Dr. Strangelove

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Introduction

- Humanity is in its first century of atomic energy
  - Who doesn't love atomic energy!!!
- "atomic energy" means energy, but also weapons
  - And nuclear weapons have been with us since WW2.
- Has it been a benefit to mankind?
  - Some say it has prevented all-out war as in the past.
- Do you know that you are lucky to be alive?
  - What do you know about the atom bomb?
- What does history tell us? There is real disagreement here!

"History is but the register of human crimes and misfortunes."

Voltaire (cynic)

"History is the version of past events that people have decided to agree upon."

Napoleon Bonaparte (manipulator)

"Human history becomes more and more a race between education and catastrophe."

H.G. Wells (eternal optimist)

Nuclear Physics

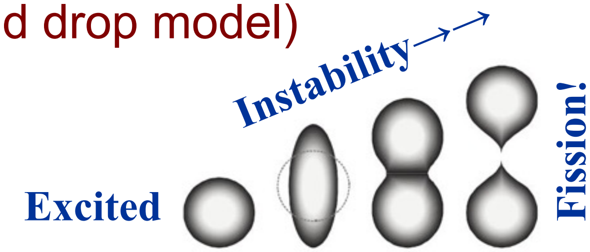
- Atomic energy and nuclear bombs come out of Nuclear Physics
- First…a primer…

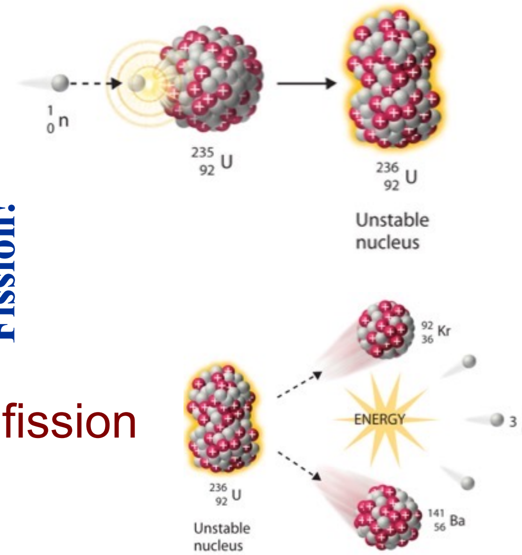
Atoms

- Made up of protons (charge +1) and neutrons (charge 0)
  - Remember, like-sign charges repel each other
- Atomic number: number of protons
  - This determines chemistry
- Atomic weight: weight of protons + neutrons
- Isotope: an atom with more than or less than "usual" number of neutrons
  - Example: Carbon has 6p+6n = C_{12} but C_{14} is an isotope with 2 extra neutrons
- Hydrogen: 1p, 0n
- Helium: 2p, 2n
  - What keeps the 2 protons from from flying apart?
  - Strong Nuclear Force!
    - Protons and neutrons are all attracted to each other by this force
- Uranium: 92p, 146n
  - Why #n > #p? So that Uranium is stable
  - But not all THAT stable as we shall see…

Nuclear Fission

- Uranium: 92 protons, 143-146 neutron, is most common isotopes
  - Naturally occurring in ore, with ~99.3% U_{238}, 0.7% U_{235}
- Fission:
  - Facilitated by neutron capture: $n + U_{235} \rightarrow U_{236}$
  - Increases isotope number by 1…
  - …and causes instability (liquid drop model)

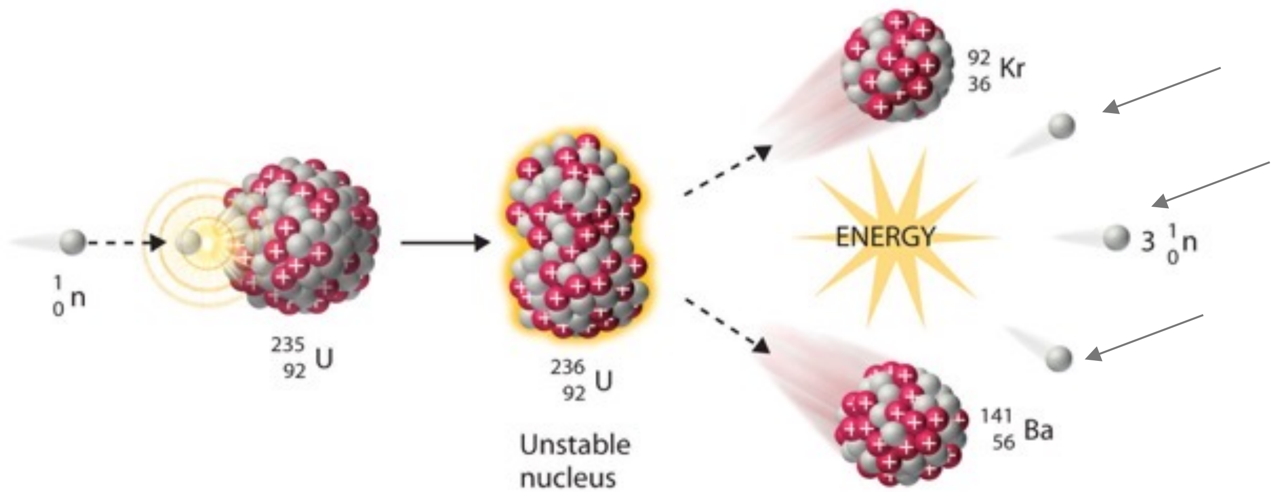




  - With sufficient energy, instability can build up and cause fission
  - Threshold to fission:
    - Isotopes w/odd number nucleons have lower threshold to fission after 1 n absorption
      - QM, Pauli Exclusion principle, nuclear shell model
    - Lower number isotopes (U235) easier to fission (than U238)
      - Neutrons hold nucleus together, counter EM force due to protons
  - Bottom line:
    - Need higher energy neutron “bullets” for U238 fission vs U235

