on its nuclear program and how willing the U.S. was to ease sanctions.

The Sanumdong factory produced the Hwasong-15 ICBM, which can fly more than 13,000 km (8,080 miles). After its test flight in late 2017, North Korea declared the completion of its "state nuclear force," before pursuing talks with South Korea and the United States last year. South Korea's presidential office and defense ministry declined to confirm the reports on Sanumdong, saying they are closely monitoring North Korea's activities together with the United States.

Movement at North Korea ICBM plant viewed as missile-related, South says

David Brunnstrom, Hyonhee Shin

WORLD NEWS MARCH 6, 2020 / 9:21 PM /

There was no immediate response from the U.S. State Department.

On Tuesday, two U.S. think tanks and Seoul's spy agency said work was underway to restore part of the North's Sohae rocket launch site that Kim, at the Singapore summit, vowed to dismantle. "I would be very disappointed if that were happening," Trump told reporters in the Oval Office, when asked if North Korea was breaking a promise.

"It's a very early report. We're the ones that put it out. But I would be very, very disappointed in Chairman Kim, and I don't think I will be, but we'll see what happens. We'll take a look. It'll ultimately get solved."

Imagery from Planet Labs Inc. analyzed by the Center for Nonproliferation Studies at the Middlebury Institute of International Studies in California showed activity at Sohae from Feb. 23 until Wednesday. The Washington-based Stimson Center's 38 North said photos from Wednesday showed the rail-mounted transfer building used to move rockets at the site was now complete, cranes had been removed from the launch pad and the transfer building moved to the end of the pad. "But we don't draw any conclusions from that besides they are restoring the facility," Joel Wit of 38 North told Reuters. "There is no evidence to suggest anything more than that." A U.S. government source said the work at Sohae probably began before the summit, which was preceded by lower-level talks in February.

Movement at North Korea ICBM plant viewed as missile-related, South says

REUTERS

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WORLD NEWS MARCH 6, 2020 / 9:21 PM /

Some analysts see the work at Sohae as aimed at pressing Washington to agree to a deal, rather than as a definite move to resume tests. The U.S. government source, who did not want to be named, said North Korea's plan to rebuild at the site could have been designed to offer a demonstration of good faith by conspicuously stopping again if a summit pact was struck, while furnishing a sign of defiance or resolve if the meeting failed. Trump's national security adviser, John Bolton, has warned of new sanctions if North Korea does not scrap its weapons program. There have been signs across Asia that Trump's "maximum pressure" campaign against North Korea has sprung leaks.

In a new sanctions breach, three South Korean companies were found to have brought in more than 13,000 tons of North Korean coal, worth 2.1 billion won ($2 million) since 2017, by making it out to have been produced in China and Vietnam, South Korea said. The Hanoi summit's breakdown, and Bolton's sanctions threat, raise questions about the future of the dialogue Trump has pursued.

Movement at North Korea ICBM plant viewed as missile-related, South says

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WORLD NEWS MARCH 6, 2020 / 9:21 PM /

Democrat Ed Markey, ranking member of the Senate East Asia Subcommittee, expressed concern about the activity at Sohae, a site he said Trump had used to argue his approach toward Kim was working.

"North Korea's apparent work at this launch site raises the troubling possibility that yet again Kim Jong Un is more interested in garnering concessions than conducting serious, good faith efforts to denuclearize," the senator said.

U.S. Secretary of State Mike Pompeo said on Monday he hoped to send a delegation to North Korea in the coming weeks but had "no commitment yet". North Korea's official media lauded Kim's Vietnam trip but its vice foreign minister, Choe Son Hui, warned Kim might lose his willingness to pursue a deal.

