Physics 280: Session 15

Extra-Credit Essay Opportunity B
"Getting Back at bin Laden: Fear, Outrage, and the American Way in the War on Terrorism"
Professor John Lynn
Northwestern University
12:00–1:00 p.m. Friday, March 11
University YMCA, 1001 S. Wright St.

Plan for This Session

Student questions

News and discussion

Schedule Midterm Exam Review Session

Module 5: Nuclear Weapon Delivery Systems

News and Discussion

Global Security Newswire
by National Journal Group
Daily news on nuclear, biological and chemical weapons, terrorism and related issues.

Obama Could Launch CTBT Ratification Push in March

Monday, March 7, 2011

The Obama administration is set to submit a new intelligence analysis to the U.S. Senate in March as part of an anticipated push to win congressional approval of the Comprehensive Test Ban Treaty, Kyodo News reported on Sunday (see ***GSN***, March 2).

Following circulation of the new National Intelligence Estimate, which outlines data said to support the case for ratification, the National Academies of Science is expected this spring to release a separate assessment in support of the pact's ratification, according to a high-level U.S. government source and an expert with administration ties.

News and Discussion

Experts Caution Against U.S. Nuclear Security Budget Cuts

Friday, Feb. 25, 2011

Experts are warning about the potentially dangerous impact of a House of Representatives measure that would cut hundreds of millions of dollars from U.S. nuclear nonproliferation activities, Yahoo!News reported today (see ***GSN***, Feb. 18).

The Republican-majority congressional chamber last week approved a continuing resolution that would cut about $60 billion proposed to be spent in this fiscal year under a never-approved budget plan. Reductions reportedly include $1.1 billion from the National Nuclear Security Administration, with $647 million of that coming from the agency's nonproliferation side.

"These cuts make it easier and more likely that a terrorist is going to acquire a nuclear weapon, and attack the United States," according to Jim Walsh of Massachusetts Institute of Technology's Security Studies Program. The impact of such an event in human casualties and to the economy would be "off the charts," he added.

News and Discussion

Nuclear Agency Officials Defend Decrease in Nonproliferation Funds

Thursday, March 3, 2011

By Martin Matishak
Global Security Newswire

WASHINGTON -- The Obama administration yesterday defended its proposal to cut nearly $140 million in spending for one agency's efforts to prevent the spread of nuclear weapons around the world (see ***GSN***, March 2).

Meanwhile, the agency's "weapons activities," which encompass all measures that directly support the nation's thermonuclear stockpile, would receive $7.6 billion, an 8.9 percent boost from the still-unrealized fiscal 2011 proposal.

News and Discussion

IAEA Chief Presses Iran, Syria to Come Clean on Nuclear Activities

Monday, March 7, 2011

By Chris Schneidmiller
Global Security Newswire

VIENNA, AUSTRIA -- The head of the International Atomic Energy Agency on Monday called on Iran and Syria to cooperate more fully with efforts to ensure the nations' nuclear programs are not intended to produce weapons (see ***GSN***, March 4).

U.S. Could Provide Russia Early Missile Threat Info

Friday, March 4, 2011

The United States could provide Russia with early warning information about incoming missile threats as part of a joint missile defense effort, ITAR-Tass reported (see ***GSN***, Feb. 22).

News and Discussion

India demonstrates capability to neutralize satellites in space

By Keith Stein, DC Space News Examiner
March 6th, 2011 10:57 pm ET

India on Sunday conducted another successful test of its ballistic missile defense system when it successfully destroyed an "attacker" ballistic missile with an interceptor missile, over the Bay of Bengal off Orissa coast. [source]

The interceptor missile was launched from Wheeler Island, off the Orissa coast, to ambush an incoming 'enemy' missile at an altitude of 16 kilometers (10 miles) over the Bay of Bengal. [source]

The fresh success of the interceptor missile mission has demonstrated the country's capability to neutralize adversarial satellites in space, according to V.K. Saraswat, Scientific Adviser to the Defence Minister. [source]

Midterm Exam Review Session

6:30 PM, Sunday, March 13th
Probably in 144 Loomis

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, shipping container)
- Explosives
  (example: artillery shell)
- Propellers
  (example: torpedo, speeds ~ 50 mph)
- Jet engines
  (example: bomber, speeds ~ 600 mph)
- Rocket motor
  (example: missile, speeds ~ 18,000 mph)
- Unconventional
  (examples: barge, boat, Ryder truck, backpack)

Examples of Weapon Delivery Methods

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

Non-missile Delivery Methods

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

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

They also can be used without attribution."

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

The U.S. Cold-War Strategic "Triad" – 1

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

- Truman administration
- Eisenhower administration

McNamara (Kennedy's SecDef) changed this —

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

  Concluded 400 'effective' megatons (EMT) would be "enough"

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

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

Strategic nuclear delivery vehicles (SNDVs) —

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

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

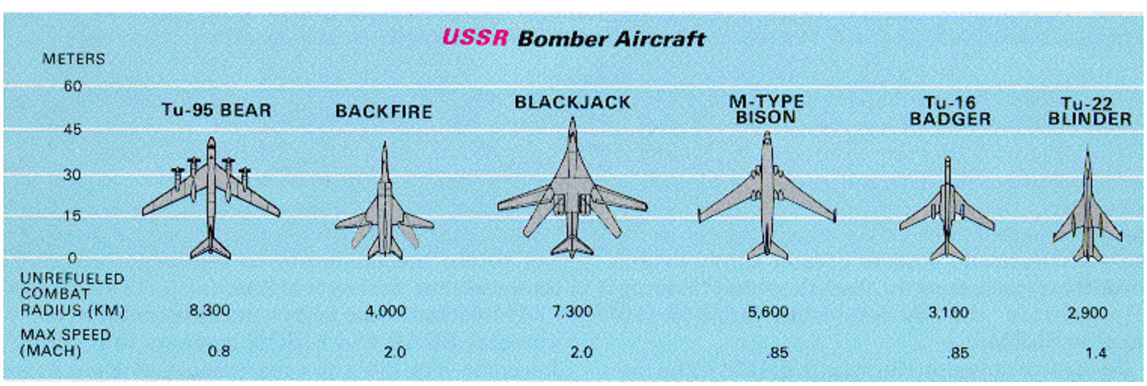
Systems in the Triad —

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

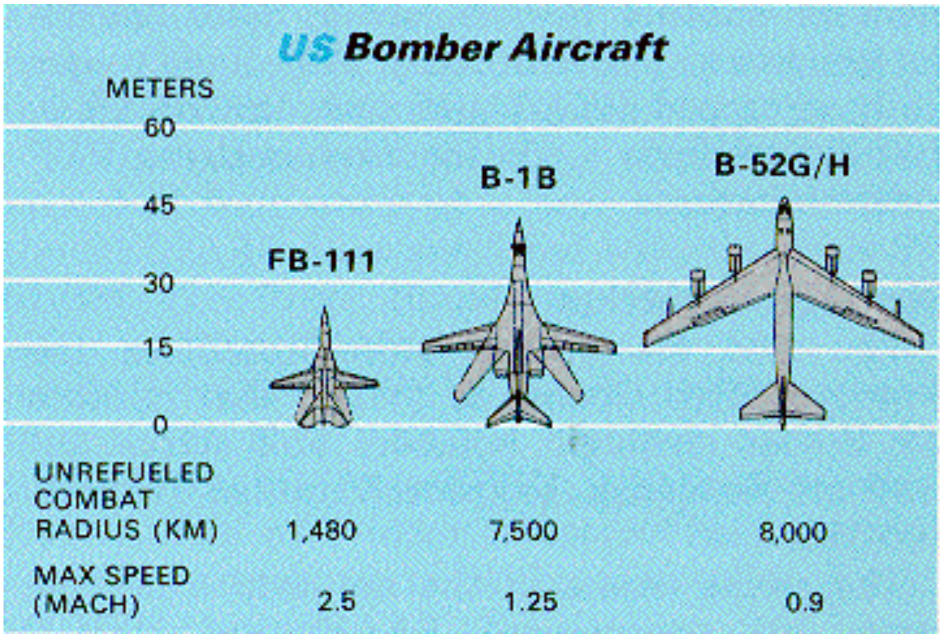
Module 5: Nuclear Delivery Systems

Part 2: Aircraft

Examples of Intercontinental Bombers – 1



Examples of Intercontinental Bombers – 2



U.S. B-2 Stealth Bomber

Speed: Mach 0.85

Height: 15 km

Range: 12,230 km

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

Currently Deployed U.S. and Russian Bombers

Current US bombers —

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

Russian bombers* —

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

*Very few are currently operational

Intercontinental Bomber Issues

Evolution of bomber missions —

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

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

Terrorism

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

A. Extreme poverty

B. A disaffected individual

C. A legitimizing ideology

D. An enabling community

Blank

iClicker Answer

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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

Blank

iClicker Answer

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iClicker Question

About how many **troops** does the current U.S. army field manual say are required for every 1 million **inhabitants** to successfully suppress an insurgency in a country?

