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Los Alamos
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Nuclear Testing, Effects, and the US Nuclear Weapons Arsenal

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Los Alamos National Laboratory

The presentation covers the history of US nuclear weapons development, with an emphasis on nuclear effects, testing, and modern missile development. Key advances which laid the foundation for the modern US nuclear weapons stockpile are examined, and the evolution of the triad is discussed. Nuclear weapon accidents and the evolution of surety is also presented. The presentation concludes with a discussion of issues in stockpile stewardship and the maintenance of the nuclear deterrent during the current test moratorium.

Nuclear Testing, Effects, and the US Nuclear Weapons Arsenal

MSE 193/293

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Nuclear Deterrence and Weapons: Fundamentals

Deterrence Definitions

Deterrence can be simply defined as:

"The ability to inflict unacceptable cost upon an adversary – such that that adversary is deterred from conducting an undesired act."

Implementation of specific words and concepts in this definition:

"ability to inflict" – assured, survivable, credible, and communicated

"unacceptable cost" – identifiable, meaningful, targetable, destroyable

"adversary" – known, communicated, rationale

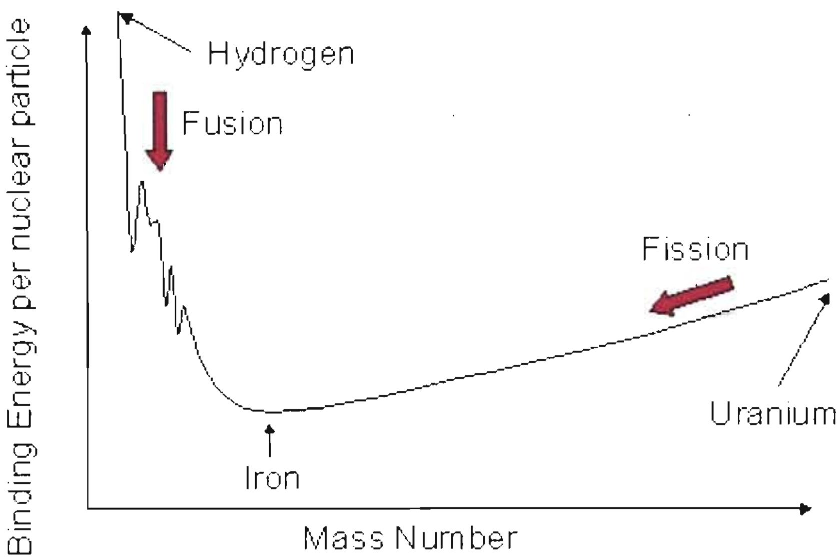


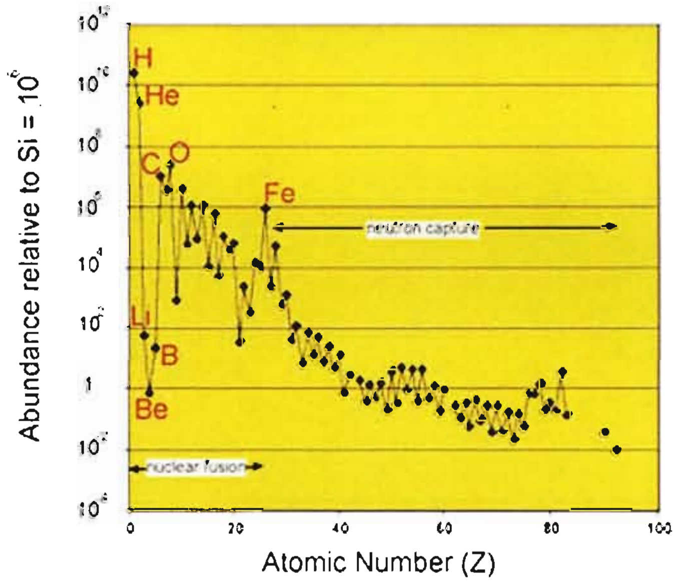

Nuclear weapons provide unrivaled ability to meet many of these requirements: destructive power, ease of delivery, stealthy and survivable

Nuclear Weapon Fundamentals: Fission and Fusion

"a factor of millions"