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

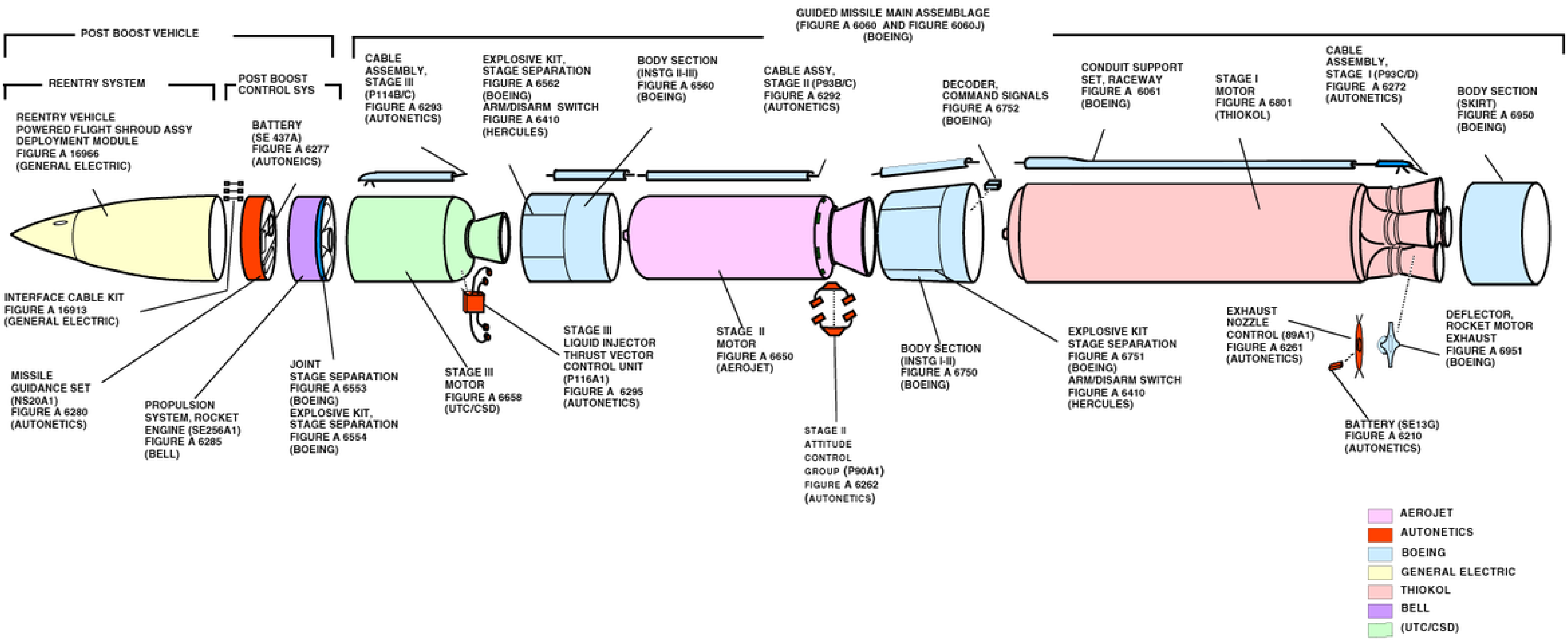
Soviet ICBM MIRV

MIRV Technology

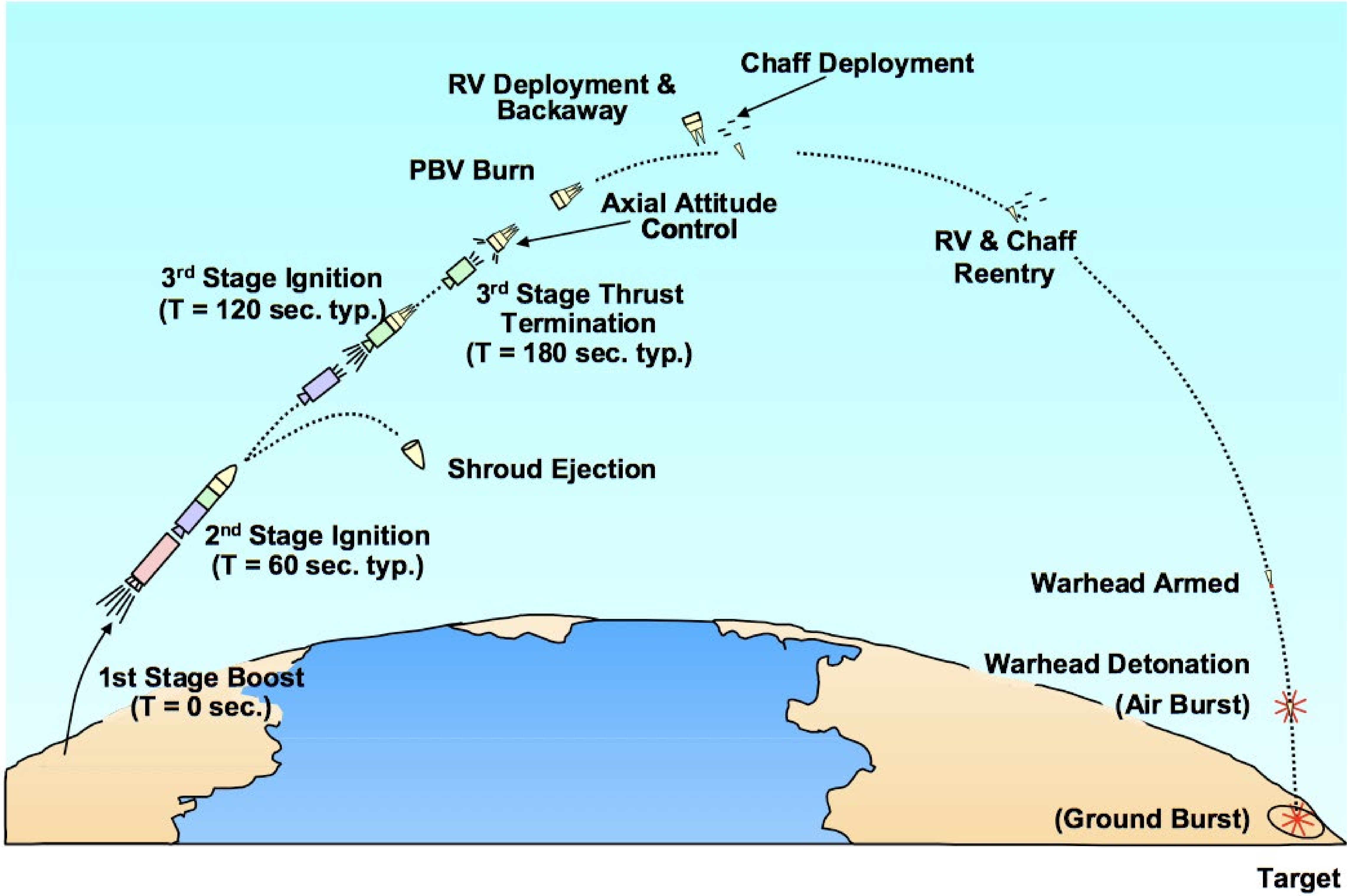
MX Peacekeeper missile tested at Kwajalein Atoll

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,
  Capability for 3 warheads (Minuteman)
  Presently deployed with 1 warhead

Recent Russian ICBMs —

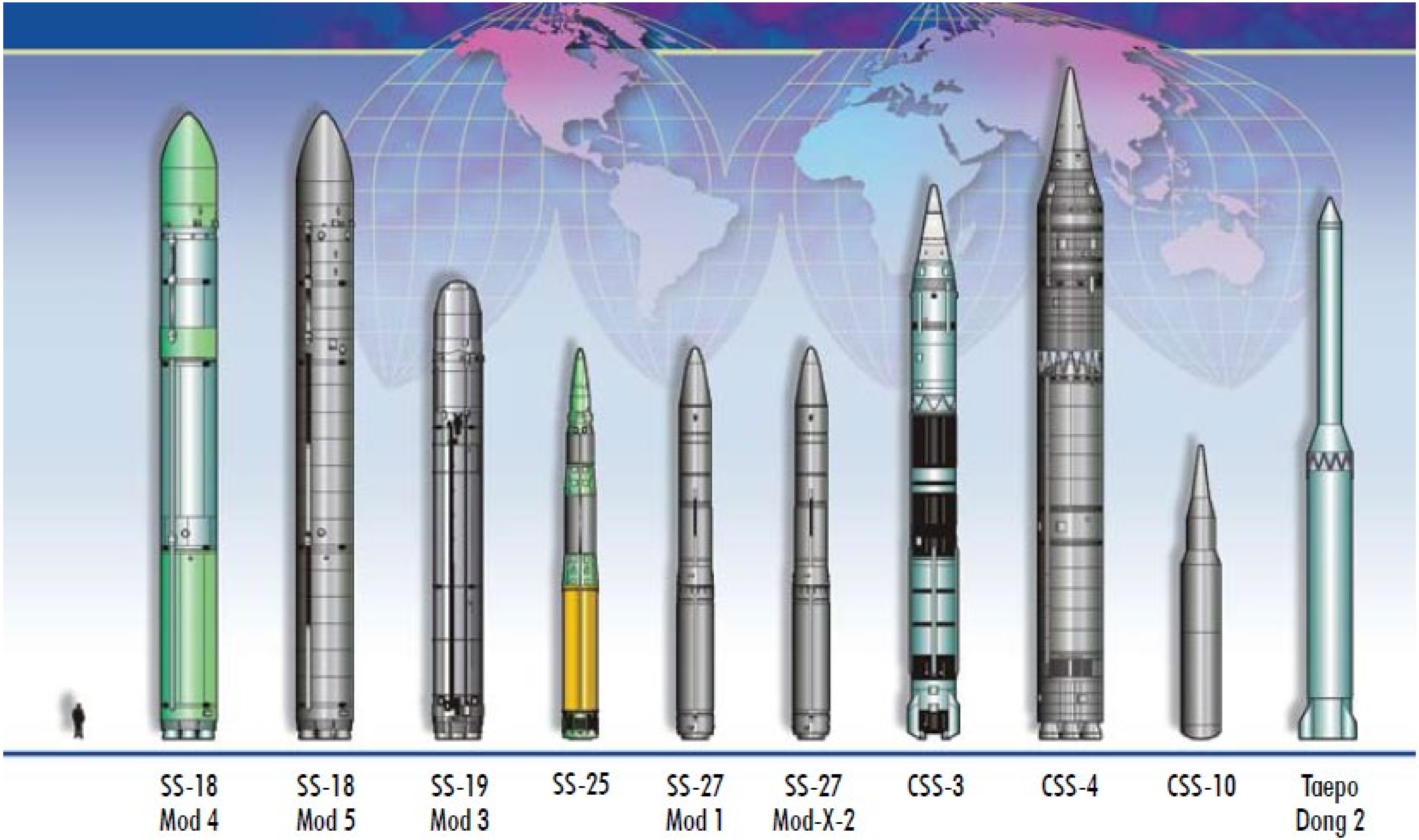
- SS-24 Solid-propellant, range > 9,000 km
- SS-25 Solid-propellant, range > 9,000 km
- SS-27 Solid-propellant, range > 9,000 km

US ICBMs – 2

Launch of a Minuteman ➔ video!