A. 1,000

B. 5,000

C. 10,000

D. 20,000

E. 50,000

Blank

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B. 5,000

C. 10,000

D. 20,000

E. 50,000

iClicker Question

According to the current U.S. army field manual, about how many troops would be required to suppress the insurgency in Afghanistan?

A. 25,000

B. 75,000

C. 150,000

D. 300,000

E. 600,000

Blank

iClicker Question

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A. 25,000

B. 75,000

C. 150,000

D. 300,000

E. 600,000

iClicker Question

Which one of the following is *not* one of Allison's "Three No's"?

A. No new reactors

B. No loose nukes

C. No nascent nukes

D. No new nuclear weapon states

Blank

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iClicker Question

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

A. Submarine-launched ballistic missiles

B. Ship-launched ballistic missiles

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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:

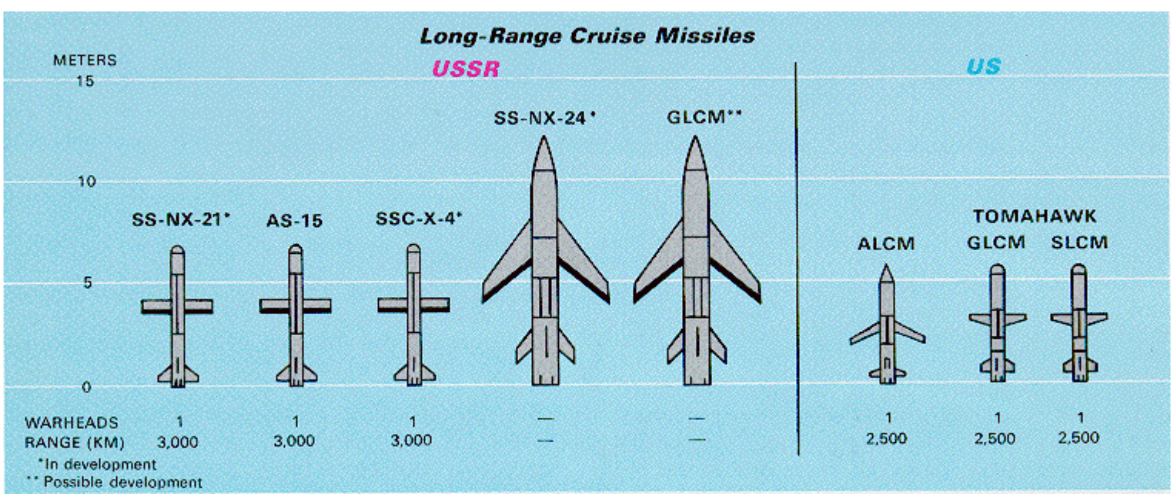
- Smaller and lighter nuclear warheads
- Efficient turbofan engines
- Highly capable miniaturized computers
- GPS, Tercom, and terminal guidance
- “Stealth” airframe technology

Introduction to Cruise Missiles – 2 (Important)

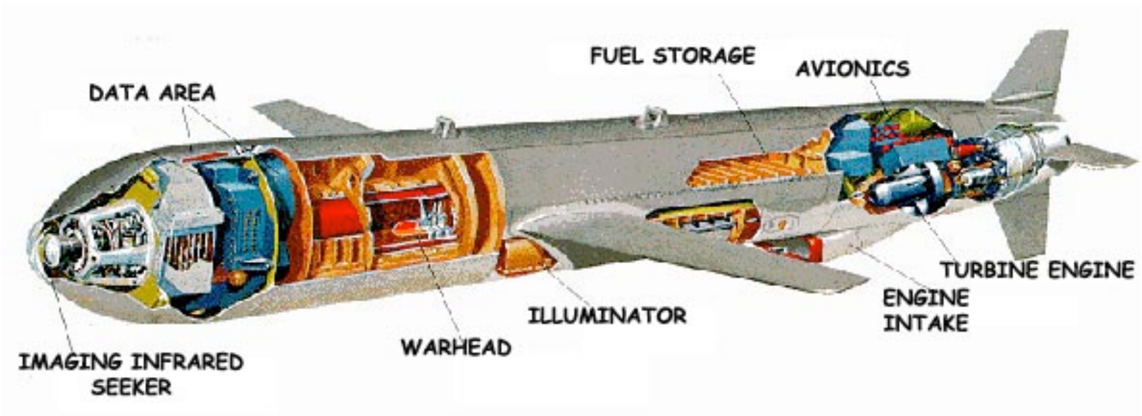
Key properties —

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

Long-Range Cruise Missiles – 1

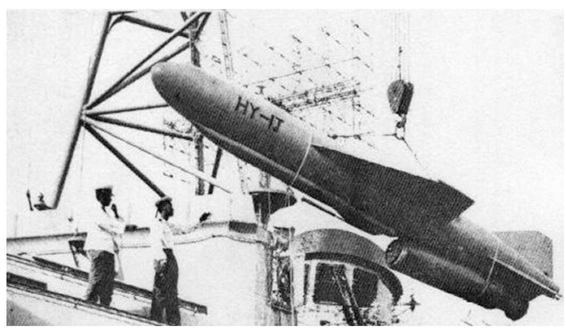


Long-Range Cruise Missiles – 2



Conventionally-Armed Tomahawk Cruise Missile

Chinese Silkworm Anti-Ship Cruise Missile



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

YingJi YJ-62 Specifications—
Length: 6.1m (without booster); 7m (with booster)
Launch weight: 1,140kg (without booster); 1,350kg (with booster)
Warhead: 300kg HE
Propulsion: One turbojet/turbofan engine, one solid booster
Max speed: Mach 0.9, Max range: 280km
Flight Altitude: 30m (flight); 7~10 m (attacking)
Guidance Mode: Inertial + GPS, terminal active radar

Physics 280: Session 16

THE DATE AND TITLE HAVE BEEN CHANGED!!

Extra-Credit Essay Opportunity B
“Getting Back at bin Laden: Fear, Outrage, and the American Way in the War on Terrorism”
Professor John Lynn
Northwestern University
12:00–1:00 p.m. Friday, March 11
University YMCA, 1001 S. Wright St.