Uranium Fission

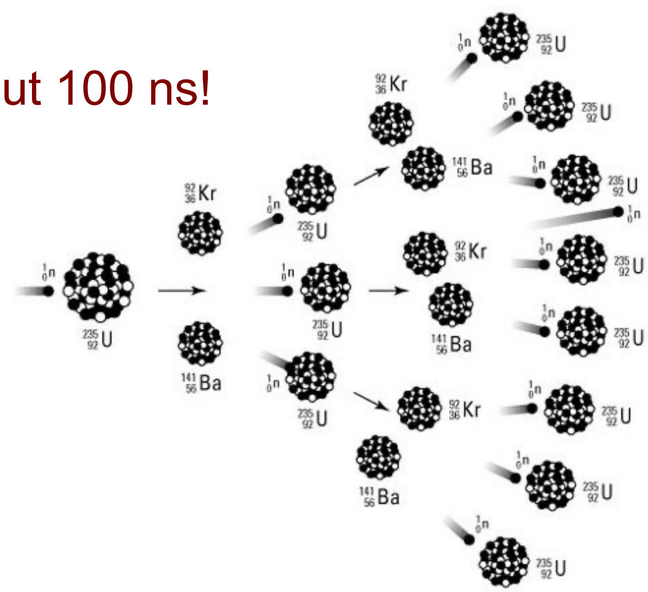
- Each fission produces fragments, energy, and more neutrons
  - n + $U_{235} \rightarrow$ Ba + Kr + ~3n + energy, or Cs + Kr + ~4n + energy
  - Energy released is around 200 MeV per fission
    - MeV = million electron volt, 1 electron volt = 1.6×10^{-19} Joules, extremely small amount of energy



- Energy of released neutrons is small.
  - Will not be able to cause fission if it collides with U238 atom
  - WILL be able to cause fission if it collides with U235!

Chain Reaction = Fission Bomb

- For U235 can build up a chain reaction
  - 1→3 →9 →27 →82 →…need 50-60 generations to cause significant explosion
  - 99% energy released in last ~10 generations, about 100 ns!



- Energy release measured in "kilotons" TNT equivalent
  - Energy released by TNT is around 1000 cal/gram. 1 kton = 4.184×10^{12} Joules
    - Note: 1 kW-hr – 3.6×10^{6} joules, so 1kton = 1.16×10^{6} kW-hr = 133 kW-yr
    - 500 kton = 66,300 kW-yr, or the energy consumed by 66,300 homes in 6 months assuming 2kW average usage. Instantaneously!

Fission Bombs

- Hiroshima bomb:
  - 64kg = ~2 $x10^{26}$ U^{235} atoms
  - About $2x10^{24}$ fissions → 64 x 10^{12} Joules released
    - About 15 ktons TNT equivalent
- Largest fission weapon: ”Ivy King”
  - 500ktons, Nov 1952, $2.1x10^{15}$ J = $2x10^{15}$ BTU energy
    - About same total amount of energy used in Kentucky in 2014

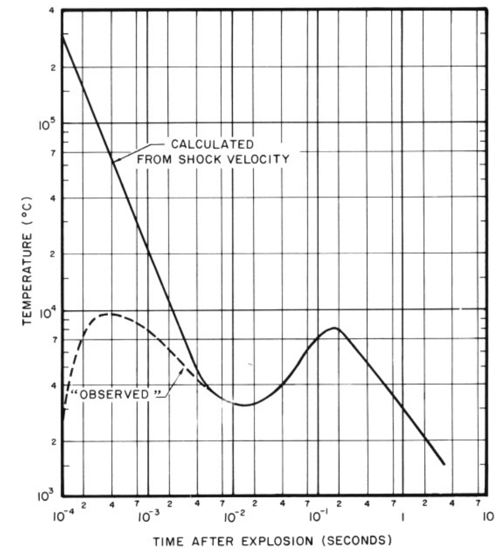
Fusion Bomb

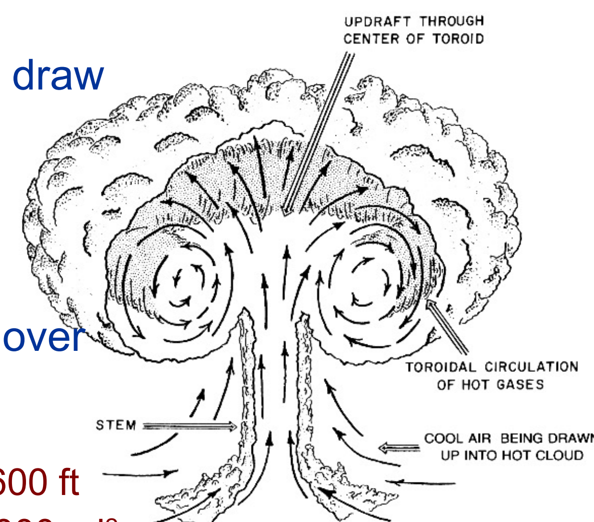
- Aka: "H-Bomb" and "Thermonuclear bomb"
- Many variations on the fusion process.
  - For stars in early stages: (note: H^2=deuterium, H^3=tritium)
    - $H^1 + H^1 \rightarrow H^2 + \nu + e^+ + 0.42$MeV (half life ~$10^9$ years)
    - $H^2 + H^1 \rightarrow He^3 + \gamma + 5.5$ MeV (half life ~few seconds)
    - $He^3 + He^3 \rightarrow He^4 + H^1 + H^1 + 12.9$ MeV (half life few 100 years, dominant in Sun)
  - For bombs:
    - $H^3 + H^2 = He^4 + n + 17.6$ MeV (yield is x3/nucleon above fission!)
    - Most bombs include Lithium-6 deuteride (Li^6H^2) to make H^3 ($Li^6 + n \rightarrow He^4 + H^3$)
- Most thermonuclear bombs use fission "ignition"
  - T > 10,000,000 K required – aka "Thermonuclear"
  - Chain reaction: increasing heat causes increasing fusion
- Fusion bomb yield: megaton range
  - Largest fusion bomb ever: USSR "Tsar Bomba" 50 Megatons, 1955