Launch of an MX

Russian, Chinese and North Korean\ ICBMs – 1



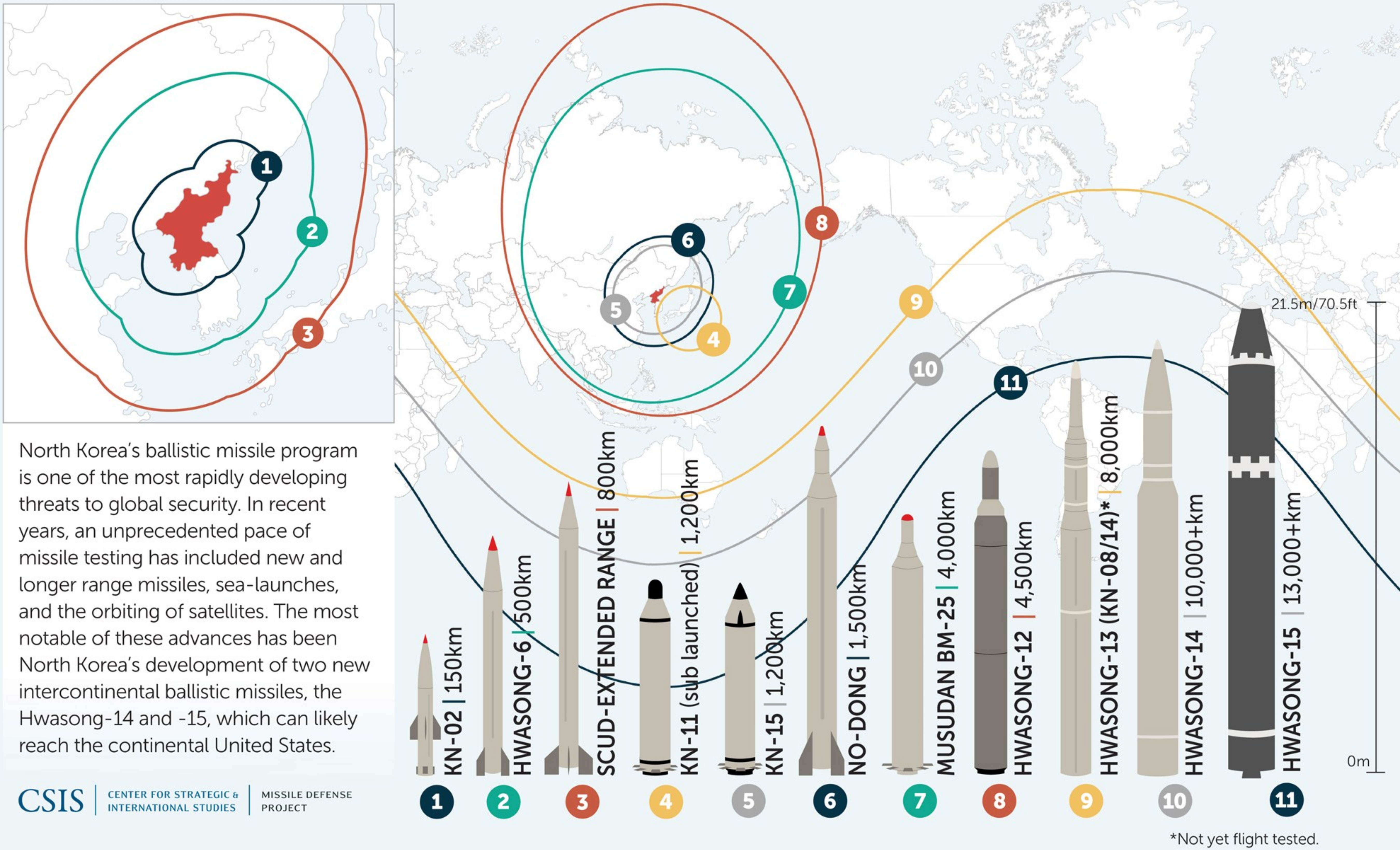
Source: national air and space intelligence center
"Ballistic and Cruise Missile Threat", 2009

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**

NORTH KOREA'S BALLISTIC MISSILES



North Korea's ballistic missile program is one of the most rapidly developing threats to global security. In recent years, an unprecedented pace of missile testing has included new and longer range missiles, sea-launches, and the orbiting of satellites. The most notable of these advances has been North Korea's development of two new intercontinental ballistic missiles, the Hwasong-14 and -15, which can likely reach the continental United States.

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Russian, Chinese and North Korean ICBMs – 4

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

THAAD and China's Nuclear Second-Strike Capability

News

China may be afraid that THAAD will degrade its own nuclear second-strike capability.

THE | DIPLOMAT
Read The Diplomat, Know the Asia-Pacific

By Ankit Panda
March 08, 2017

Earlier this week, hours after North Korea's launch of a four-missile salvo into the Sea of Japan, the United States delivered and began deployment of part of the Terminal High-Altitude Area Defense (THAAD) system. "Continued provocative actions by North Korea, to include yesterday's launch of multiple missiles, only confirm the prudence of our alliance decision last year to deploy THAAD to South Korea," said the head of U.S. Pacific Command, Admiral Harry Harris, underlining the rationale behind the decision.

China, South Korea's neighbor and the United States' great power competitor in Asia, has long been vocally opposed to the deployment of THAAD on the Korean peninsula. In response to the deployment, Geng Shuang, a Chinese foreign ministry spokesperson, noted that China was "resolutely against the deployment of THAAD by the US and the ROK in the ROK, and will take firm and necessary steps to safeguard our security interests."

For starters, let's put to rest the misconception that China's opposition to the THAAD deployment is because it is worried about the interceptor shooting down its missiles. As the 'T' indicates in THAAD, the system is only capable of intercepting projectiles in their "terminal" phase (or as they're hurtling towards the earth in descent). Unless China would consider firing ballistic missiles at South Korea, THAAD will do no good against its missiles (say, it's intercontinental ballistic missiles going toward the United States in a nuclear exchange).

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For China, opposition to THAAD is simple: it's all about the X-band AN/TPY-2 radar unit that accompanies the interceptor battery and aids in targeting. The radar unit has yet to be delivered; it is expected to arrive in South Korea in April.

To be clear, China hasn't been coy about specifically pointing to the radar issue. In fact, it has been explicit. Chinese Foreign Minister Wang Yi has made multiple references to the "X-band radar" that accompanies the THAAD battery, pointing out last February that it "goes far beyond the defense need of the Korean Peninsula." This isn't a case of Beijing nebulously stating its opposing to the deployment in terms of its national interest.

Two Competing Hypotheses

There are two possible serious explanations for how THAAD infringes on Chinese national interests. One is less convincing than the other. I'll address both in order, beginning with the less convincing explanation.

The first hypothesis is that China may fear that the AN/TPY-2 radar at the former Lotte Group golf course in Gyeongsangbuk-do will give the United States unprecedented surveillance insight into sensitive Chinese missile testing and development work deep within the mainland.

This may sound convincing at first glance, but there's a few reasons why it doesn't hold water. First, the South Korean THAAD deployment is *not* the first AN/TPY-2 deployment from the United States; nor is it even the first deployment of an advanced radar by the United States to the region. The U.S. already has two AN/TPY-2 installations in Japan, at the Kyogamisaki Communications Site in Kyoto prefecture and Shariki in Aomori prefecture.

Second, while we have no watertight estimates on just how capable the AN/TPY-2 radar is and in what configurations, even the most generous estimates don't leave the Gyeongsangbuk-do unit capable of any useful surveillance deep into the Gobi desert, where China has its most active and sensitive missile testing ranges. (AN/TPY-2 range estimates go from "several hundred miles" to 3,000 km.) I've mapped out the ranges below with the most generous range estimate of 3,000 km, using a