Midterm Exam Review: Sunday, March 13th at 6:30 PM in 144 Loomis

Plan for This Session

Student questions

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

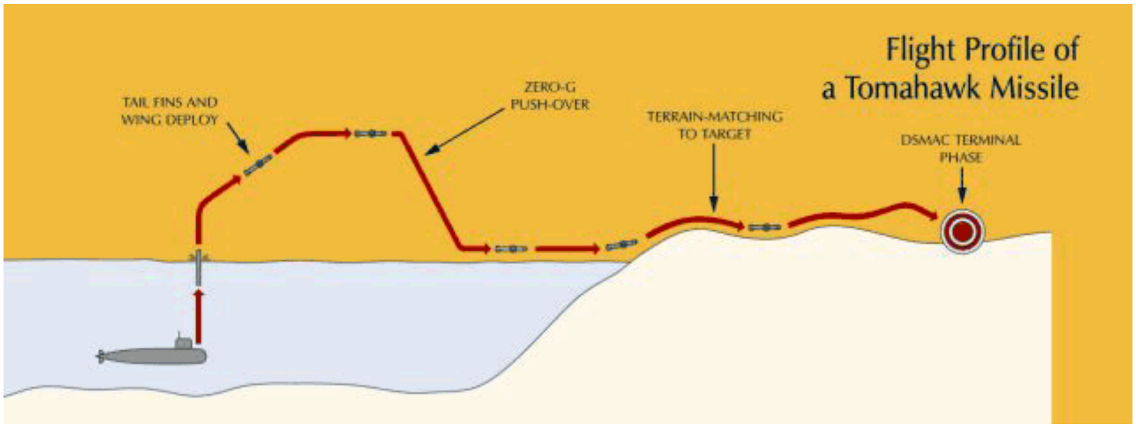
Launching Cruise Missiles – 1

Launching Cruise Missiles – 2

Cruise-Missile Guidance – 1

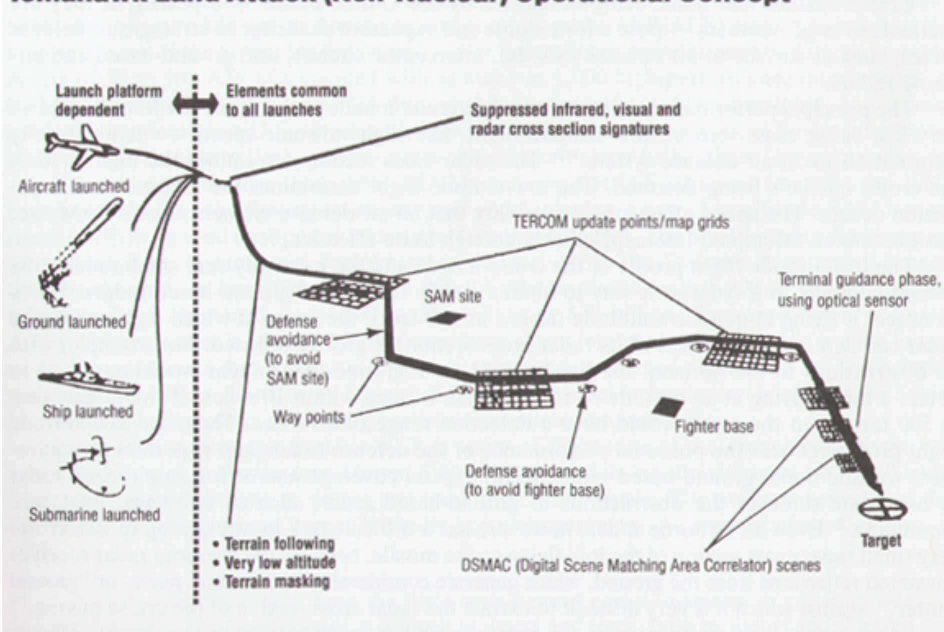
TERCOM: Terrain Contour Matching
DSMAC: Digital Scene Matching Area Correlation

Cruise-Missile Guidance – 2



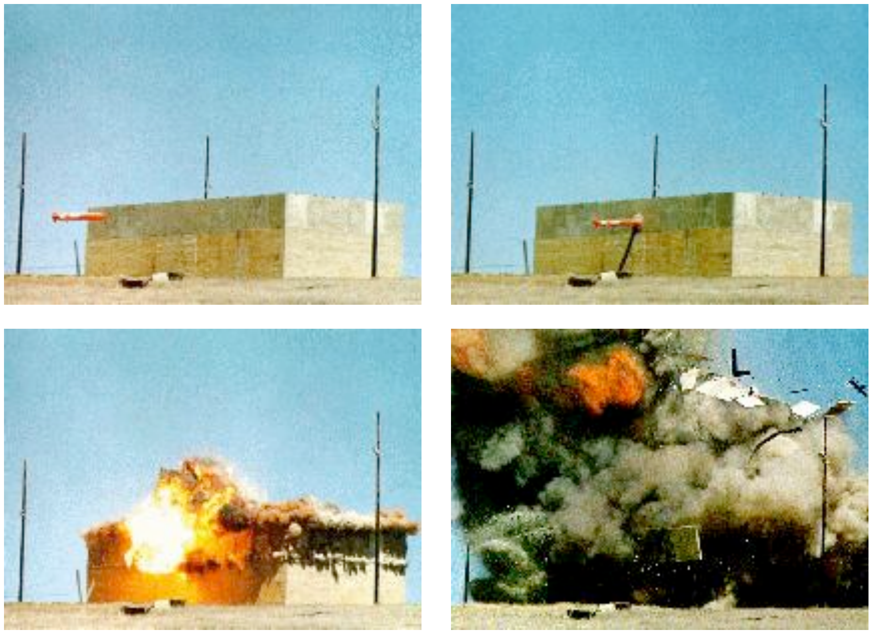
Cruise-Missile Guidance – 3

Tomahawk Land Attack (Non-Nuclear) Operational Concept



Source: Joint Cruise Missiles Project Office.

Accuracy of Cruise Missiles



Implications of Cruise Missiles – 1

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

Military history —

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

Implications of Cruise Missiles – 2

Implications for U.S. security—

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

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

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

Module 5: Nuclear Delivery Methods

Part 4: Ballistic Missiles

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.

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: passage through atmosphere