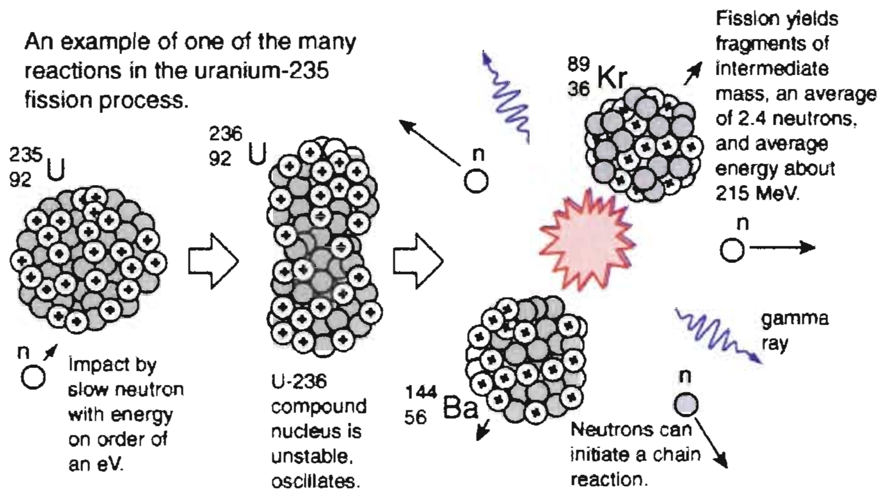
- Derives from the curve of binding energy – perhaps the most important observation in science!





Nuclear Weapon Fundamentals: 3 characteristics of fission reactions

- Fission reactions are 100,000,000 times more *energetic* than chemical

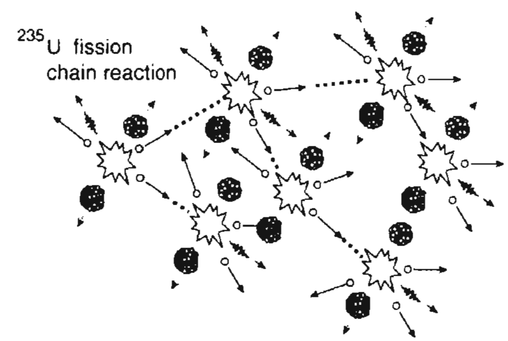


2+ extra neutrons
215 MeV of energy!

- Fission reactions are 10,000 times *faster* than equivalent chemical reactions
  - Many generations of fission in a small time; before system “blows apart”

- *Fissile*: elements which *fission* when subjected to neutron bombardment
  - Allows a “chain reaction”

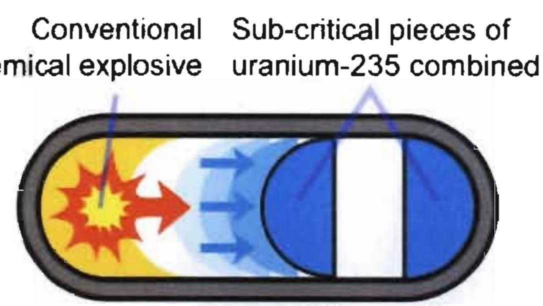
These 3 factors make the atomic bomb possible



Manhattan Project developed both paths to the bomb

- **Uranium-235 (Produced by enrichment)**
  - Uranium ore (0.7% U-235, the fissile isotope, the rest is U-238)
  - Enrich uranium in U-235, typically > 90% (HEU)
    - Gas centrifuge, for example
  - A few tens of kg required for a hypothetical bomb
  - >20% HEU is weapons usable