News

THAAD and China's Nuclear Second-Strike Capability

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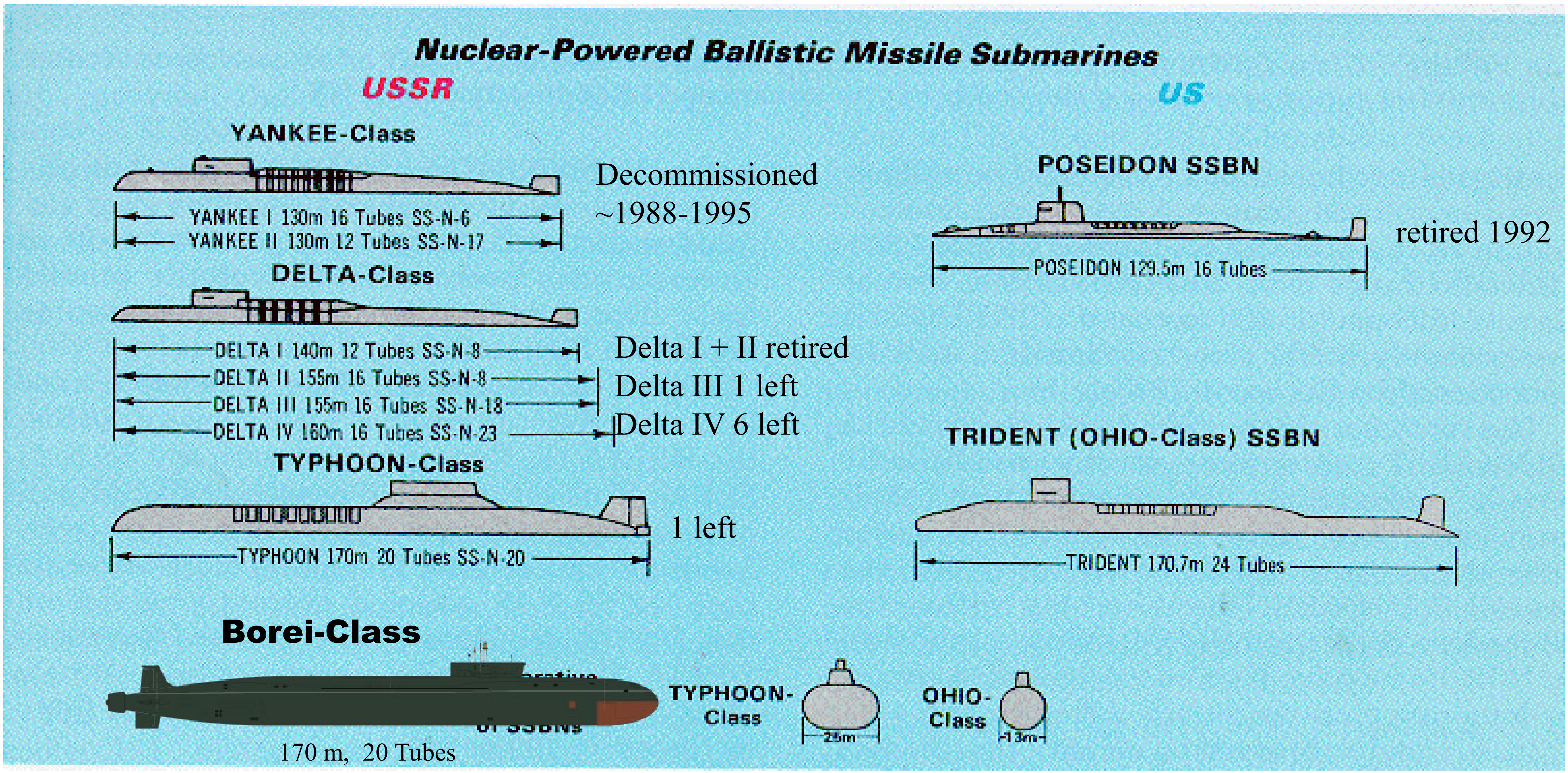
The second hypothesis is, I think, more convincing, and one where Beijing may have legitimate concern about the Gyeongsangbuk-do AN/TPY-2 radar upsetting U.S.-China strategic nuclear stability. Specifically, China may — correctly or incorrectly — fear that its nuclear second-strike capability is significantly degraded as a result of a third U.S. AN/TPY-2 radar going up specifically near the southern tip of the Korean peninsula.

To avoid the need for a massive nuclear build-up and to feel comfortable with its several hundred or so nuclear warheads for targeting, China needs to feel comfortable enough its intercontinental ballistic missiles can reliably penetrate U.S. antiballistic missile countermeasures. Pre-THAAD-in-South-Korea, a Chinese ICBM launch would still have been exposed to the AN/TPY-2s in Japan, but that exposure alone wouldn't have been enough to reliably help U.S. ground-based interceptors (GBI) in Alaska get a convincing edge against incoming Chinese warheads. (Set aside GBI's patchy success record for the moment.)

With a third AN/TPY-2 in South Korea, the resolution of U.S. data on incoming Chinese warheads would potentially be greatly enhanced. Specifically, China may fear that penetration aids for its ICBMs — such as decoy warheads — would be degraded, lowering the certitude that its existing arsenal would be sufficient for penetrating past the U.S. ABM apparatus. Theoretically, a triangulated AN/TPY-2 setup between Japan and South Korea could give U.S. midcourse interceptors in Alaska enough warning to have a better shot at an incoming Chinese missile.

Moreover, specifically, a Gyeongsangbuk-do-based AN/TPY-2 would also potentially have a unique vantage point for differentiating real warheads from decoys. Li Bin, writing for the *Kyunghyang Daily*, outlines this case in greater detail: "The THAAD radar to be deployed in the ROK would be in a very special position where it could view the back of the Chinese warheads flying over the northeast part of China when it is deployed to watch missiles from North Korea."

US and Russian SSBNs



US Trident SSBN (14 SSBNs, 4 SSGNs)

Trident Missile Tubes
With Covers Open

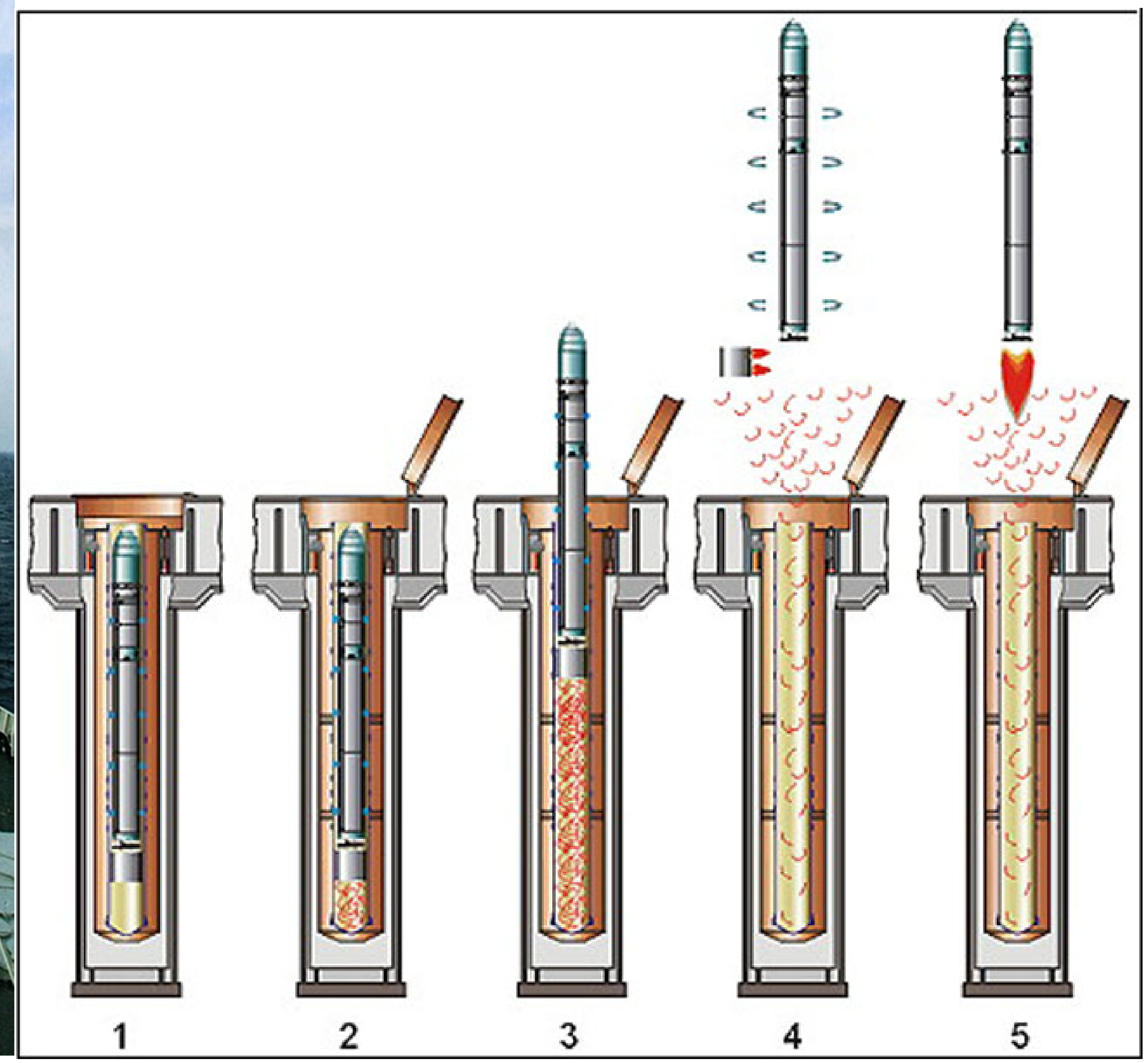
24 Trident C4 SLBMs
8 MIRVs with 100kt W76
➔ up to192 targets
SLBM range 7400 km