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) —

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

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

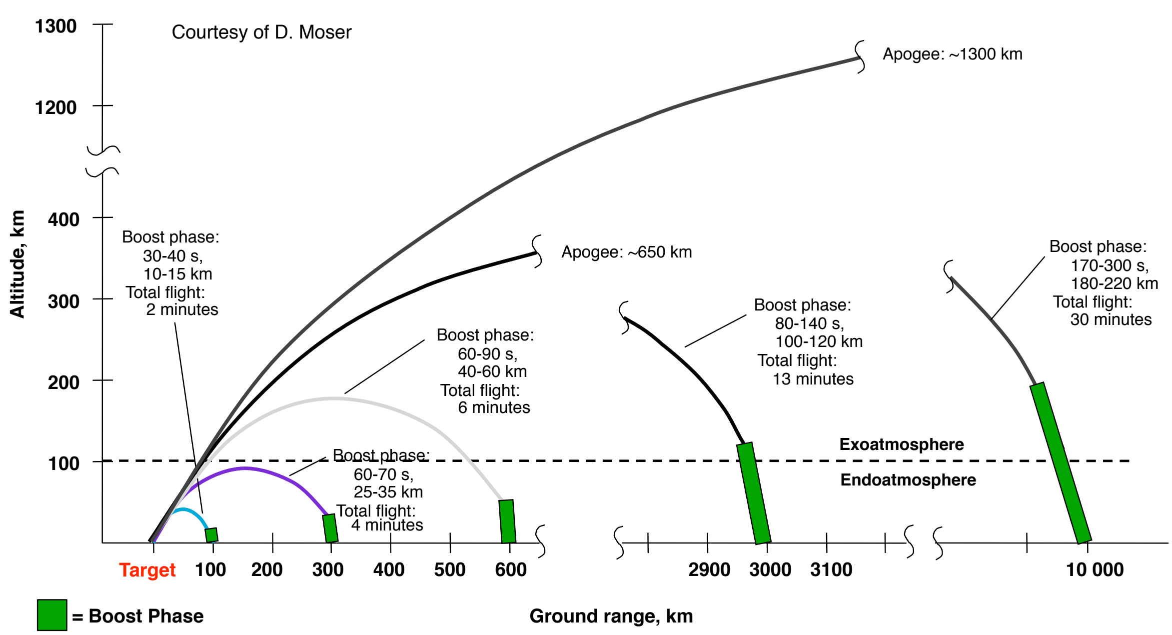
Missile Guidance Technologies

Inertial —
- Uses gyroscopes and accelerometers
- No contact with outside world

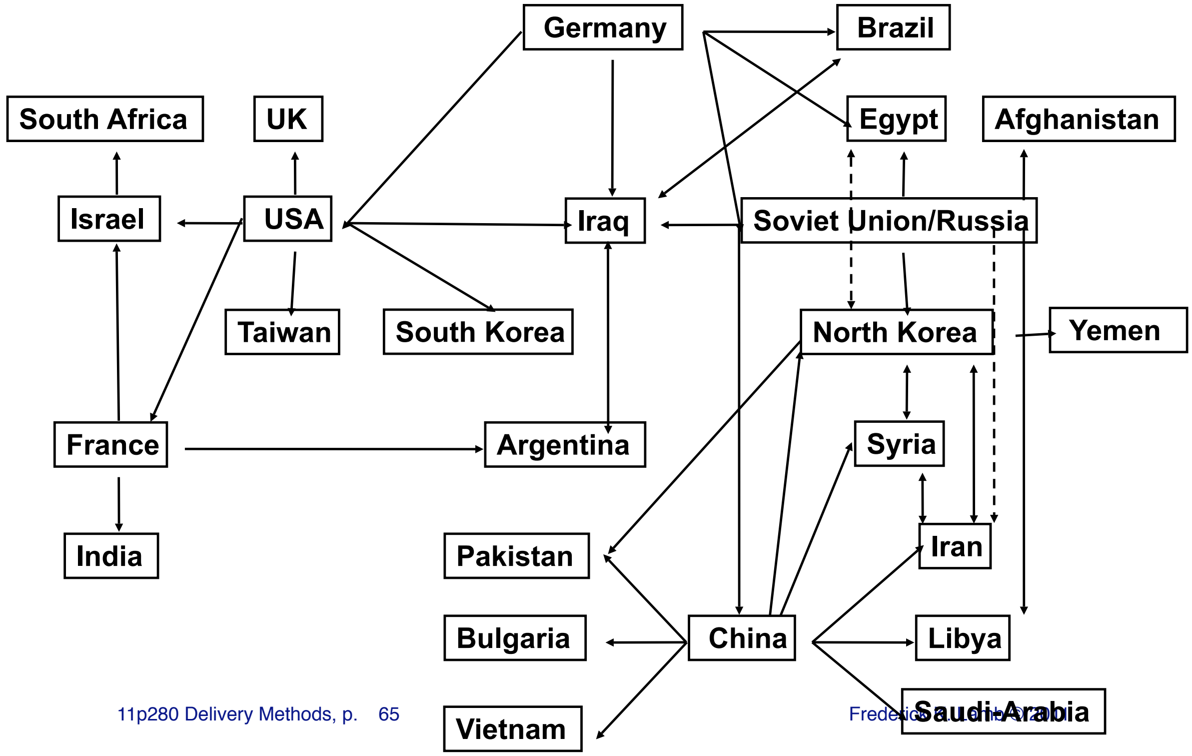
Stellar —
- Star trackers update inertial guidance system

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

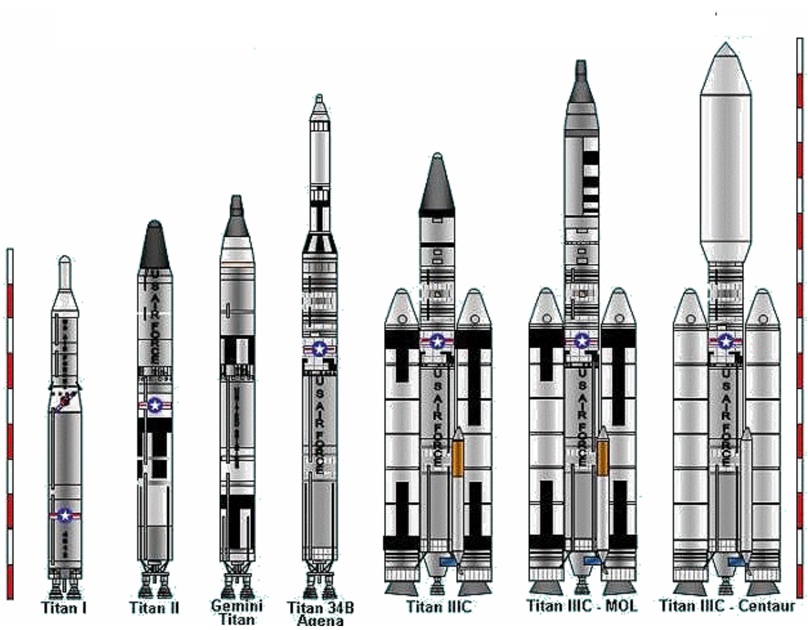
Trajectories and Phases of Flight of Missiles With Various Ranges



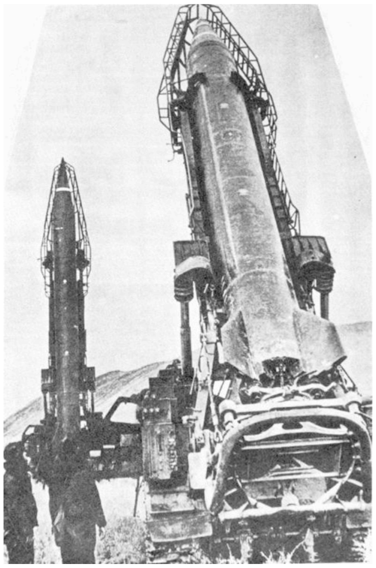
Proliferation of Ballistic Missile Technologies



Titan Family of Missiles and Launch Vehicles



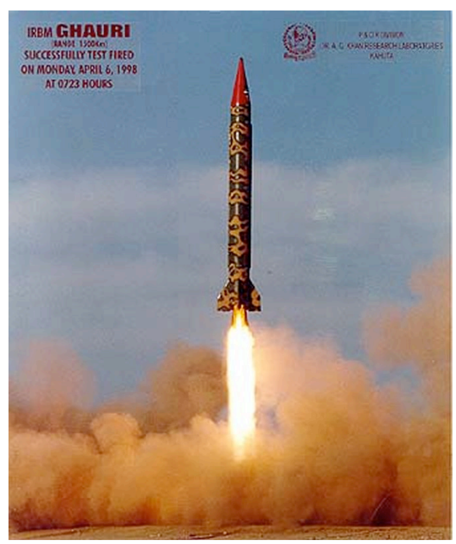
Soviet Scud Missiles and Derivatives - 1



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.

Short-Range Ballistic Missiles

Russia | Iraq | India | Egypt | Pakistan | China | Iraq

Source: www.missilethreat.com/picture/srbm_comparison.html

iClicker Question

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

A. Lighter metals for the airframes

B. More efficient engines

C. Much smaller and more capable computers

D. GPS and other methods for more accurate guidance

E. “Stealth” technologies to make them harder to detect

Blank

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iClicker Question

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

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B. Land-based intercontinental ballistic missiles

C. Land-based intercontinental bombers

Blank

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Physics 280: Session 17

Midterm Exam
Thursday, March 17th at 2:00 PM
Room 100, Materials Science and Engineering Bldg

Plan for This Session

Student questions

News and discussion

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

News and Discussion

The Washington Post

Japan steps closer to a full-blown nuclear catastrophe

By Steven Mufson, Monday, March 14, 11:12 PM

Officials from Tokyo Electric Power, the plant owner, said the 6:14 a.m. explosion took place in the unit 2 reactor at or near the suppression pool, which collects water and radioactive elements from the containment vessel.

Experts said that, unlike the two previous explosions that destroyed outer buildings, this one might have damaged valves and drain pipes, possibly creating a path for radioactive materials to escape.

The explosion — more serious than the earlier blasts — was followed by a brief drop in pressure in the vessel and a spike in radioactivity outside the reactor to levels more than eight times what people ordinarily receive in a year, the company said. Tokyo Electric, which over the weekend said it had 1,400 people working at the complex, said it was evacuating all nonessential personnel, leaving about 50 people there.

News and Discussion

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News and Discussion

Japan's nuclear crisis leads to dangerous spike in radiation levels

1 microSv = 0.1 mrem

Radiation levels shot up early Tuesday after the third explosion in four days rocked the seaside Fukushima Daiichi complex and fire briefly raged in a storage facility.

12,000 microSv/h = 1.2 rem/h

Three hours after the explosion, the radiation level at the plant measured 11,930 micro sieverts per hour — several times the amount a person can safely be exposed to in one year.