Hiroshima - Aug. 6, 1945



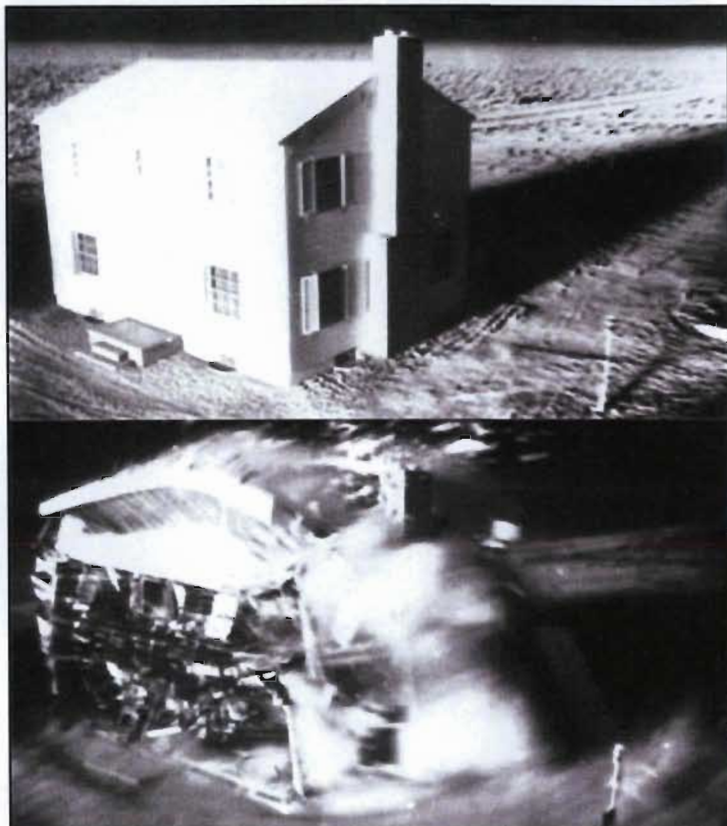
Gun-type assembly method

- **Plutonium-239 (Produced in reactors)**
  - Uranium ore to fuel rods or reactor targets
  - Irradiate U-238 in reactor to make Pu-239
  - Separate (extract) Pu-239 from spent fuel
  - Pu-239 metal, typically >93% Pu-239 for bombs
  - < 10 kg required for a hypothetical bomb
  - Reactor-grade Pu (> 19% Pu-240) can be used for bombs, but is less desirable

Trinity - July 16, 1945

Nagasaki - Aug. 9, 1945

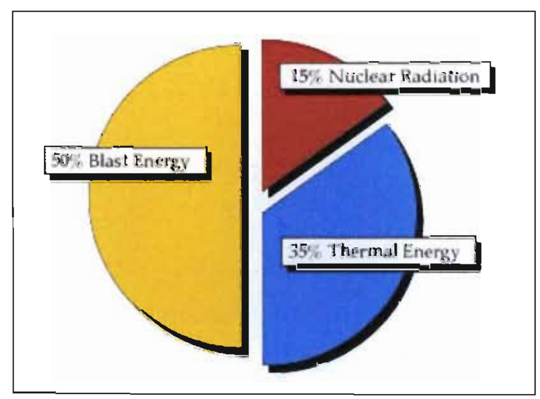
Nuclear Testing



Blast

Heat

Radiation

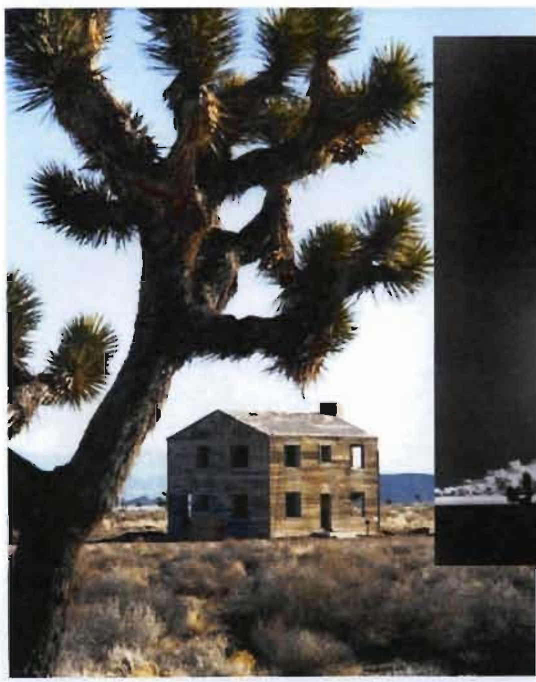


Nuclear Effects Testing

- First priority: survivability of US military forces
  - Crossroads test series, 1946

Crossroad Baker – July 26, 1946

- Civil Effects
  - Teapot Series, 1952-1955



Teapot Apple II – May 5, 1955

Surviving House from Teapot Apple II

Nuclear Effects Testing

- Nuclear Detonations in Space – electromagnetic pulse
  - Dominic Starfish, 1962

View from Honolulu

Dominic Starfish Prime – July 9, 1962

- Civil Engineering - Plowshare
  - Storax Sedan Cratering Shot

July 6, 1962

Storax Sedan, 104 kT

640' emplacement depth

1300' diameter crater
330' deep

Blast

Nuclear explosion in atmosphere produces blast and high-speed winds and debris similar to conventional explosives of similar energy release.

- The pressure wave is the most reliable damage mechanism to structures. It has been the basis for military targeting.
- It is most effective if the explosion occurs at the optimum height of burst, which eliminates fallout.
- The distance at which a given damage occurs increases slowly with yield.

Overpressure	Physical Effects
20 psi	Heavily built concrete buildings are severely damaged or demolished.
10 psi	Reinforced concrete buildings are severely damaged or demolished. Most people are killed.
5 psi	Most buildings collapse. Injuries are universal, fatalities are widespread.
3 psi	Residential structures collapse. Serious injuries are common, fatalities may occur.
1 psi	Window glass shatters Light injuries from fragments occur.