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

Launch video

Submarine-Based Missiles

US SLBMs —

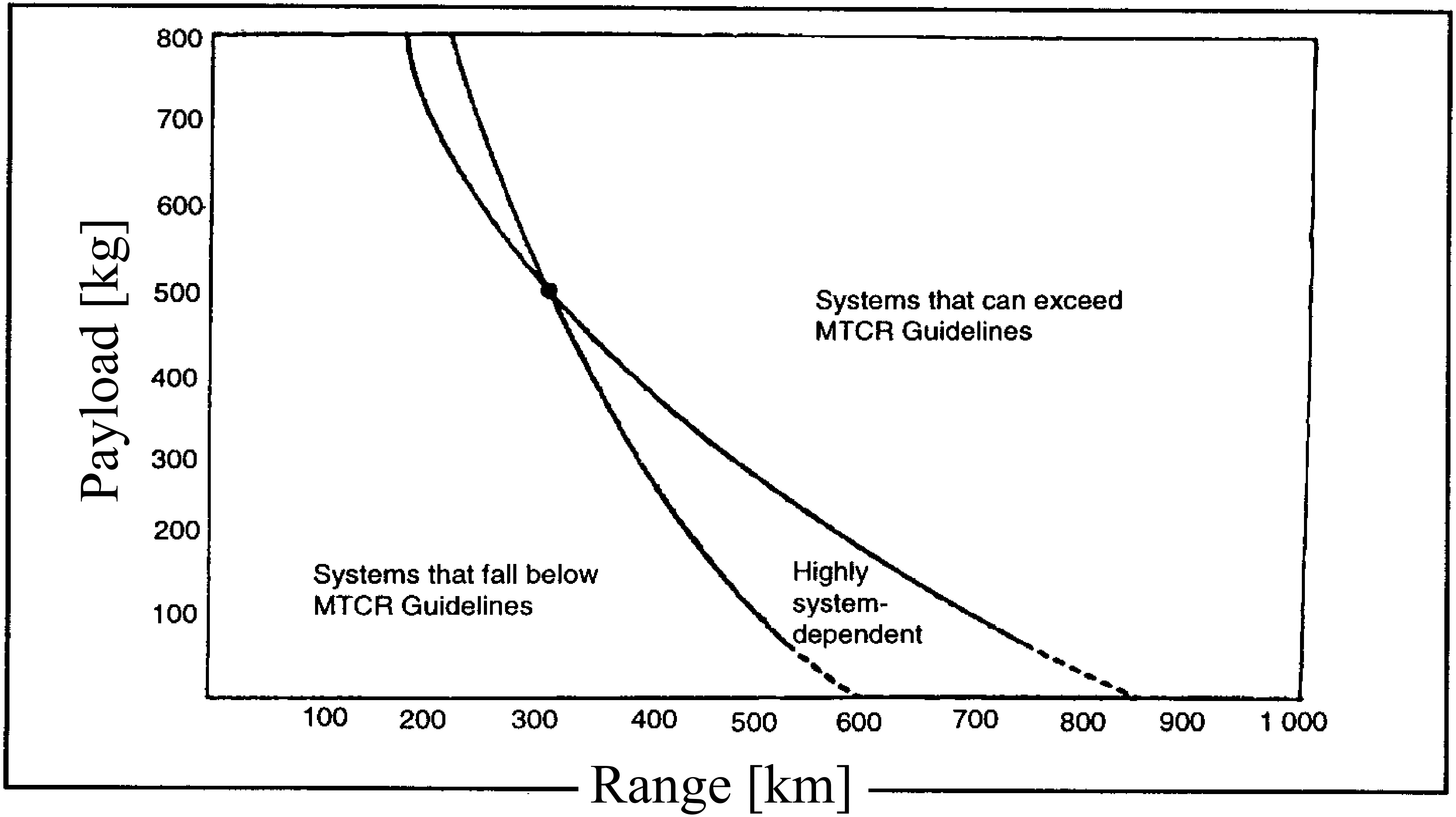
- Trident C4 missiles carried 8 MIRVs each (solid propellant, range 7400 km)
- Trident D5 missiles carry 8 MIRVs each (solid propellant, range 7400 km)

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)