Destruction

- Temperature: >T_{sun} at fireball
  - Initial energy released in first microsec
    - Energy densities of around 1 Gigajoule/cm^3
    - High intensity gamma and x-rays
    - X-rays absorbed within a few feet
    - Forms “**FIREBALL**”
      - 1 Megaton fireball can be seen 50 miles away
        - Brighter than sun
      - Is around 1 mile across after 10 sec
      - Rises at around 300 mi/hour
      - Rising hot air expands, causes vacuum to draw cooler air and material up.
      - Results in huge upward going winds
      - Can suck up lots of material, mixes with radioactive residual of bomb material
      - “Fallout” can be carried by trade winds all over globe.
        - Worsens as height of blast decreases
        - Not significant in Nagasaki/Hiroshima, ~1600 ft
        - 1954 Bikini surface blast fallout covered 7000 mi^2

20 kton Blast





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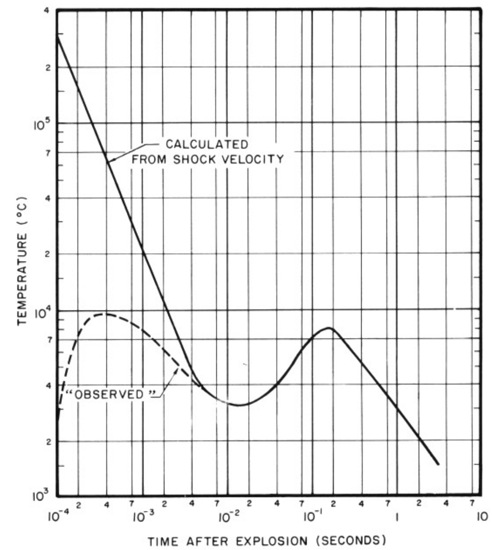
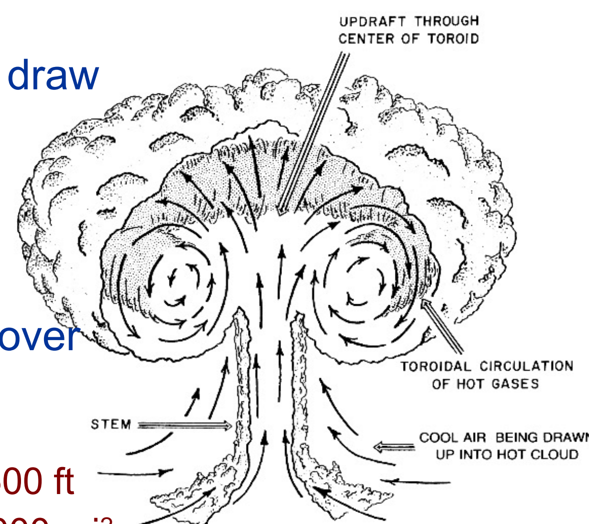


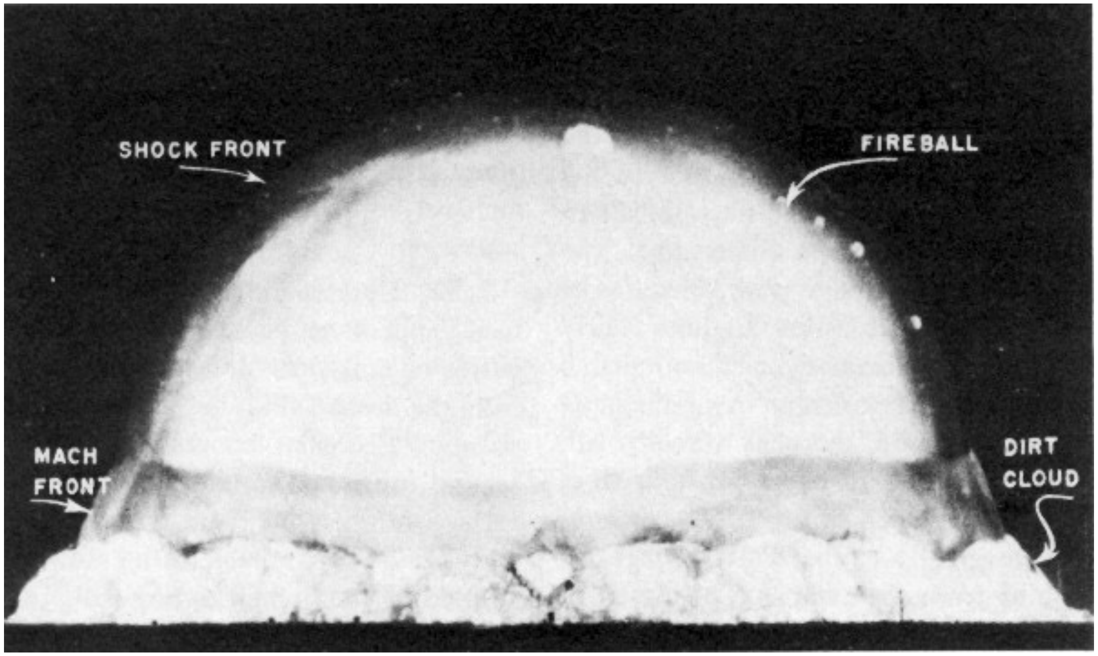


Famous nuclear bomb tests

- RDS-37 Soviet H-bomb test 1955
  - 2-stage H-bomb, Andrei Sakharov and Ykov Zel'dovich
    - Initial stage A-bomb, generates intense X-rays
    - 2nd stage: X-rays compress H_3+H_2 fusion
  - Yield 2 Megatons
- Tsar Bomba, Soviet H-bomb test 1961
  - Largest H-bomb ever detonated
  - Yield 50 Megatons
- *Ivy, first US bomb, 1952*
  - More of a physics experiment to see if it was possible
  - 82 tons, liquid deuterium at cryogenic temperatures
  - Yield 10 Megatons
- Atomic Canon, atomic artillery, US, 1953
  - Yield 15 ktons
- Bighorn, US, 1962
  - Yield 7.65 Megatons
- Operation Teapot, Turk, US, 1955, slow motion
  - Discussion
  - Yield 43 ktons
- Early tests, South Pacific, US, late 1940s – 1950s
  - Huge number of tests.
- See atomcentral.com for more