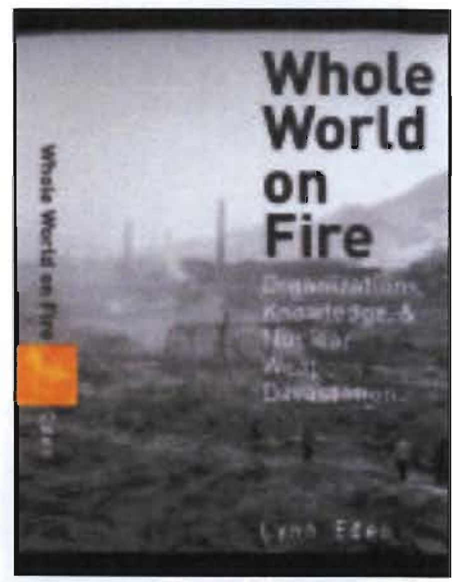
Blast Effects

YIELD	Lethal (50 psi)	Moderate (5 psi)	Light (2 psi)
1 kt	150 m	500 m	920 m
10 kt	320 m	1100 m	2000 m
1 Mt	1500 m	5000 m	9200 m

Heat

- Heat can be more destructive than blast, given clear weather and flammability.
- Some calculations show that firestorms would occur in most cities.
- Heat is not effective against many military structures or protected personnel.

Lynn Eden at CISAC has dealt with the underappreciated effects of devastating firestorms following nuclear detonations.



Radioactivity

- Prompt Radioactivity
  - Matters most for low yields (< 10 kt)
  - Can be shielded against

- Fallout
  - Generated by ground bursts
  - Pattern depends on wind and rain
  - High yields (> 1 Mt) carried globally

Dose-rem	Effects
5-20	Possible late effects; possible chromosomal damage.
20-100	Temporary reduction in white blood cells.
100-200	Mild radiation sickness within a few hours: vomiting, diarrhea, fatigue; reduction in resistance to infection.
200-300	Serious radiation sickness effects as in 100-200 rem and hemorrhage; exposure is a Lethal Dose to 10-35% of the population after 30 days (LD 10-35/30).
300-400	Serious radiation sickness; also marrow and intestine destruction; LD 50-70/30.
400-1000	Acute illness, early death; LD 60-95/30.
1000-5000	Acute illness, early death in days; LD 100/10.

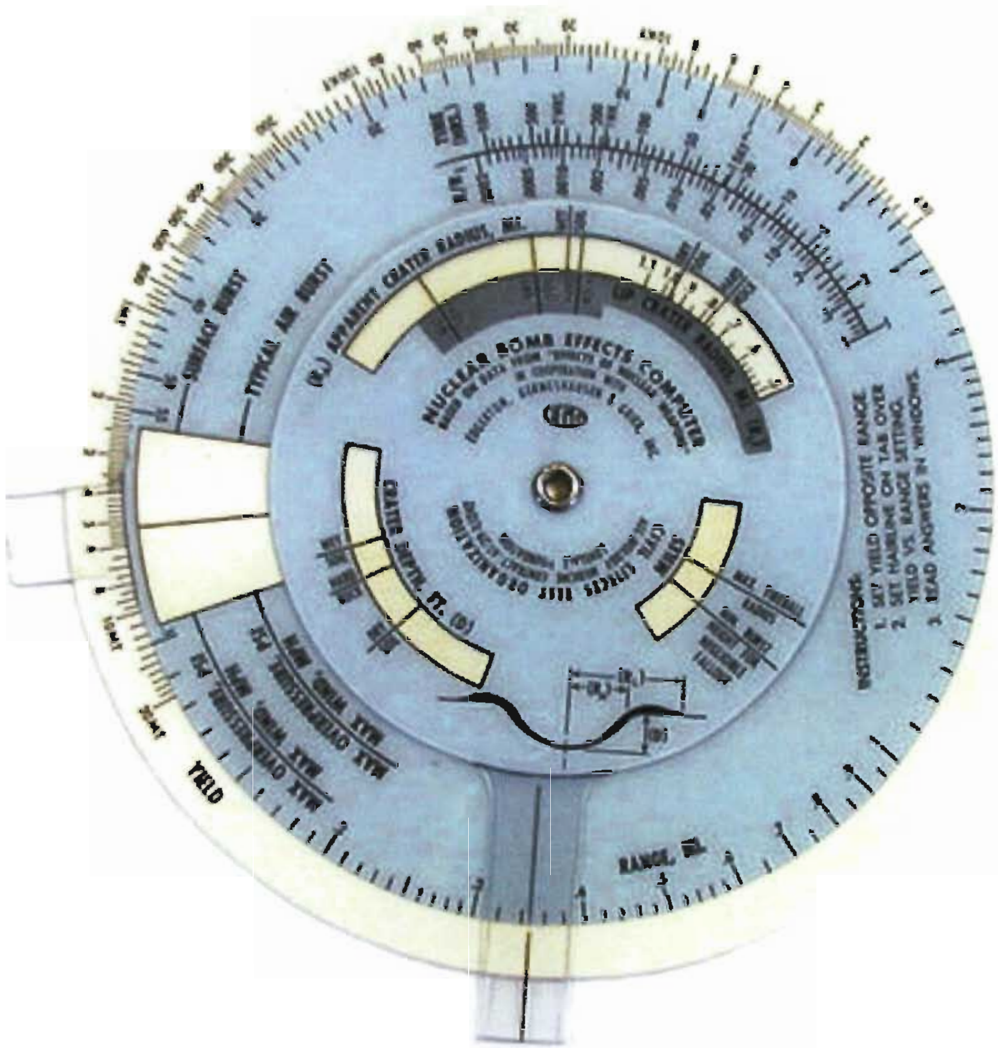
Prompt Radiation and Heat
12 Miles Visibility