Part 5: Technical and Operational Aspects

MTCR: Range-Payload Limits

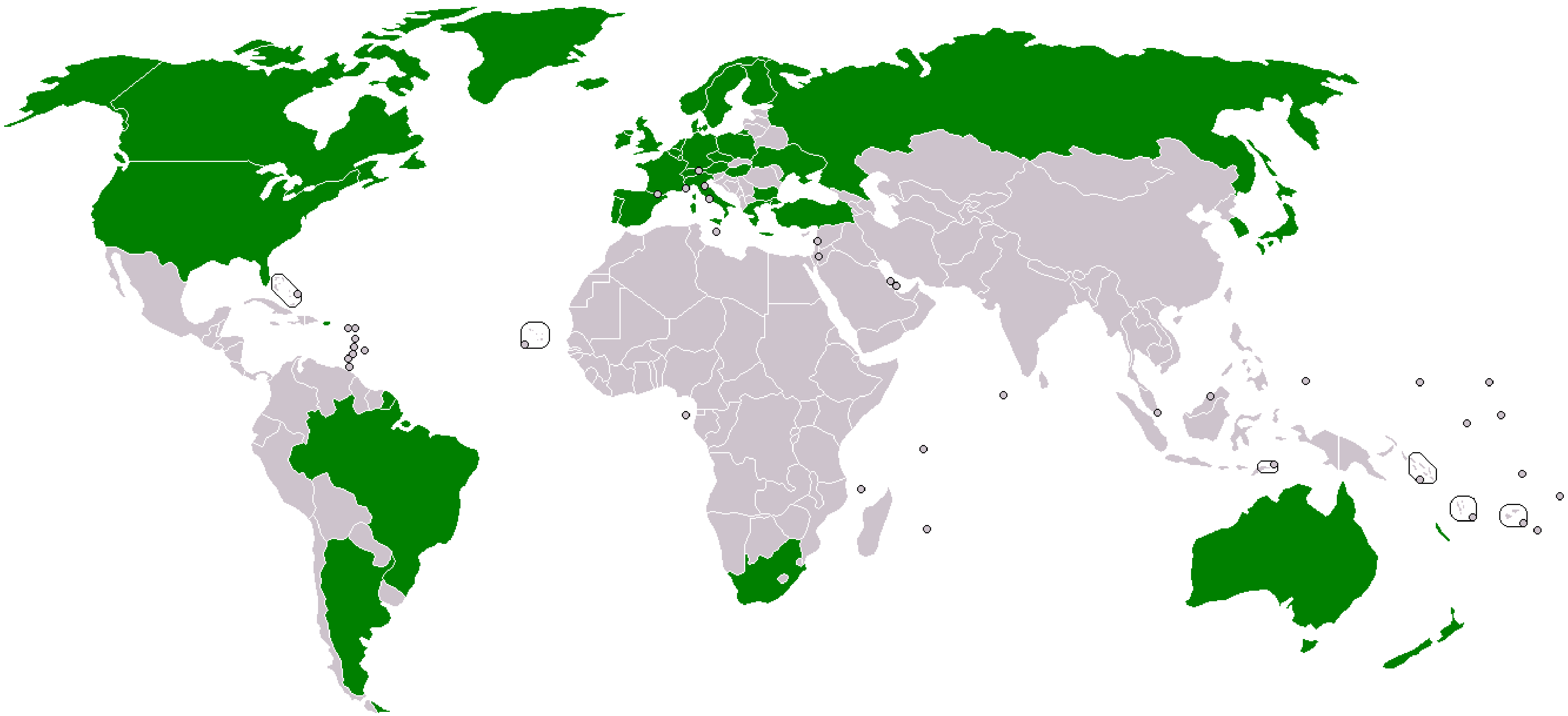


MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

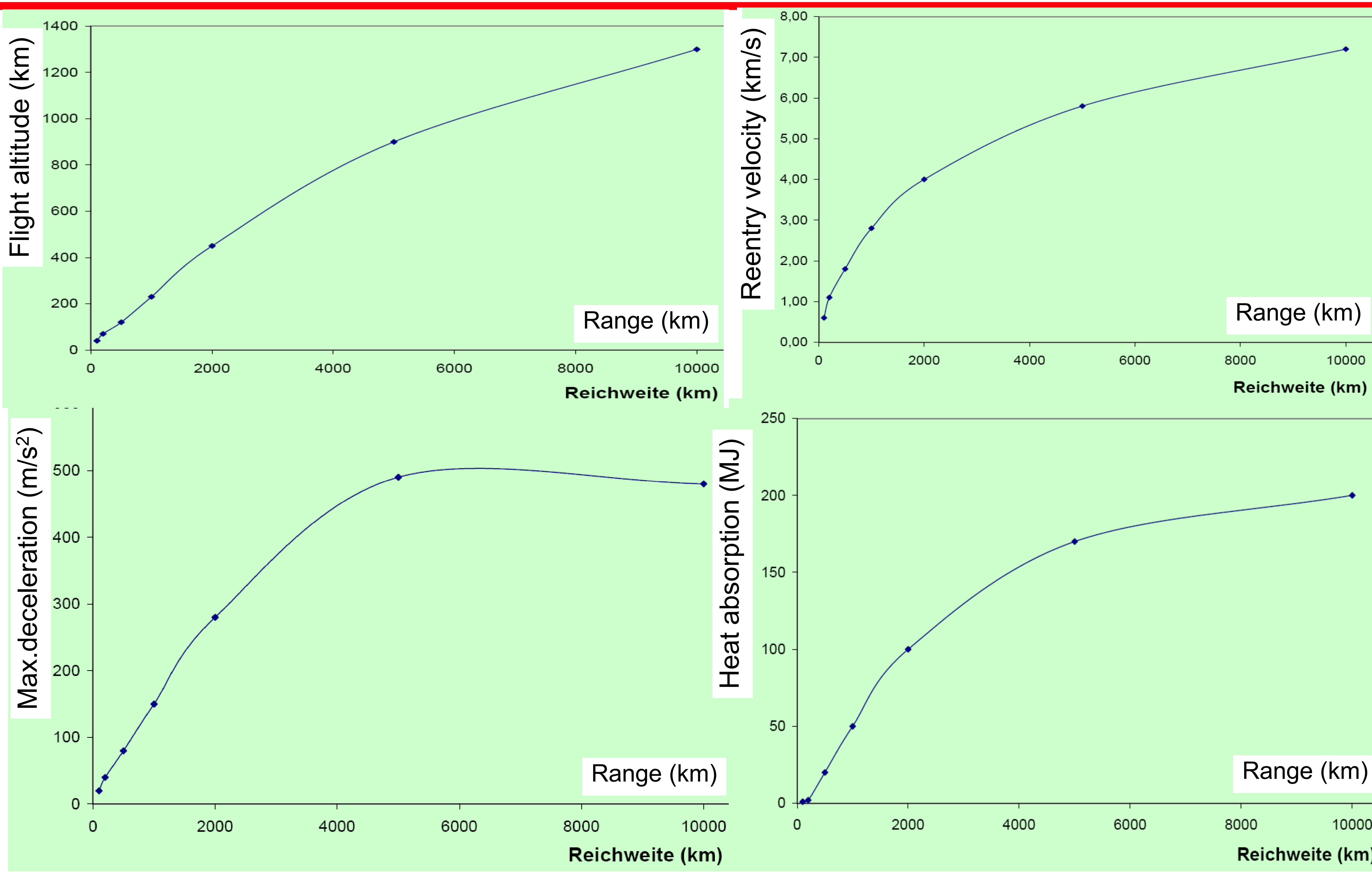
A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 157

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



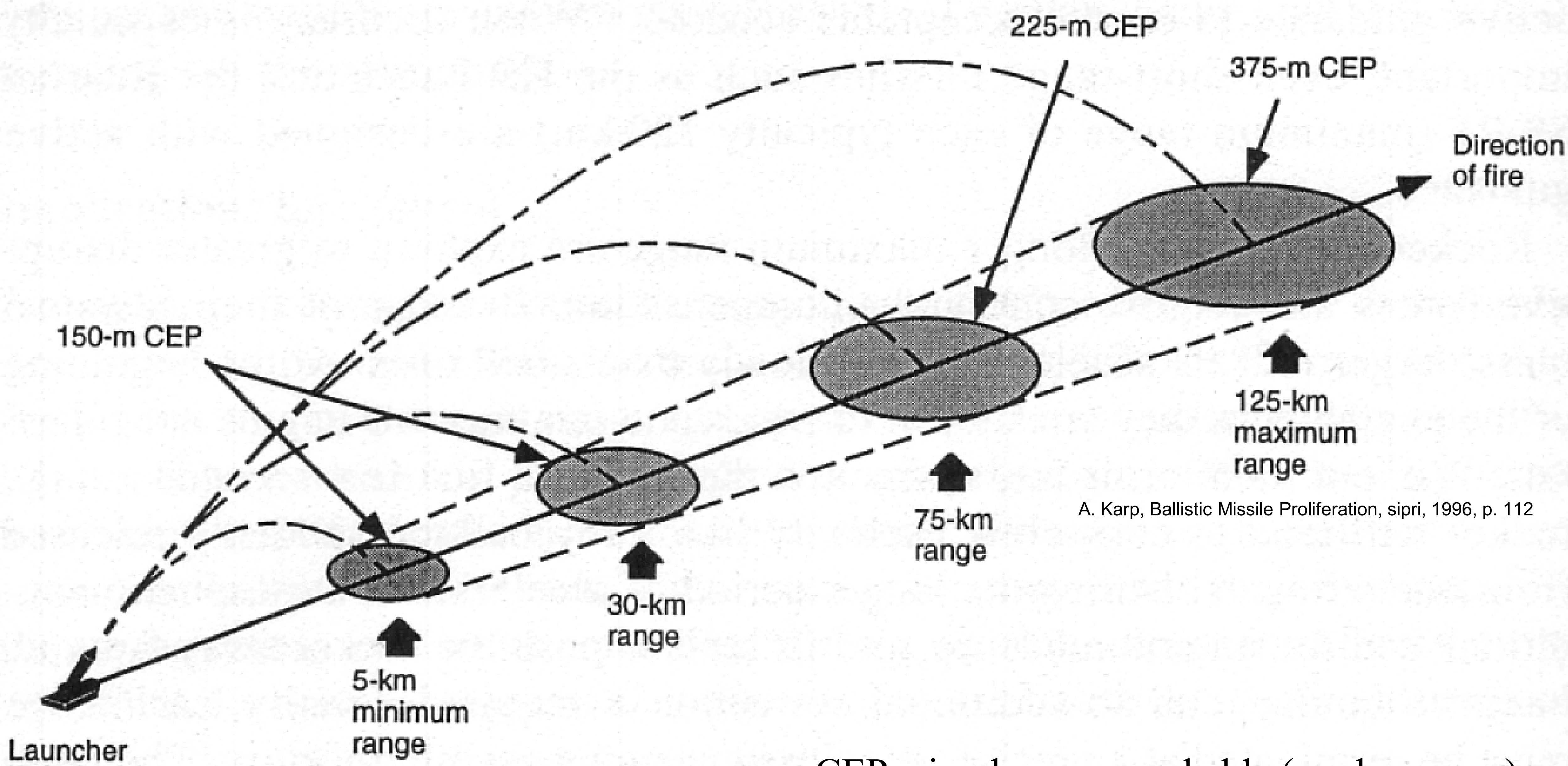
How Does this Translate into Challenges During Re-Entry into the Atmosphere?

Large frictional forces on re-entry lead to

➔deceleration up to 500 m/s^2 = 51 g
~ car with 70mph into concrete wall
g-forces can be lethal if > 25 g

➔200 MJ of energy is enough to heat
W76 warheads to the melting temperature
of iron ~ 1540 C !