Blast Wave

- Heat and high temps cause initial outward-going shock wave
  - 1 Megaton blast shock wave moves with $v \sim v_{sound}$ (1100 ft/sec)
  - Reflected waves combines with initial wave to produce "Mach" Front
    - Pressure front of several atmospheres
    - Winds of 100s mph
  - Vacuum is caused by initial waves, which causes relaxation
    - Causes inward-going shock wave a short time later
    - Low altitude means more density means more shock means more destruction



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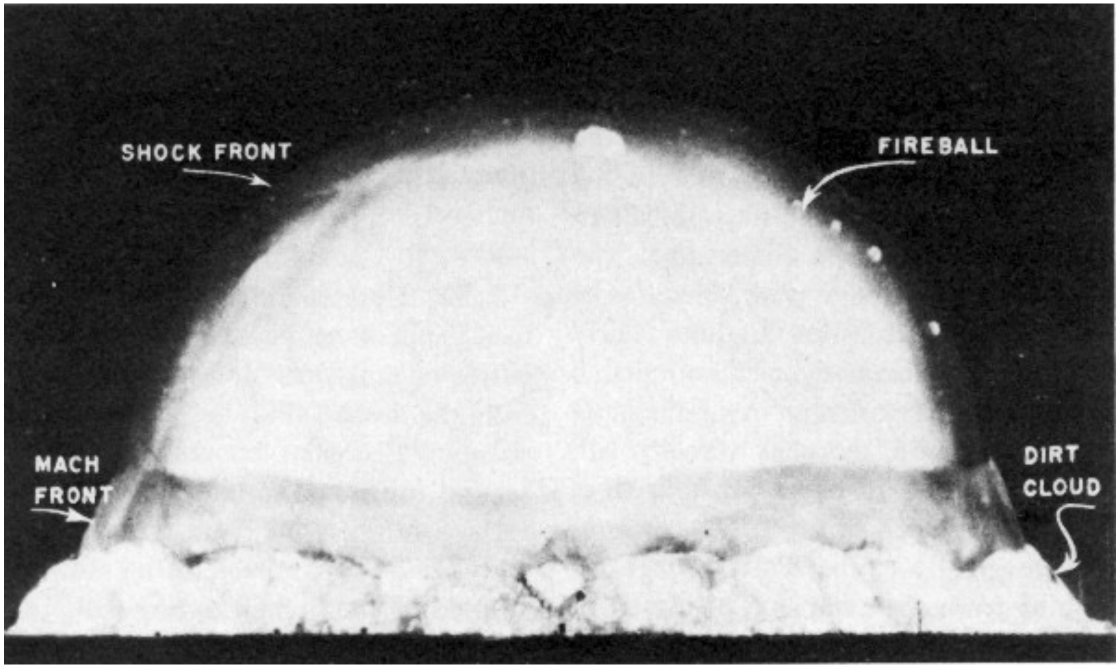
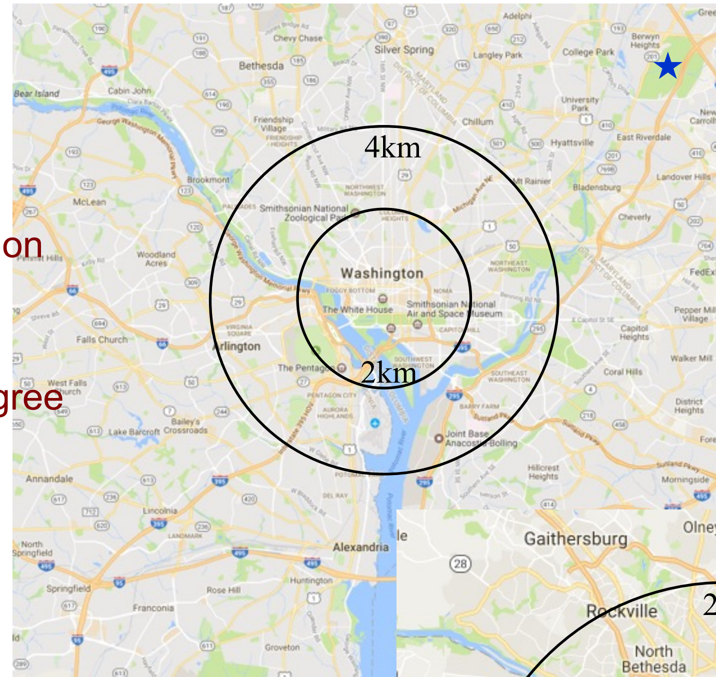
- Examples
  - Plane fuselage
  - Land vehicle
  - Trees
  - Houses

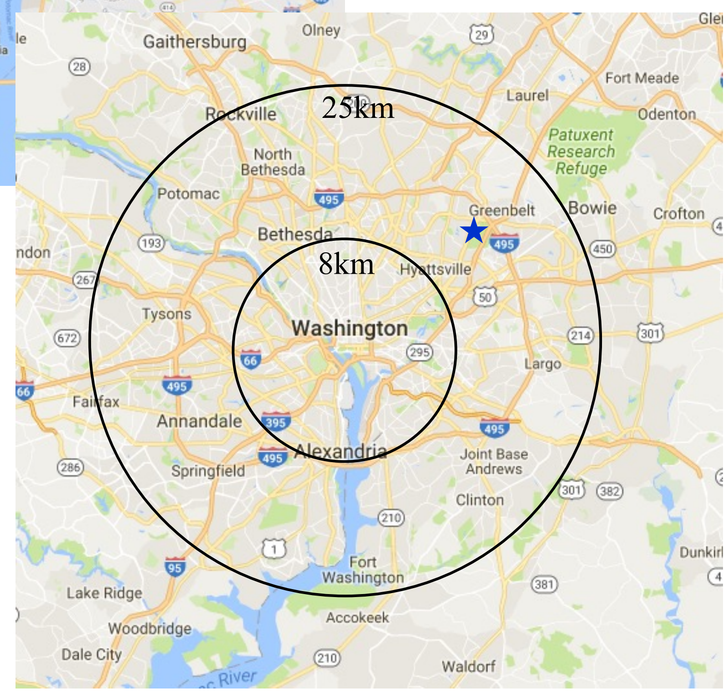


Effects of detonation: 1Megaton bomb at White House

- Initial blast wave
  - Destroys reinforced concrete: 2km
  - 600 km/hr winds: 4-5 km
  - Destroys brick/wood blds, lethal radiation :~8km
  - Fires: 20km
  - Breaks all windows and causes 3rd degree burns:~25km
- Resulting firestorms
  - burst fuel tanks, gas mains
  - sucks away all oxygen from nearby surroundings to feed fire
    - If you survive the fire you probably die of suffocation (ala Dresden)
- Survivability
  - Depends on height and magnitude of blast
  - Rule of thumb if outside:
    - 0% survivability if <3km away
    - 50% if <8km away