500 microSv/h = 0.05 rem/h

Radiation levels shrank dramatically within the next six hours, to 496 micro sieverts per hour, which government spokesman Yukio Edano called "much higher than the normal level . . . but one that causes no harm to human health."

News and Discussion

The new setbacks came on the heels of a difficult Monday at Fukushima Daiichi unit 2. Utility officials there reported that four out of five water pumps being used to flood the reactor had failed and that the other pump had briefly stopped working. As a result, the company said, the fuel rods, normally covered by water, were completely exposed for 140 minutes, hastening the partial meltdown of them that most experts think is underway.

According to a report by the Kyodo news agency, the fifth pump was later restarted, and seawater mixed with boron was again injected in a desperate bid to cool the reactor, but the fuel rods remained partially exposed and ultra-hot. On Tuesday morning, Tokyo Electric said that 2.7 meters of the rods were still exposed.

News and Discussion

A commercial satellite photo of the complex showed piles of debris on top of units 1 and 3, which raised new fears about the condition of the pools where spent fuel is stored, especially at unit 1, where a design by General Electric placed the pool on top of the reactor but below the outer structure, which was destroyed. But the ability of workers to assess the damage was hindered by fears that another explosion might occur.

Last March, 1,760 tons of spent fuel were stored in the six pools — 84 percent of capacity, according to Tokyo Electric.

A likely indirect consequence of a nuclear war:
failure to cool reactor cores and spent fuel, causing
dispersal of highly radioactivity material.

Module 5: Nuclear Delivery Methods

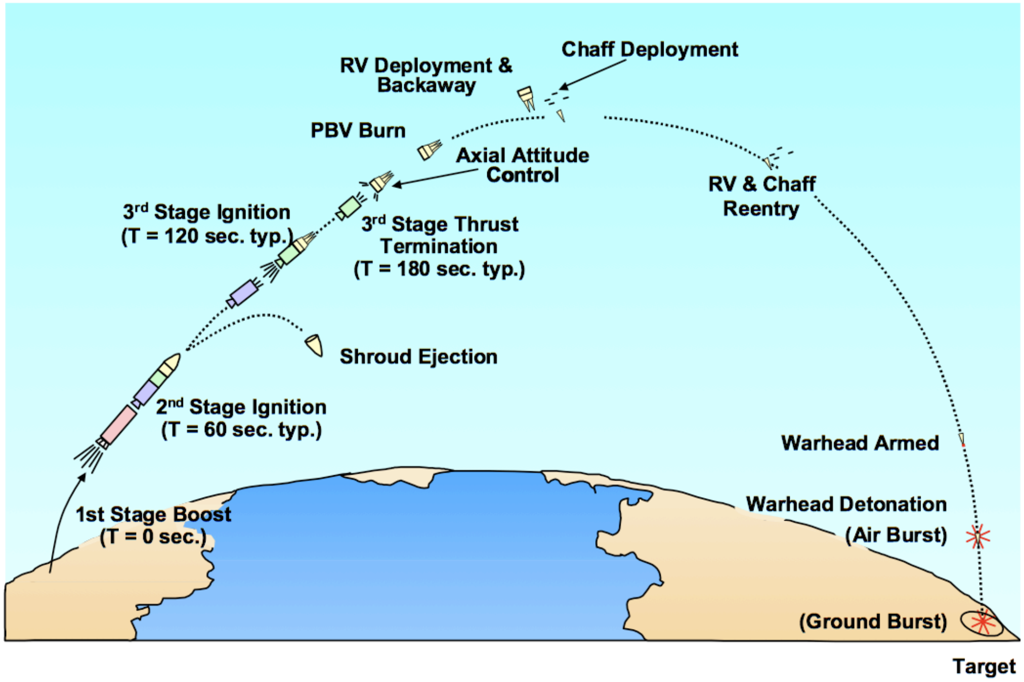
Part 4: Ballistic Missiles (Cont'd)

Re-Entry Vehicles (RVs)

Basic types —

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

Flight of a Minuteman ICBM (Schematic)

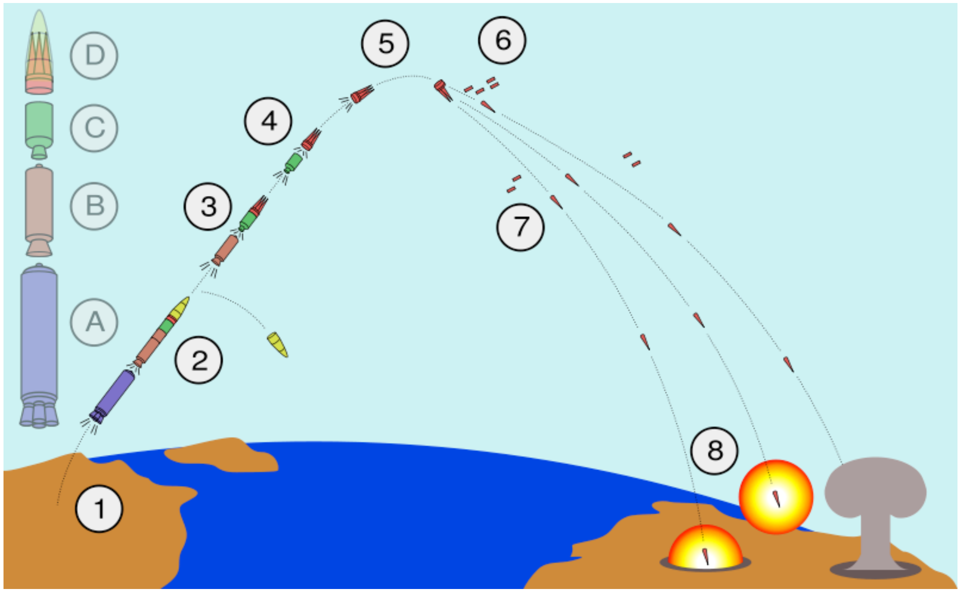


Flight of MIRV'd ICBMs

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

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

Flight of a MIRV'd ICBM (Schematic)



Flight of a MIRV'd ICBM (Schematic)