Missile Range–Accuracy Tradeoff



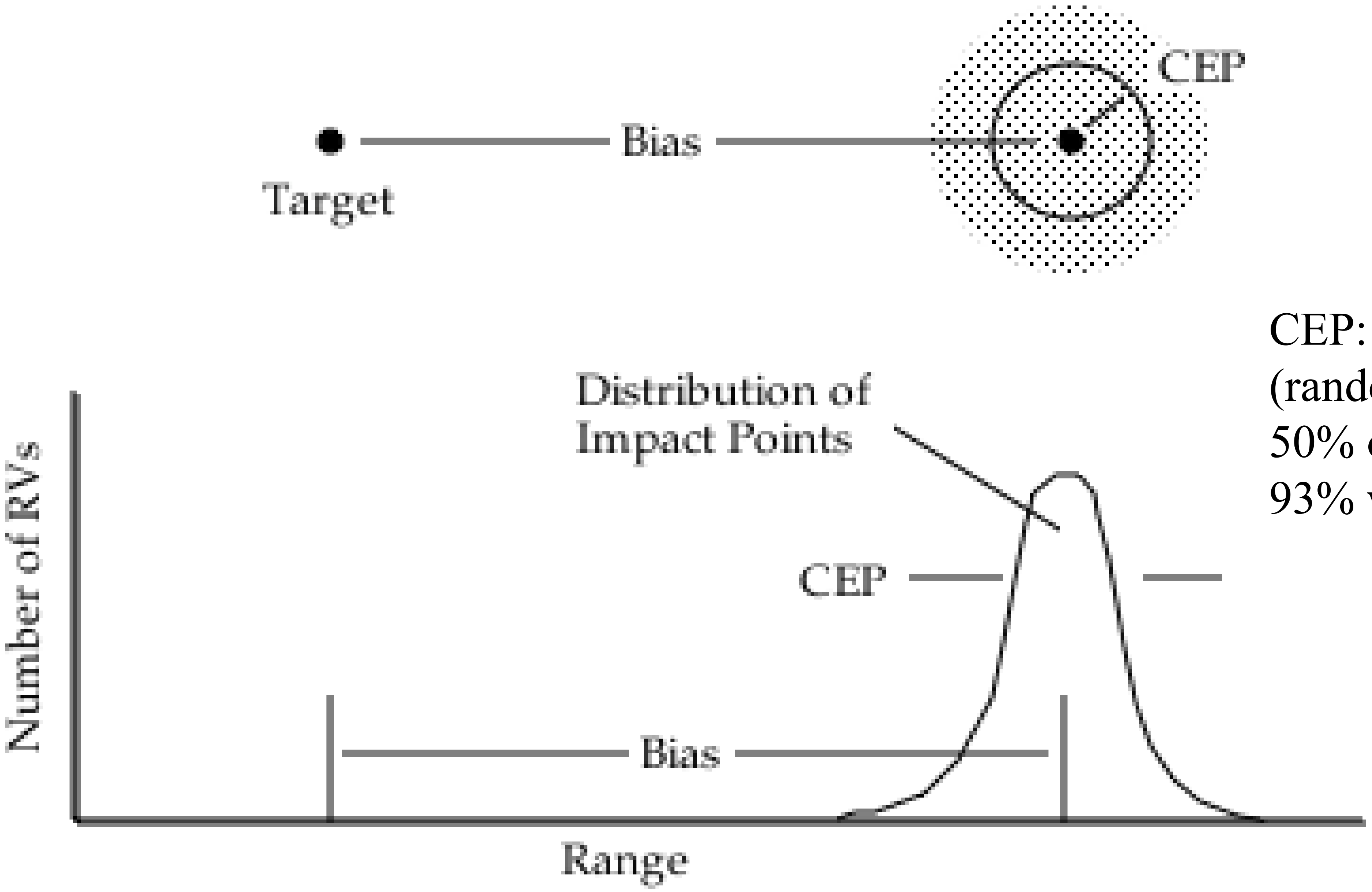
A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 112

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.

Physics/Global Studies 280: Session 17

Plan for This Session

News

Midterm, Thursday, March 14th, **2.00-3.20 pm in 100 MSEB**

(Material Science and Engineering Building)

- ➔ midterm will cover modules 1 to 5 + news
- ➔ old tests will be available on course web-page
- ➔ 50% of problems will be from old exam
- ➔ Review session, Wednesday evening,
  March 13th, 5-7pm in Loomis 144.
- ➔ Conflict exam, March 13th, 5 – 6.20 pm, Loomis 428

Module 5: Nuclear Weapon Delivery Systems

News

France is prepared to extend its nuclear deterrent to Germany

By William Drozdiak
February 28

Washington Post

William Drozdiak is the author of "Fractured Continent: Europe's Crises and the Fate of the West." His forthcoming book about French President Emmanuel Macron and the future of Europe will be published early next year. As exasperation grows in Europe about U.S. leadership of the Atlantic alliance, **France has taken the bold and unprecedented step of pledging to extend its nuclear deterrent to cover German territory in the case of armed aggression**. The French action comes as perhaps the strongest signal yet that European governments are reevaluating basic defense doctrines that have underpinned the Western alliance for the past 70 years. Senior officials in France and Germany say Europe needs new security concepts that address the rise of China, the return of Russia as a belligerent actor and the disengagement of the United States.

The implicit French promise is contained in a 16-page treaty signed in the town of Aachen, Germany, last month by German Chancellor Angela Merkel and French President Emmanuel Macron. The treaty is designed to deepen cooperation in military and foreign policy between the two leading powers of the European Union.

The treaty commits the two countries to "providing aid and assistance by all means at their disposal, including armed forces, in case of aggression against their territory." During an hour-long interview at the Elysee Palace in Paris, for a book I am writing about him and the future of Europe, Macron acknowledged that "all means" would include the French nuclear deterrent force.

In the past, France has regarded its nuclear arsenal, estimated to include about 300 nuclear warheads mainly aboard submarines, as a strictly national force. Germany has been reticent about embracing a European deterrent because of strong anti-nuclear sentiment at home and a reluctance to weaken U.S. commitments.

But the accelerating estrangement with the United States, coupled with uncertainty about Britain's future defense role on the continent if it leaves the European Union, have compelled France and Germany to reconsider the foundations of European security. French and German officials say there are growing strategic differences with the United States over how to deal with Russia, Iran, China, global trade and multilateral institutions. They contend European leaders have begun to realize that these conflicting approaches are not likely to end with the Trump presidency.

The binding character of the Aachen treaty is striking in that it goes well beyond the NATO treaty's Article Five, which commits a member state to take only "such action as it deems necessary" to come to the aid of a fellow ally under armed attack.

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

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.

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 (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) 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.