YIELD	500 rem Prompt Radiation	50 % of Pop. 4-6 cal/ cm^2 2^{nd} Deg. Burn	50% of Pop. 6-12 cal/ cm^2 3^{rd} Deg. Burn
1 kt	730 m	800 m	630 m
10 kt	1300 m	2400 m	1900 m
1 Mt	2400 m	13,000 m	11,000 m

Fallout within 24 hours
500 rem areas

YIELD	AREA
1 kt	2 km^2
10 kt	20 km^2
1Mt	2000 km^2

Nuclear Effects Testing – Civil Defense



Analog Nuclear Weapon Effects Calculator

A few additional facts about Nuclear testing

United States
1030 total (215 atmosphere)

Soviet Union
715 total (207 in atmosphere)

France
204 total

United Kingdom
45 total

China
43 total

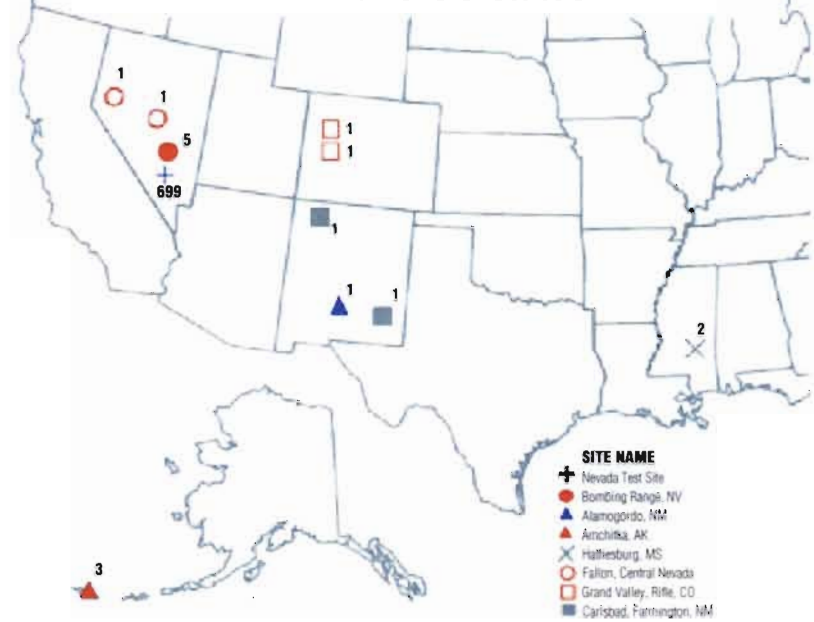
India
6 underground

Pakistan
6 underground

North Korea
2 underground

Enigma
1 over South Atlantic (Sept. 22, 1979)

Nuclear tests have been conducted in 5 US states



Salmon Nuclear Test Site
Tatum Salt Dome
Mississippi

Nuclear Weapon History and Development

Advancements in Nuclear Weapon Design

Early, first generation weapons were fission-only devices, 10's of kT of yield, 1000's of kg in mass

The first test series, Operation Crossroad, did not advance nuclear weapon design.

Priority was more efficient use of nuclear material. Operation Sandstone was this effort

Sandstone X-Ray – 5th nuclear explosion, 37 kT, April 14, 1948

Sandstone Yoke – 6th nuclear explosion, 49 kT, April 30, 1948

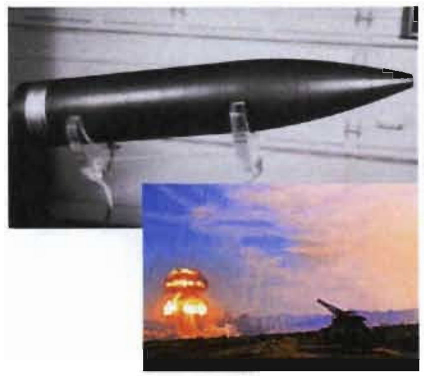
Sandstone X-Ray

Sandstone Yoke

Advancements in Nuclear Weapon Design

- Beginning with Sandstone, advances in nuclear weapon design allowed a **reduction** in mass of the implosion device by a **factor of 30** from 1948 to 1956
  - Development of "boosting" was key: use of fusion in the primary
  - **Diameter** was reduced a factor of 3
  - Plastic-bonded explosives (PBX) were developed in 1956