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

MIRV Technology

MX Peacekeeper MIRV

Soviet SS-20 ICBM MIRV

MIRV Technology

MX Peacekeeper missile tested at Kwajalein Atoll

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

Historical Examples of US and Russian ICBMs

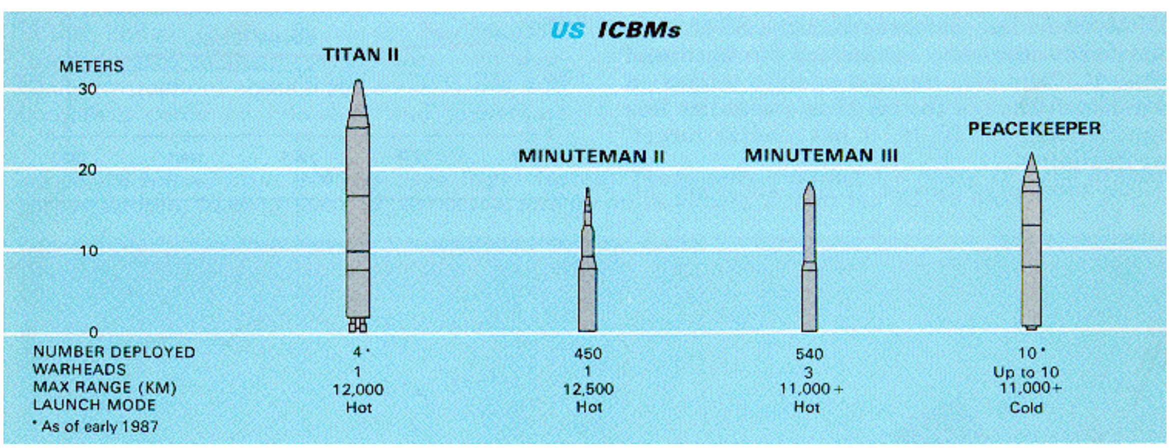
Recent US ICBMs —

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

Recent Russian ICBMs —

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

US ICBMs – 1

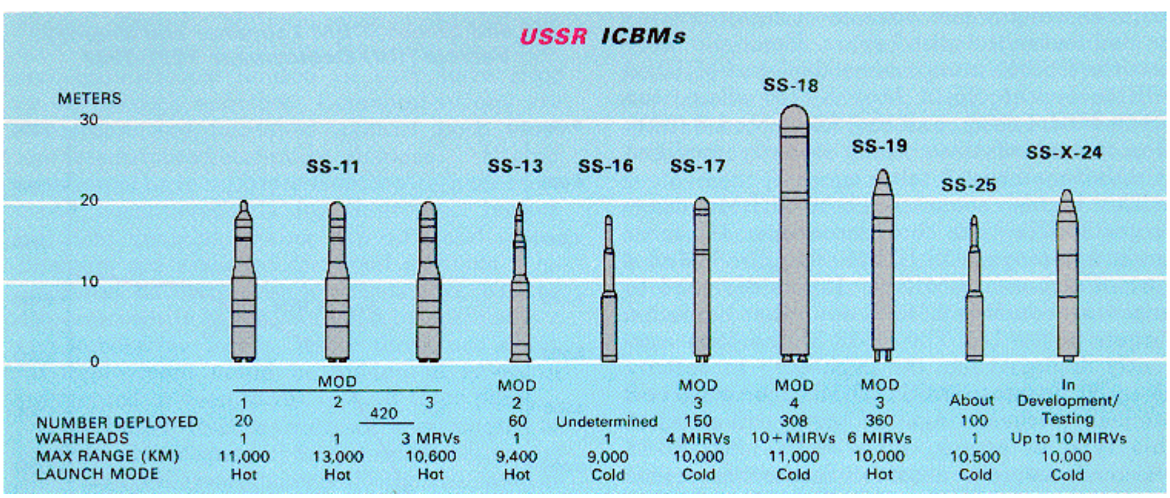


US ICBMs – 2

Launch of a Minuteman

Launch of an MX

Russian ICBMs – 1



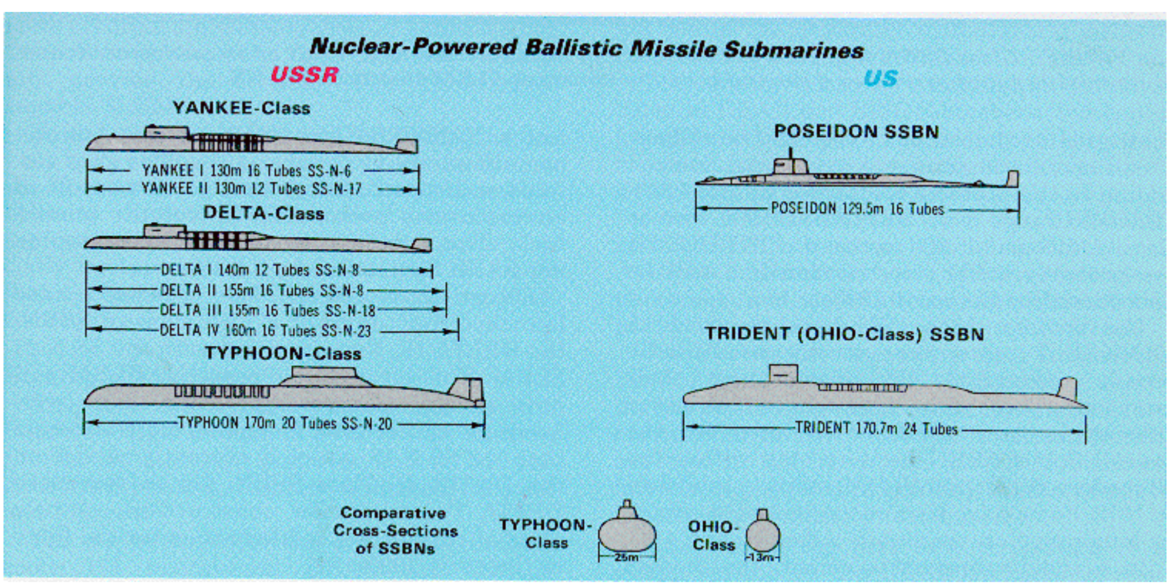
Russian ICBMs – 2

SS-18 "Satan"