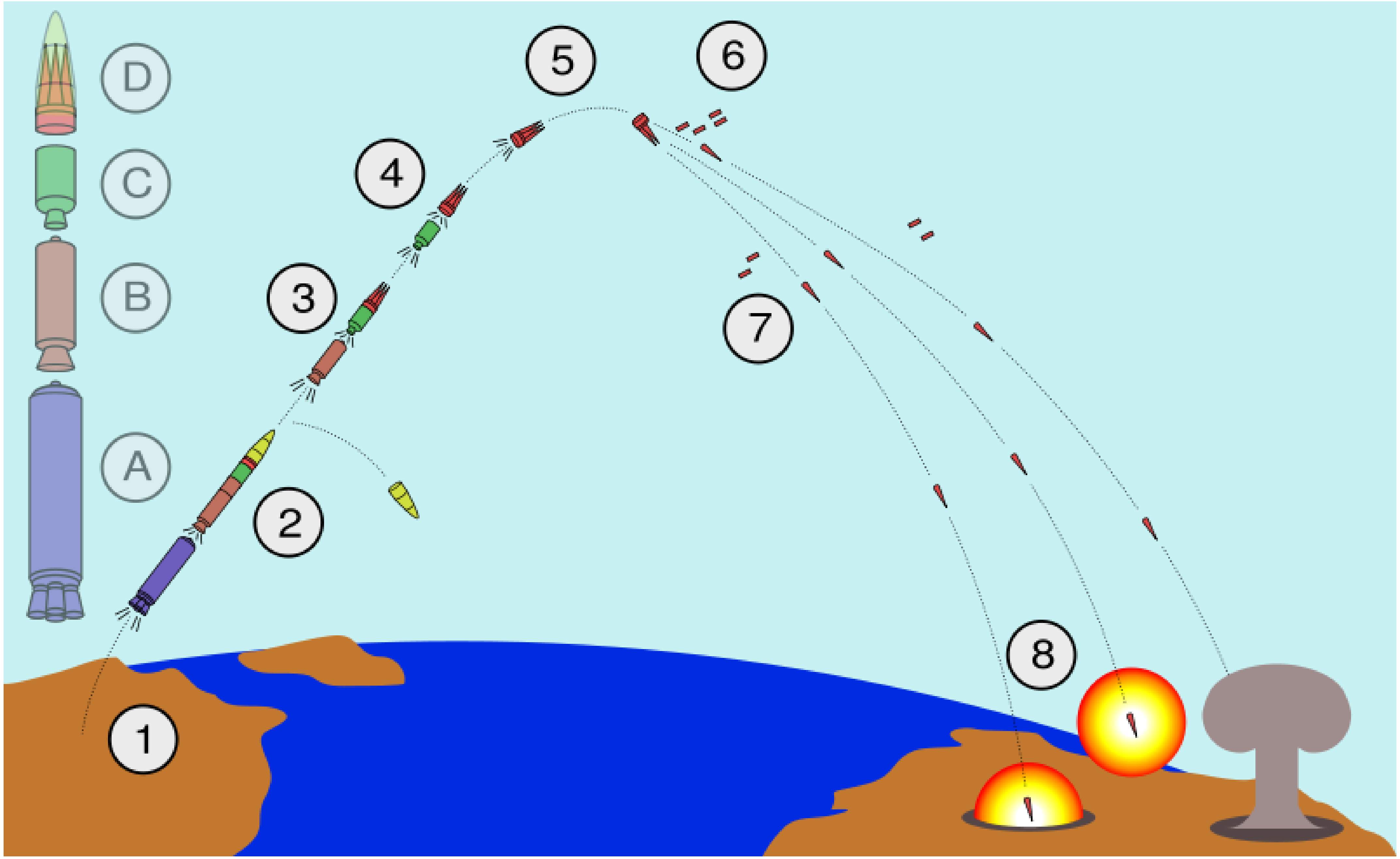
Possible Risk Reduction Measures

- 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

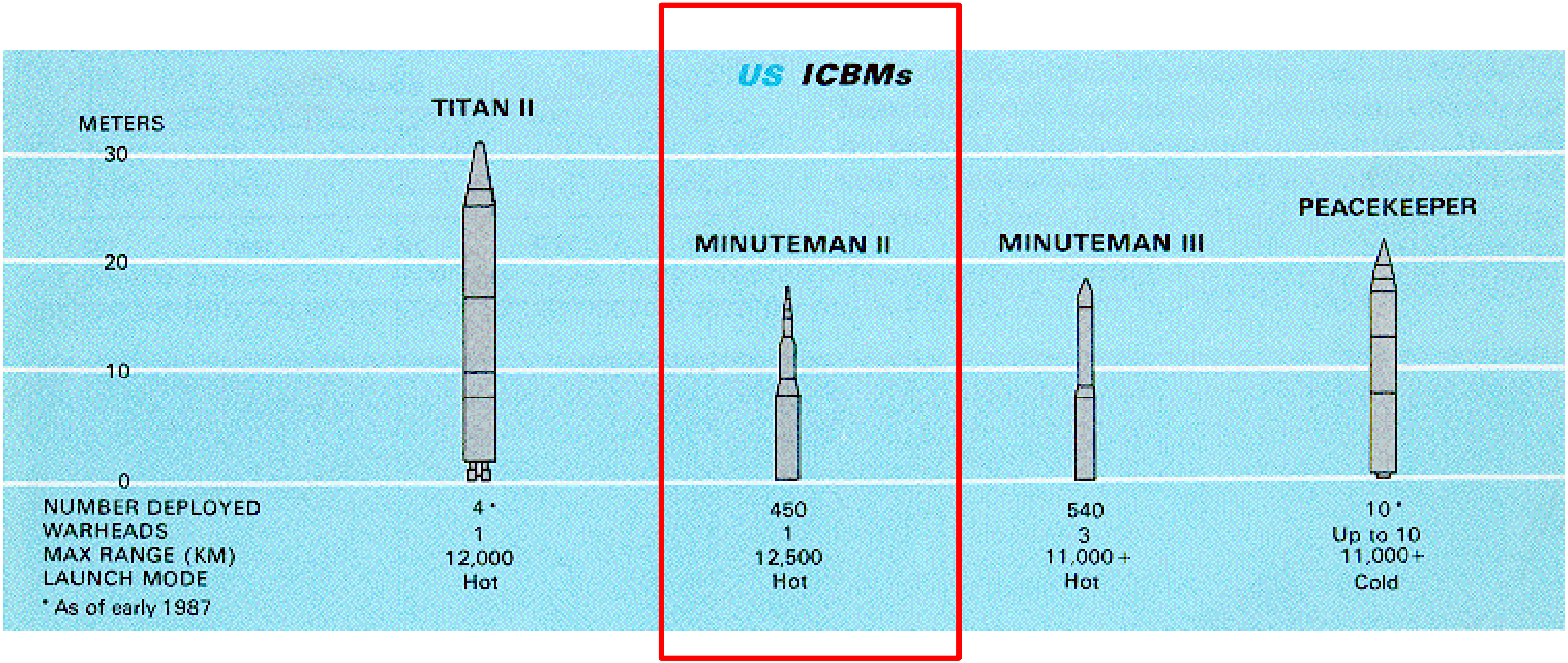
Flight of a MIRV'd ICBM (Schematic)



Flight of a MIRV'd ICBM (Schematic)

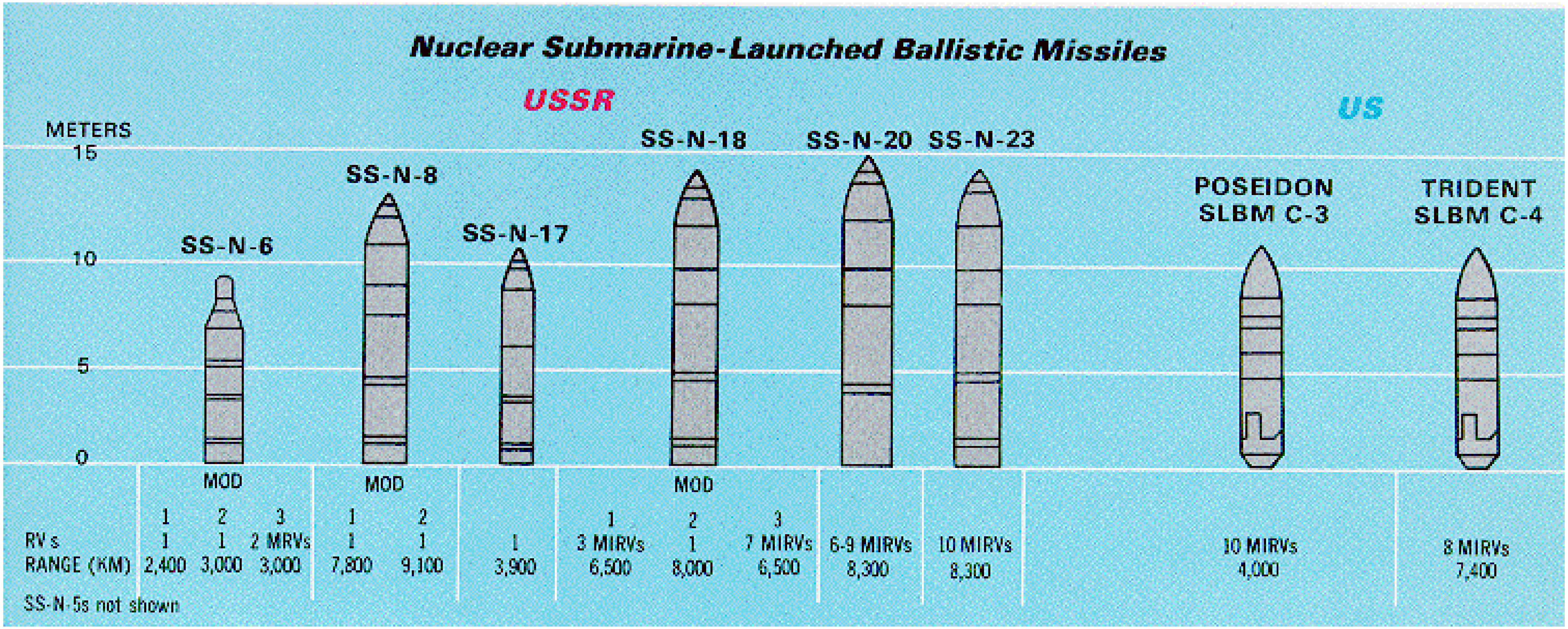
1. The missile launches out of its silo by firing its 1st stage boost motor (*A*).
2. About 60 seconds after launch, the 1st stage drops off and the 2nd stage motor (*B*) ignites. The missile shroud is ejected.
3. About 120 seconds after launch, the 3rd stage motor (*C*) ignites and separates from the 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.

US ICBMs – 1



current land based
US ICMB

US and Russian SLBMs



Physics/Global Studies 280: Session 15

Plan for This Session

News

Module 5: Nuclear Weapon Delivery Systems