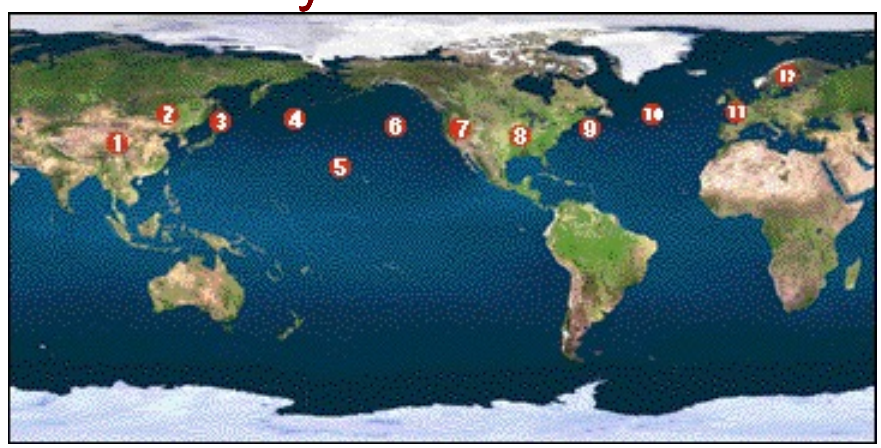
★ YOU!



Damage to life forms

- From heat and high temperatures, 1 Megaton yield
  - Can be blinded up to 80 km away if viewed w/naked eyes
  - Within 30 km:
    - 2nd degree burns on exposed flesh
    - Clothing catches on fire
    - Worse for detonation on clear and dry day
  - Radiation sickness, cancer, etc. over longer range
    - Depends on detonation height, weather conditions, yield, etc.
- Estimated population survival statistics:
  - 1/3 dead instantly
  - 1/3 seriously injured, death in hours or days
  - 1/3 slightly injured if at all

Daily observations of the cloud of radioactive dust particles after a Chinese test at Lop Nor on May 9, 1966. The cloud moved about 1,400 miles per day.

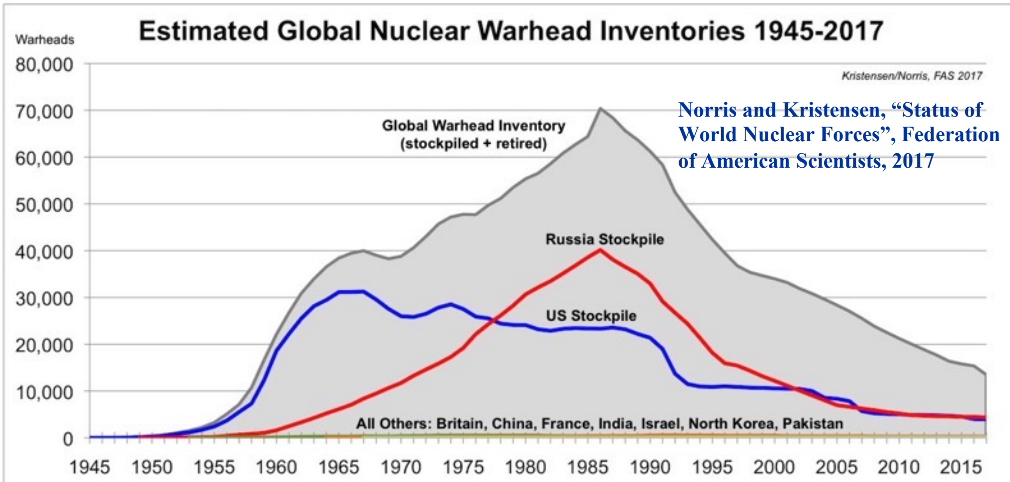


Nuclear Arsenal

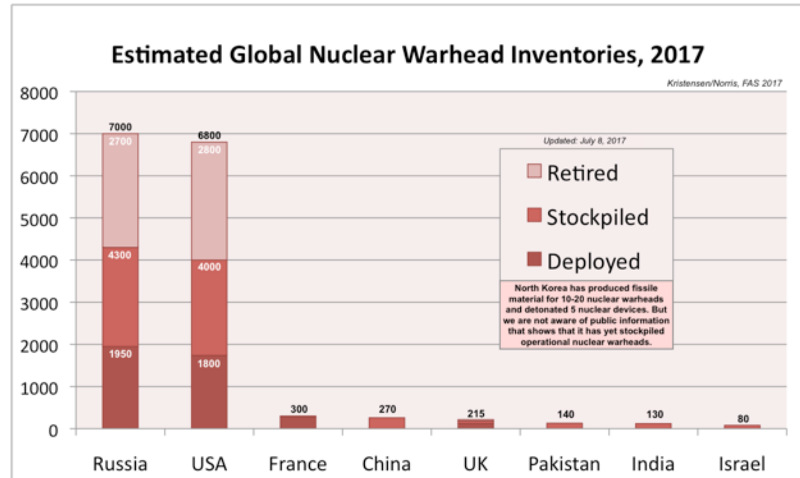
- Cold war: US and USSR
- Massive reliance on nuclear weapons
- Full out exchange of nuclear weapons? Probably means the end of civilization
- At the height of the cold war, the average nuclear weapon yield was around 300ktons
  - Hiroshima, 15ktons, about 20x smaller
- Quiz: what was the total number of nuclear weapons at the height of the cold war, c 1970s?
  - 100?
  - 1,000?
  - 10,000?
  - 100,000?