SS-18 in its launch canister

SS-18 leaving its launcher

US and Russian SSBNs

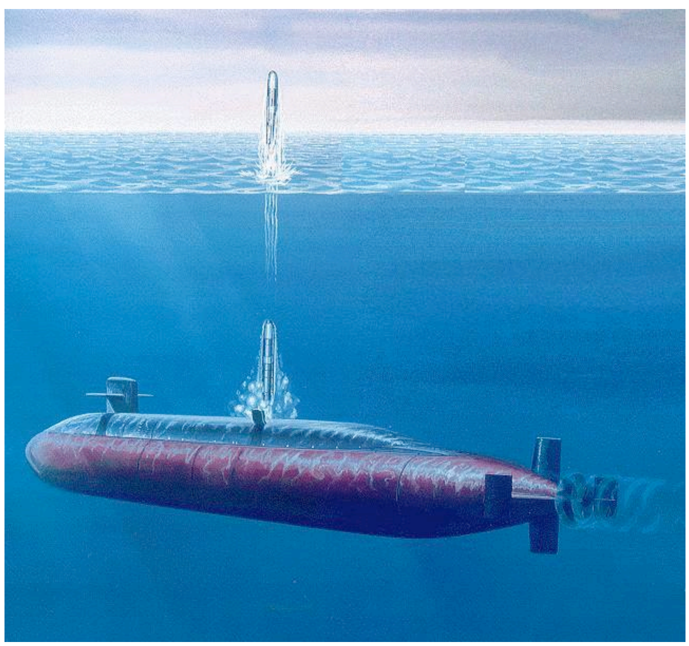


US Trident SSBN

Trident Missile Tubes
With Covers Open

Trident Submarine Underway

US Trident SSBN



Submarine-Based Missiles

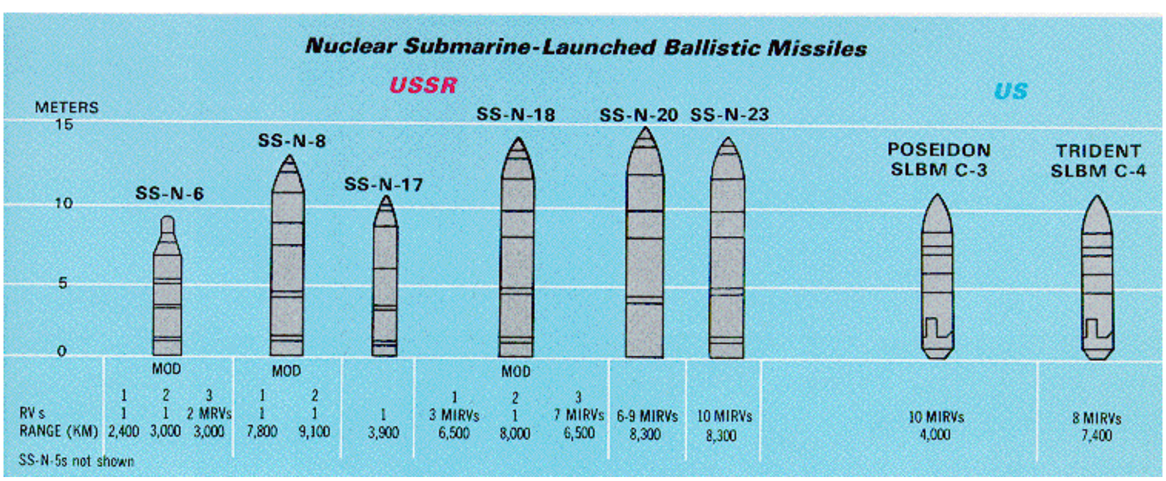
US SLBMs —

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

Russian SLBMs —

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

US and Russian SLBMs



iClicker Question

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

A. Lighter metals for the airframes

B. More efficient engines

C. Much smaller and more capable computers

D. GPS and other methods for more accurate guidance

E. “Stealth” technologies to make them harder to detect

Blank

iClicker Answer

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

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iClicker Question

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

A. The captain

B. The first officer

C. The captain and the first officer

D. A majority of the crew

E. All of the crew members

Blank

iClicker Question

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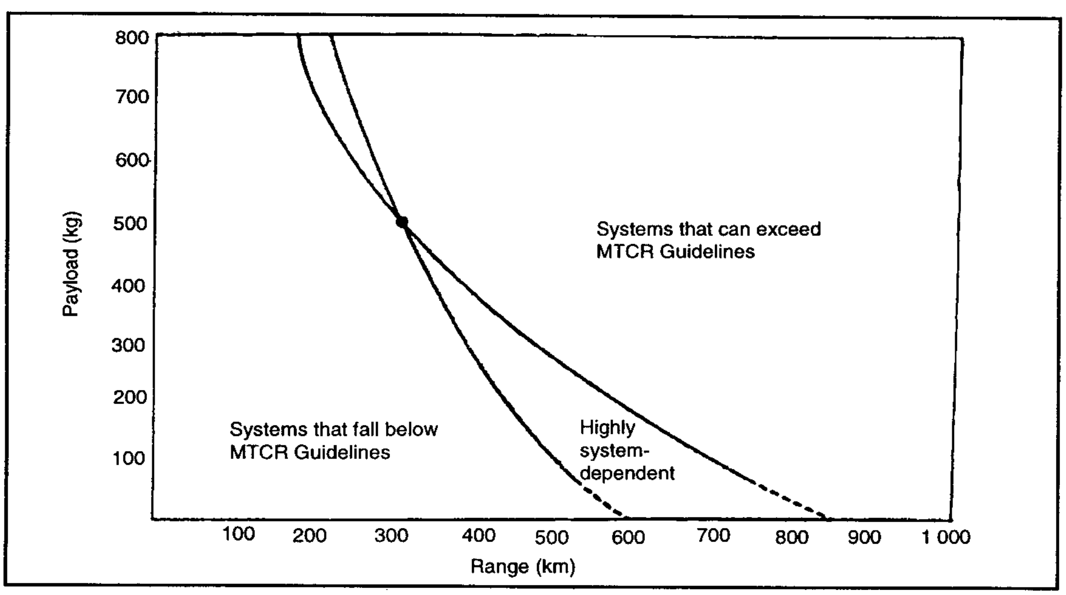
Module 5: Nuclear Delivery Systems

Part 5: Technical and Operational Aspects

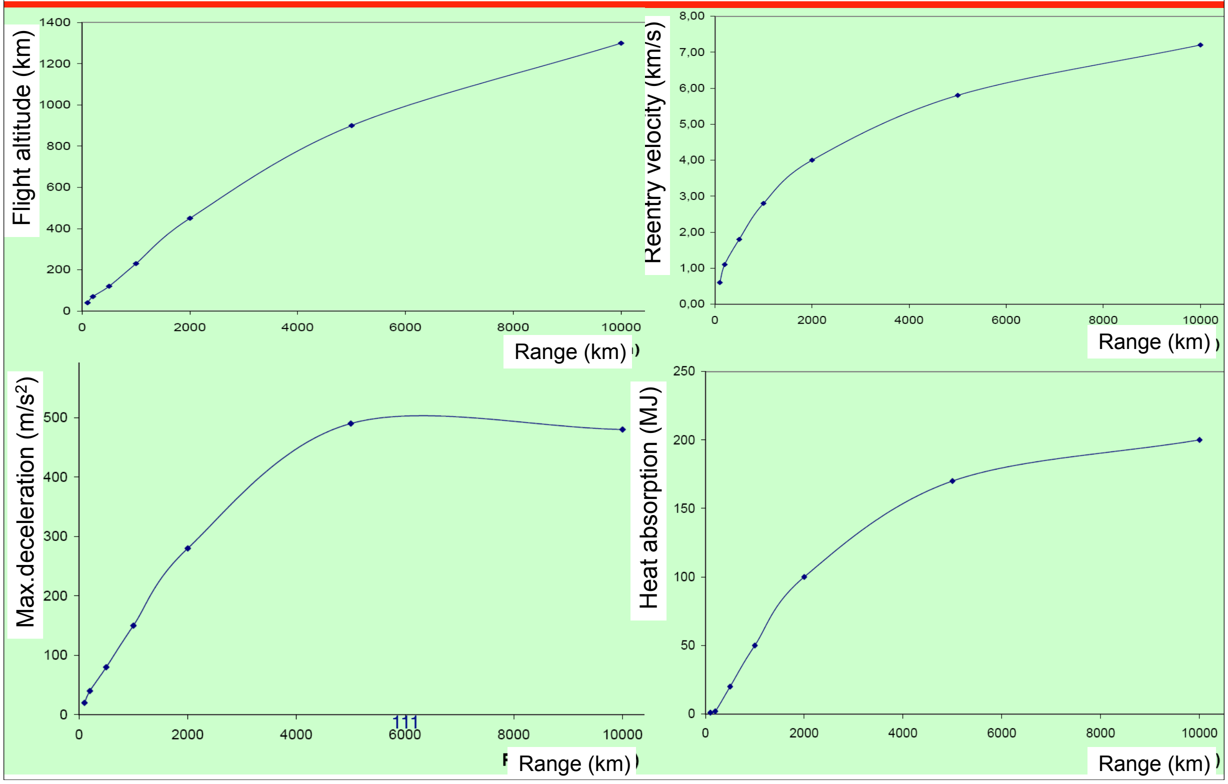
Range-Payload Tradeoff



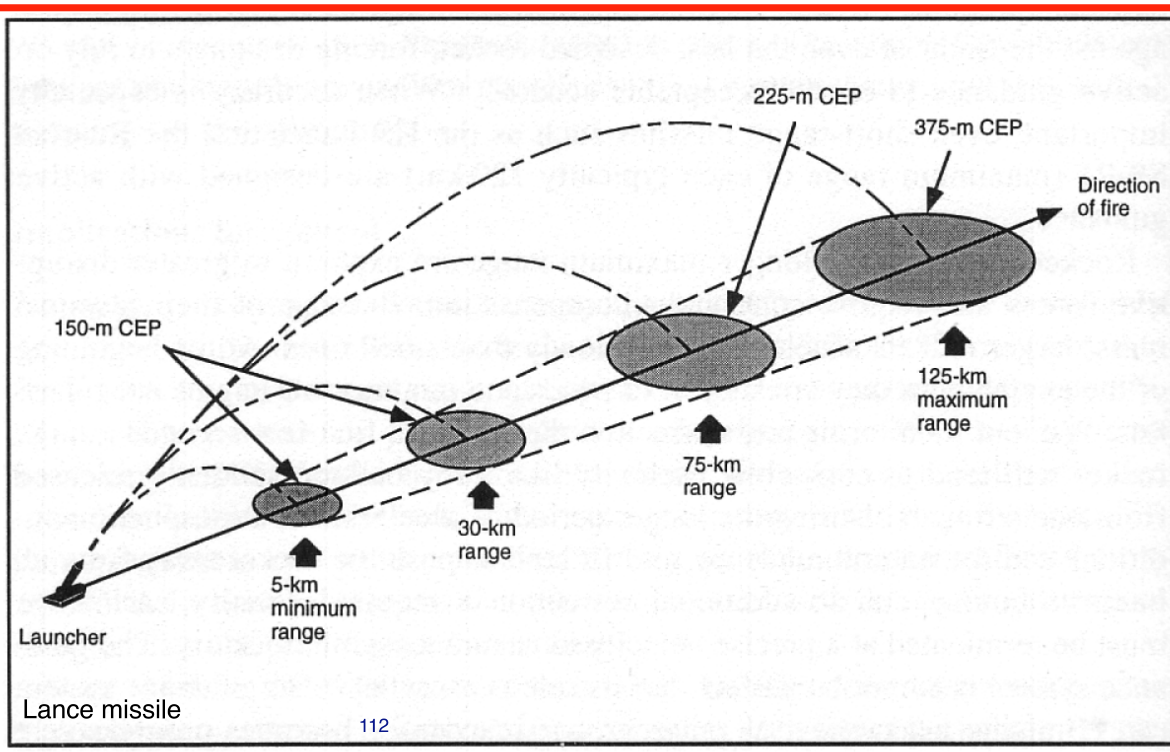
MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