- This dramatic reduction in weight and size enabled a huge diversity of new delivery systems
  - Tactical Missiles
  - Depth charges
  - Artillery shells
  - Landmines
  - And many, many more



Mk48 Artillery Shell

Davy Crockett W-54 SADM
(Special Atomic Demolition Munition)

B54 "Backpack" SADM

Mk7 Nuclear Depth Charge

Development of the Hydrogen Bomb

- Edward Teller and Stan Ulam conceived of the key principle
  - *radiation implosion*
  - Tested in Ivy Mike – Oct. 31, 1952 (33 months from initiation of development!)
  - "physics" test; difficult to weaponize configuration with liquid deuterium fuel
  - Andrei Sakharov of the USSR independently proposes the same concept

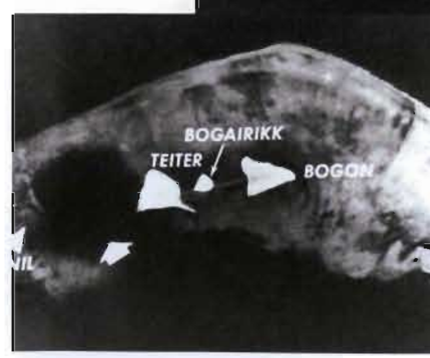
Ivy Mike device with diagnostic pipes

Ivy Mike, 10.4 MT

Elugelab Island is vaporized

before

Enewetak Atoll



after

Advancements in Thermonuclear Weapon Design

- Ivy Mike was a spectacular physics success, but several key problems remained to weaponize this new concept:
  - Cryogenic fuels were a nightmare
  - Tritium has a short half life (12.3 years)
  - The race to develop a long-range missile delivery system required dramatic reductions in mass and size

- The solution? "dry" thermonuclear fuel
  - lithium deuteride, LiD
  - Breeds tritium *in situ* with neutrons

$$D + T \rightarrow {}^{4}He + n + energy$$

$$Li + n \rightarrow {}^{4}He + T + energy$$

$$D + Li \rightarrow 2\,{}^{4}He + energy$$

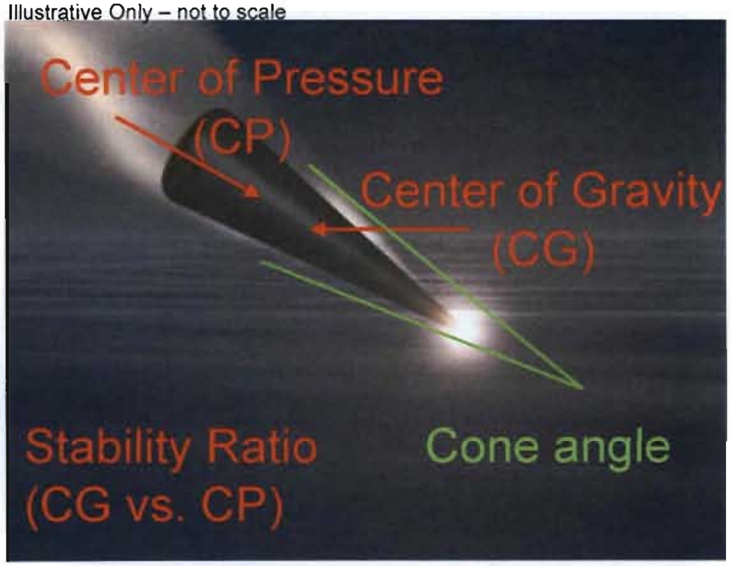
lithium deuteride

Castle Bravo – March 1, 1954
First test of staged, dry thermonuclear fuel
Largest US nuclear detonation – 15 MT

Advancements in nuclear weapon miniaturization enabled dramatic improvements in accuracy

- Nuclear Weapon Blast effects scale with the cube-root of yield
- Given a choice between accuracy and yield, accuracy is far superior!