Nuclear Arsenal

Historical



Now

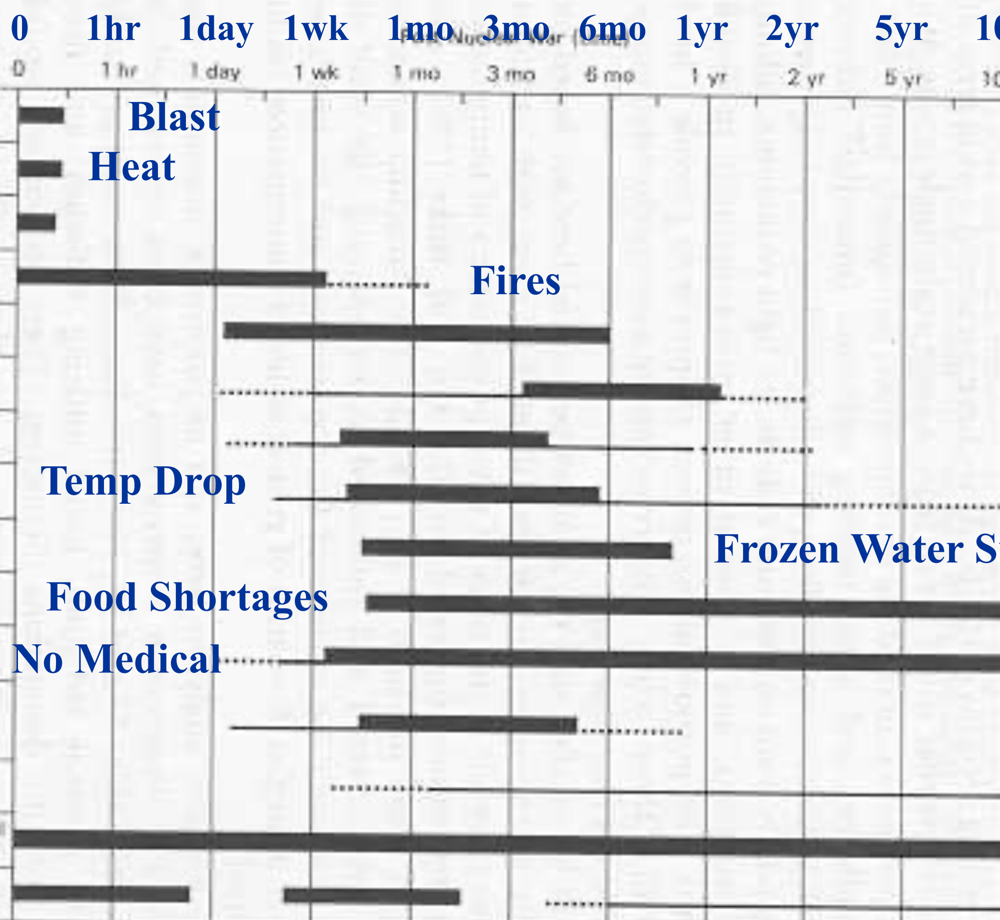


- Cold war: US and USSR "roughly" equal numbers at maximum
  - Total yield at height of cold war ~25,000 Megatons (>1,000,000 Hiroshimas)
- Considerable strategic reductions since ~1990
  - US and Russia are now roughly equal, maybe 4,000-7,000 each (secret)
    - Very complicated to figure out what's what, but here is a rough estimate:
      - They differentiate between "stockpiled", "deployed", etc.   Roughly 2,000 each US and Russia "deployed"
      - Stockpiled: not active, many waiting dismantlement
      - Around 4,000 total world wide are deployed in operational forces, ready for use on short notice
  - These are warheads.   Average yield/warhead probably ~300kton
  - Other nuclear states: France + UK ~ 500, China ~300, Israel ~ 100, Pakistan + India ~300 + ????
    - Some countries have stockpiled fissile material, not included here

“Survival” of Nuclear War?

- No infrastructure left for recovery
  - No rescue, power, water, hospitals, communication
  - Not enough hospital beds in entire USA to cover needs of 1 city of ~1 M people
- Recovery time after exchange
  - Decades (or maybe infinite)
- “Nuclear Winter” - Estimates based on simulation, extrapolation, interpolation….guesses:
  - All-out nuclear war between USA and USSR/Russia:
    - ~1 billion humans die immediately
    - ~1 billion soon after
    - Remainder reduced to barbarism
  - Huge firestorms would erupt near each ground zero
  - Resulting dust would cover both hemispheres
    - Blocks sunlight, reduces temperatures
    - Surface temperatures in some regions drop 20-40 ºF for weeks
    - Detonation of 100 megatons over 100 cities could produce temp drops from 1 to 20 ºF worldwide
  - Ecological devastation similar to dinosaur extinction period 65M yrs ago

Nuclear Winter guesses….



Mechanism of Effect	Population at Risk: U.S.[1]	N.H.[2]	S.H.[3]	Casualty Rate for Those at Risk	Potential Global Deaths[4]
Blast	H	M	L	H	M-H
Thermal Radiation	M	M	L	M	M-H
1° Ionizing Radiation	L	L	L	H	L-M
Fires	M	M	L	M	M
Air Pollution	H	M	L	L	L
Stratospheric O_3 Reduction	H	H	M	L	L
Light Reductions	H	H	M	L	L
Temperature Reductions	H	H	H	H	M-H
Frozen Water Supplies	[illegible]	[illegible]	M	M	M
Food Shortages	H	H	H	H	H
Medical System Collapse	H	H	M	M	M
Diseases: Contagious (shelter period)	M	M	L	H	M
Epidemics (pest vectors)	H	H	M	M	M
Psychological/Societal Stress	H	H	L	L	L-M
Radiation	H	H	L-M	M	M