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

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



Missile Range–Accuracy Tradeoff



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

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 many warheads against each silo

Effect of silo hardness

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

Silo-Based Missiles

Effect of missile accuracy

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

Ballistic Missile Accuracy

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

Important concepts:

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

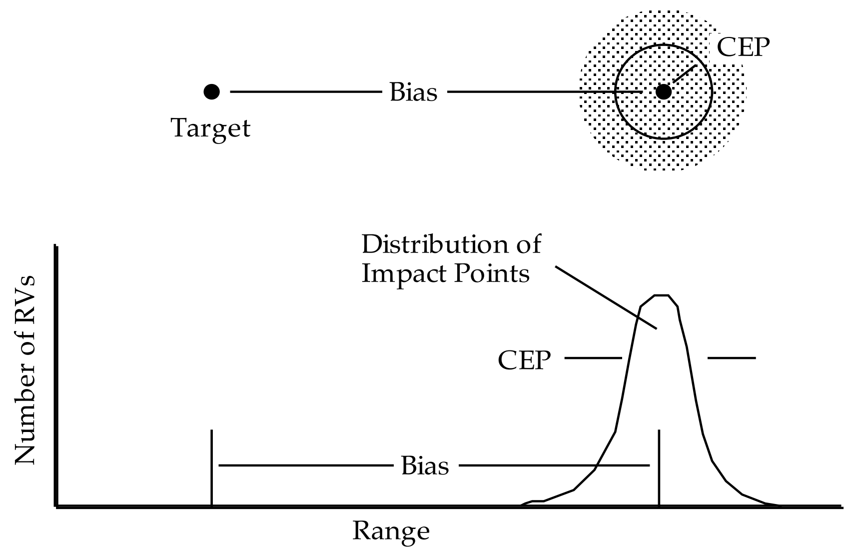
Algebraic relation —

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

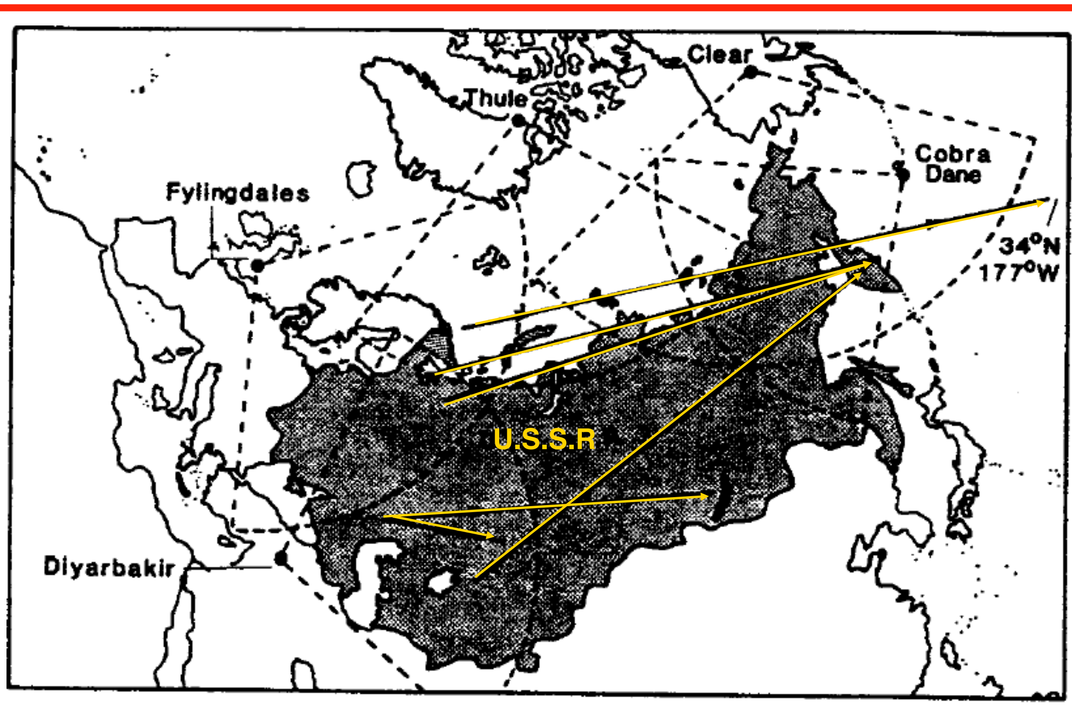
CEP is *not* a measure of the miss distance. The miss distance is *at least as large* as the CEP, but can be *much larger* if there is significant bias.

Ballistic Missile Accuracy

Distribution of RV impact points —



U.S. Radars That Can Observe Soviet Missiles



Modified from: Scribner/Ralston/Metz, The Verification Challenge, Birkhäuser 1985.

Ballistic Missile Accuracy

Published CEPs for some ICBMs and SLBMs

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

Sources of Systematic Error

- 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

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

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

Probability of destroying (“killing”) a missile silo: $P_K = 1 - e^{-K/f(H)}$

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

Counterforce Capabilities in 1985

U.S. ICBMs:	K = 107,000
U.S. SLBMs:	K = 48,000
U.S. Trident II D5:	K = (475,000)
Russia ICBMs:	K = 131,000
Russia SLBMs:	K = 9,500

Submarine-Based Missiles

Operational considerations

- Relative vulnerability
  (size of operational areas, ASW threat, counter-ASW capability)
- Ability to survive
- US SSBNs are quieter than Russian SSBNs
  (but Russia is improving rapidly)
- US leads in anti-submarine warfare (ASW) capability Access to high seas, time to reach stations
  (Russian subs used to take longer; not any more)
- Fraction of forces on-station
  (duration of patrols, time required for repairs)
- System reliability
- Effectiveness of command and control

Submarine-Based Missiles

Effective number of warheads (example)

- United States

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 —

DEFCON 5 Normal peacetime readiness
DEFCON 4 Normal, increased intelligence and strengthened security measures
DEFCON 3 Increase in force readiness above normal readiness intelligence and strengthened security measures
DEFCON 3 Increase in force readiness above normal readiness
DEFCON 2 Further Increase in force readiness
DEFCON 1 Maximum force readiness.

Nuclear Command and Control – 3

Satellite systems

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

Response Times for Attack or Breakout

The Threat of Accidental Nuclear War – 20 Dangerous Incidents

1) November 5, 1956: Suez Crisis Coincidence

2) November 24, 1961: BMEWS Communication Failure

3) August 23, 1962: B-52 Navigation Error

4) August-October, 1962: U2 Flights into Soviet Airspace

5) October 24, 1962- Cuban Missile Crisis: A Soviet Satellite Explodes

6) October 25, 1962- Cuban Missile Crisis: Intruder in Duluth

7) October 26, 1962- Cuban Missile Crisis: ICBM Test Launch

8) October 26, 1962- Cuban Missile Crisis: Unannounced Titan Missile Launch

9) October 26, 1962- Cuban Missile Crisis: Malstrom Air Force Base

10) October, 1962- Cuban Missile Crisis: NATO Readiness

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

The Threat of Accidental Nuclear War 20 Dangerous Incidents

11) October, 1962- Cuban Missile Crisis: British Alerts

12) October 28, 1962- Cuban Missile Crisis: Moorestown False Alarm

13) October 28, 1962- Cuban Missile Crisis: False Warning Due to Satellite

14) November 2, 1962: The Penkovsky False Warning

15) November, 1965: Power Failure and Faulty Bomb Alarms

16) January 21, 1968: B-52 Crash near Thule

17) October 24-25, 1973: False Alarm During Middle East Crisis

18) November 9, 1979: Computer Exercise Tape

19) June , 1980: Faulty Computer Chip

20) January, 1995: Russian False Alarm

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

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