Illustrative Only – not to scale



1959 Air Force Test Vehicle

This conflict – placing the center of gravity forward in narrow cones – defines many decades of weapon development

The miniaturization of warheads enabled successful long-range missile development

- Twin goals in development:
  - Long range strike potential
  - Survivability, especially after an opponents nuclear strike
- USSR's Sputnik – a soviet R-7 long-range missile – was launched on Oct. 4, 1957
  - The US Atlas-A missile (also known as Mercury in manned space flight) was tested 4 months later on Dec. 17, 1957
- ICBMs – Intercontinental Ballistic Missiles – were deployed starting in 1959
  - Continual upgrades in both warheads and missiles
  - Generally, based at fixed locations with hardened silos
- SLBMs – Submarine Launched Ballistic Missiles were deployed starting with the Polaris A-1 system in 1961


Atlas A1 ICBM


Minuteman III ICBM


Trident D5 SLBM


Trident II Test Launch

Nuclear Weapon Accidents

- The constant patrols and alert status of nuclear forces meant that nuclear weapons were on-board aircraft with constant handling and movement
- Department of Defense cataloged 32 significant US nuclear weapon accidents from 1950 to 1980
  - *No US accident has resulted in nuclear yield* – and *this* was no accident
  - Safety of weapons in accidents has always been considered
  - Often, high explosives did detonate, and nuclear material was spread

January 17, 1966
Palomares, Spain
B-52 collides with KC-135 refueling tanker
2 bombs have HE detonation
3rd bomb lost in the Mediterranean

January 21, 1968
Thule, Greenland
B-52 has fire on board
crashes 7 miles from runway
while attempting emergency landing
At least one bomb has HE detonation
Plutonium spread for 600 yards on either side

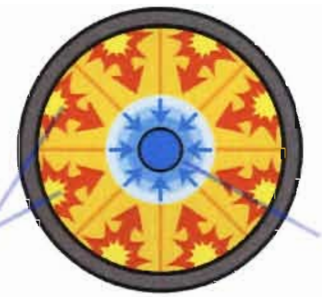
Nuclear Weapon "Surety"

- In response to these incidents, an increased focus on nuclear weapon safety and security occurred

- This became known as "Surety"
    - Safety
    - Security/Use Control

Security
•Permissive action links
  •Coded locks
•Launch environment detectors
  •Unique sequence to arm
•Stronglinks/weaklinks

Safety
•Avoid nuclear yield!
•One-point safety
  •1 in 1,000,000 of less than 4 pounds
•Insensitive High Explosives
•Fire resistant pits
  •Plutonium containment in aircraft fires
•Stronglinks/weaklinks



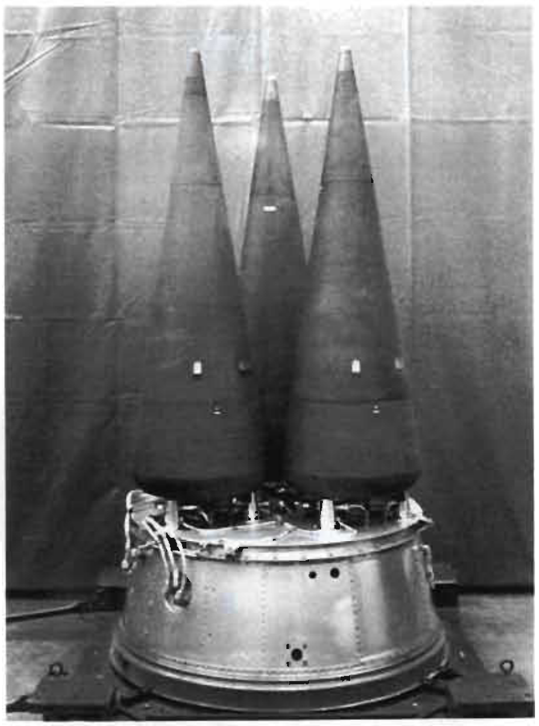
Plutonium metal

Permissive Action Link (PAL) controller

Nuclear Weapons in the Present

The US Enduring Stockpile - ICBMs

- All of these developments came to fruition in the mid 1970s
    - surety, compact delivery systems, robust performance
- Triad was composed of several highly-developed systems

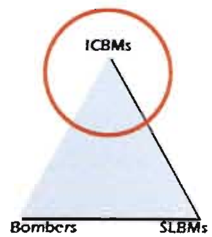


W78/Mk12a RVs on a "bus"

ICBMs

Ease of maintenance at remote sites
Optimized yield/weight
MIRVed - multiple reentry vehicles/missile

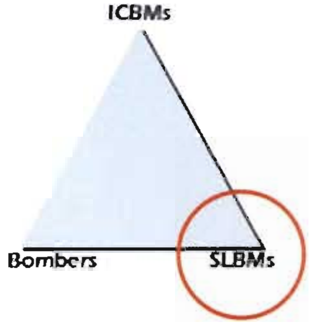
- W78
    - Minuteman III
- W87
    - Peacekeeper
    - 8-RV MIRV
    - IHE, fire-resistant