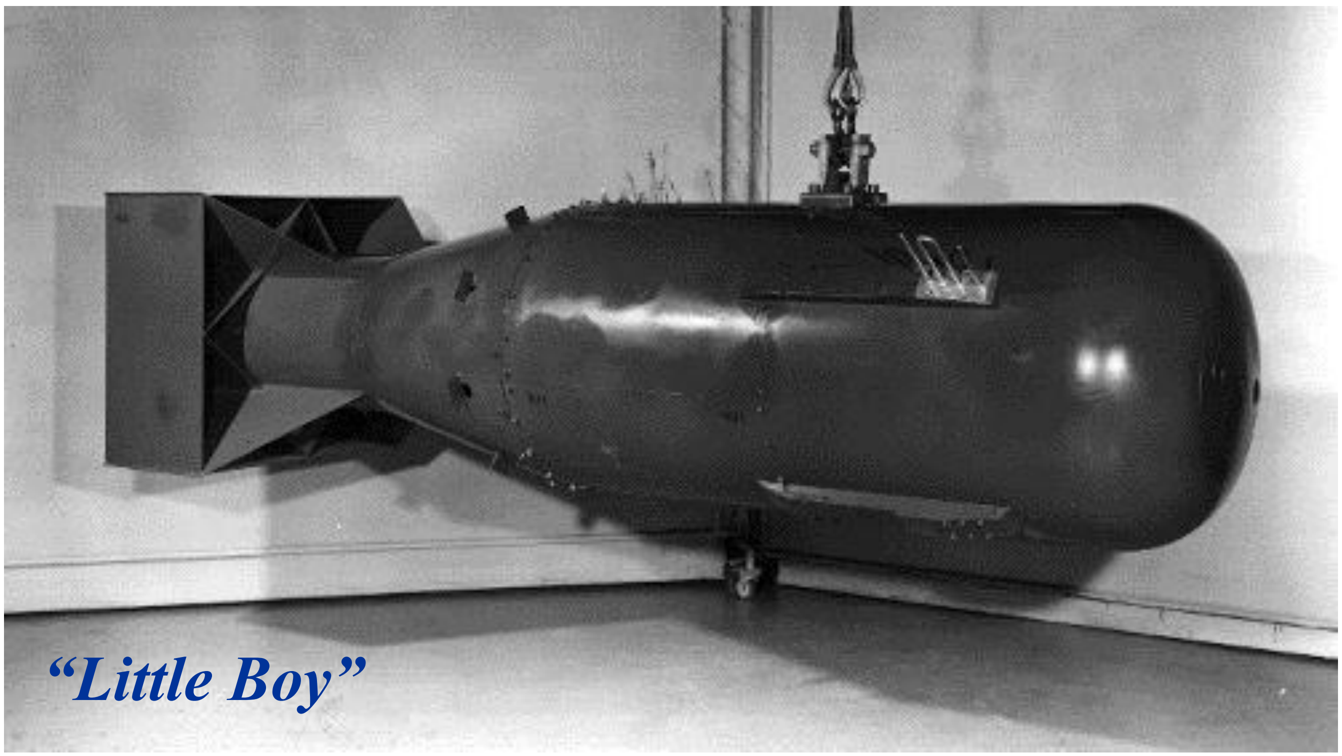
[1] U. S., United States [2] N. H., Northern Hemisphere [3] S. H., Southern Hemisphere [4] Global deaths: L, 0-10^7; M, 10^6-10^8; H, 10^9

Figure 27. Summary of timing and magnitude of direct and indirect effects from a large-scale nuclear war.

Hiroshima Aug 6, 1945

10.5 ft long

Uranium



Weighs 5 tons. Yield 12-15ktons TNT equivalent

Hiroshima

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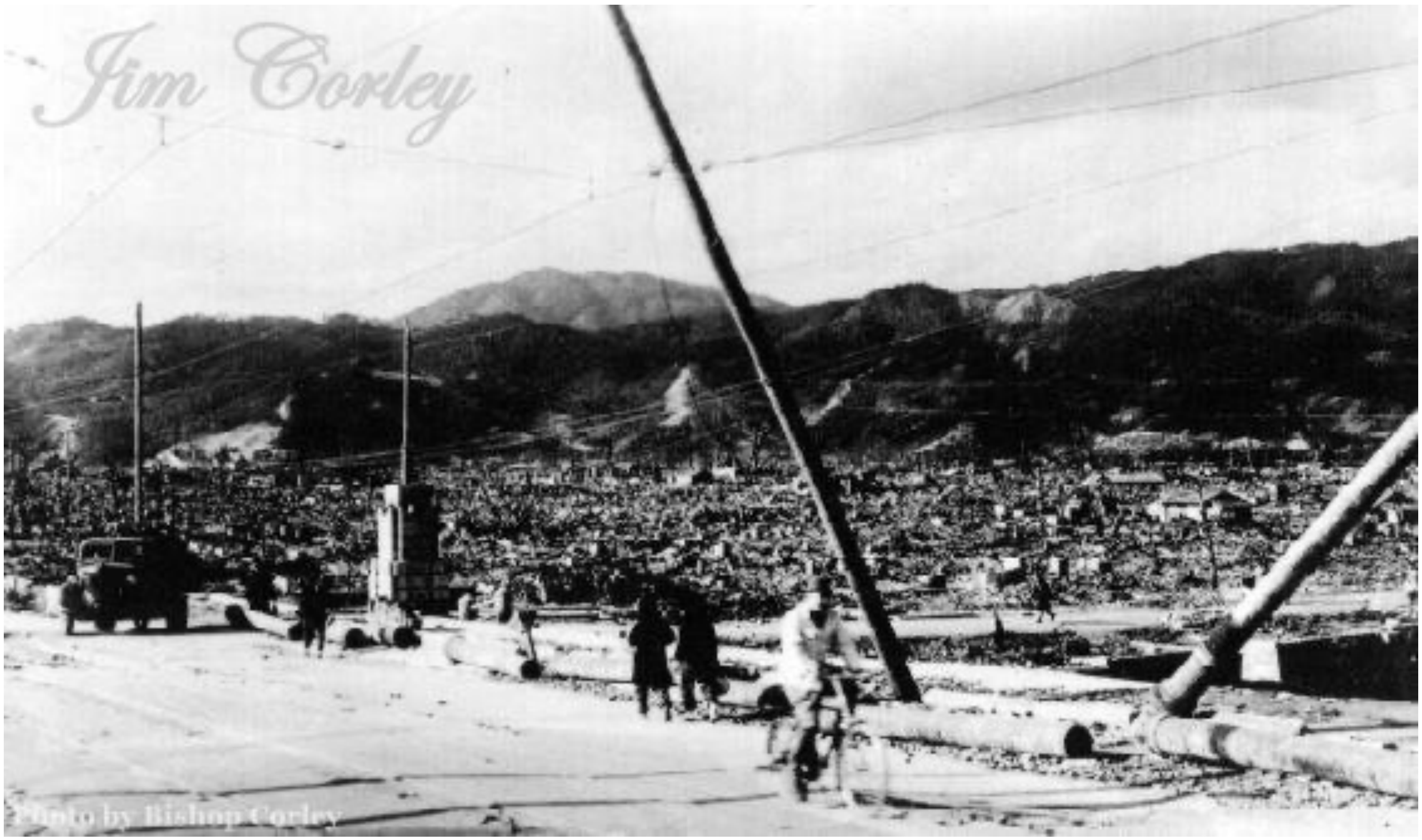