W87/Mk21 RVs

The Air Force refers to the delivery vehicle as a Reentry Vehicle - RV

The US Enduring Stockpile - SLBMs



SLBMs

Highly compact RBs for submarine deployment
Highly optimized yield/weight to extend range
Maintenance at 2 sub bases
- Kings Bay, Georgia
- Bangor, Washington

- •W76
  - •Trident C4 Missile
  - •Compact RB
  - •8-RB MIRV
- •W88
  - •Trident D5 Missile
  - •8-RB MIRV

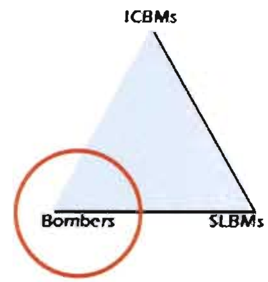
W76/Mk4a RBs on maintenance stands

Trident D5

The Navy refers to the delivery vehicle as a Reentry Body - RB

The US Enduring Stockpile – Air Carried

Air-Carried Platforms



B61-11 loading

Bombs and cruise missiles
enhanced surety features
extended STS environment compatibility
- all have IHE, PALs

- B61 Gravity Bomb
  - many variants
  - B61-11 earth penetrator
    - latest US "mod"
- B83 Gravity Bomb

- W80 Cruise Missile

B83 Gravity Bomb

AGM 86 Cruise Missile

W80-0 Warhead

Issues in the Current Nuclear Weapon Stockpile

Berlin wall falls

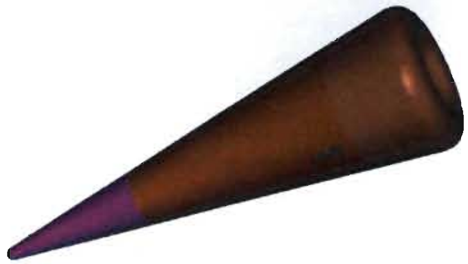
- The period from 1989 to 1992 saw incredible change
  - US production complex shutdown
  - US test moratorium begins
  - Soviet Union dissolves – the Cold War ends
- These changes drive several new issues in ensuring a safe, reliable deterrent
  - Is there a continued role for nuclear weapons?
    - In the near-term we'll have them - considerably smaller numbers desired
  - Can weapons be maintained in the long term without testing?
    - A science-based approach, *stockpile stewardship*
  - Can a stockpile be reliable and safe without regular new production?
    - Perhaps the biggest unknown of all – weapons do age!
    - Stockpile changes are a simple fact – either aging or remanufacture

IBM Roadrunner
World's fastest computer

plutonium aging
Pu-238 accelerated-aged ingot

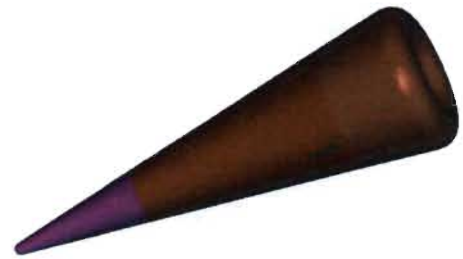
Non-nuclear testing
RRW "hydro" test

A comparison of the Reliable Replacement Warhead (RRW) to the legacy stockpile



Legacy Design

- Optimized for high yield-to-weight ratio
- Relatively low margin-to-failure
- Energetic high explosives
- Limited security features
- Exotic materials
- Hard to manufacture components
- Frequent surveillance
- Dismantlement difficult



RRW Design

- Optimized for high margin-to-uncertainty ratio
- Insensitive high explosive
- Enhanced security
- Ease of manufacturer
  - Eliminate exotic materials
  - Alternate materials
  - Reduced process steps
- Reduced surveillance requirements
- Improved dismantlement and material disposition

Agile, assured ability to produce RRW enables a capability-based deterrent

Recommended References

Nuclear weapon effects:
"The Effects of Nuclear Weapons", Samuel Glasstone and Philip Dolan – in several editions, latest is 1983
versions with the analog nuclear effects calculator are highly-sought

Nuclear testing:
"Trinity and Beyond – the Atomic Bomb Movie", 1995, directed by Peter Kuran, William Shatner narrates

Nuclear weapons safety and accidents:
"The Limits of Safety: Organizations, Accidents, and Nuclear Weapons", Scott Sagan, Princeton University Press, 1993

Plutonium aging and pit lifetimes:
"Plutonium: Aging Mechanisms and Weapon Pit Lifetime Assessment", Joseph Martz and Adam Schwartz, Journal of Metals, 55(9) pp.19-23, (2003) – available online at http://www.tms.org/pubs/journals/JOM/0309/Martz-0309.html