Hiroshima

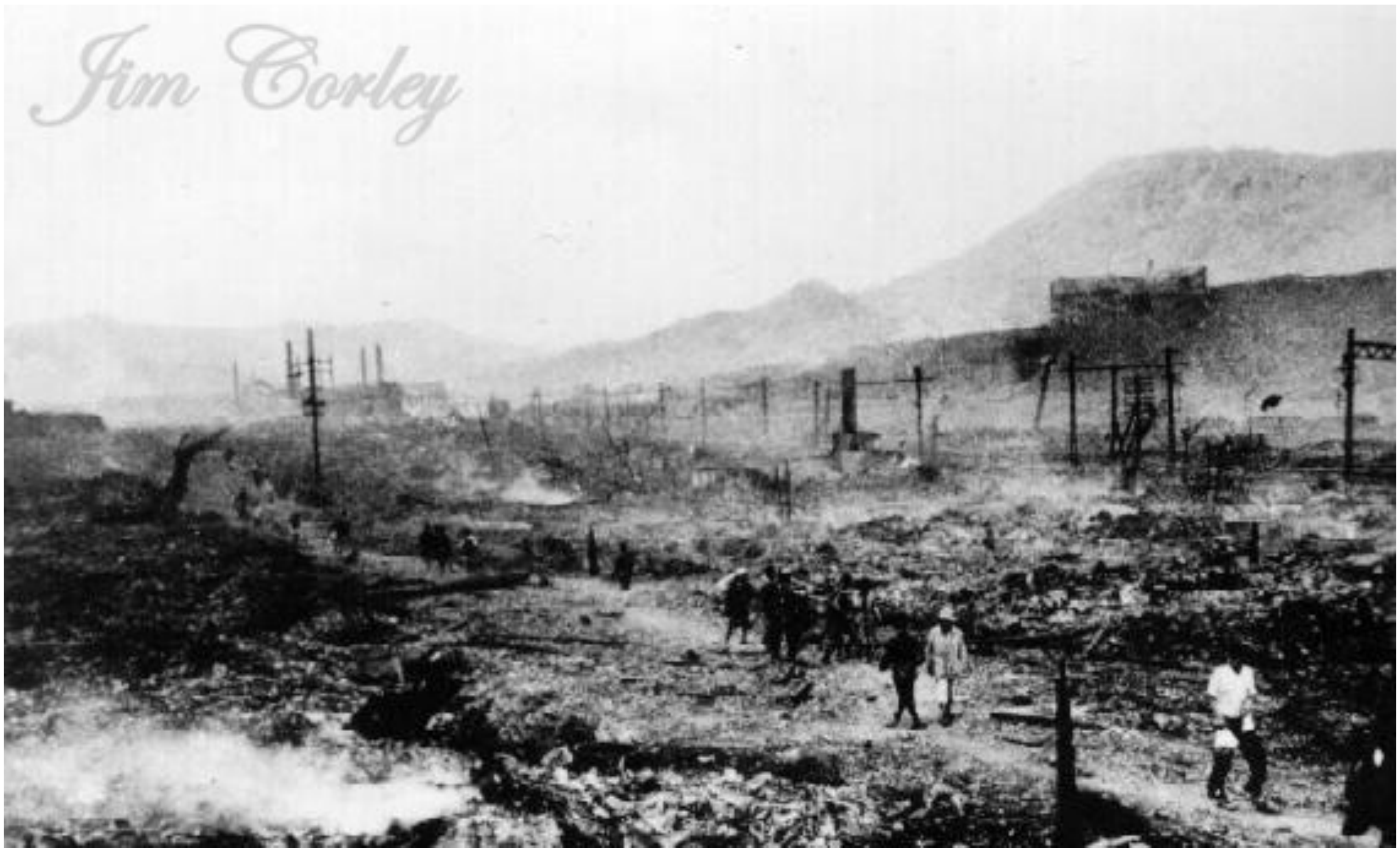
Nagasaki Aug 8, 1945

10.75 ft long

Plutonium

Weighs 5 tons. Yield 15ktons TNT equivalent

Nagasaki



Nagasaki

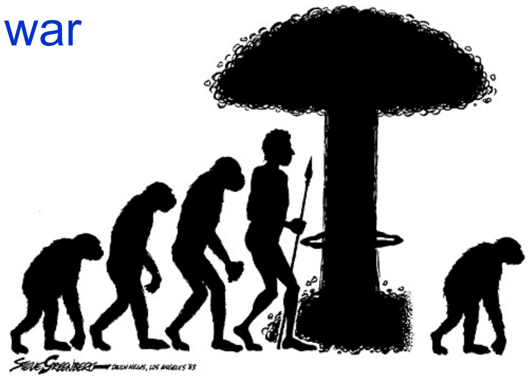
Nagasaki

What is our strategy?

- Could any nation “win” (“survive”) a nuclear war?
  - Doubtful. And anyway unethical to try!
  - Can we (should we) prepare the population? Civil Defense? Arguably fruitless.
    - We used to consider this a serious strategy: “Duck and Cover”?
    - "Dig a hole, cover it with a couple doors and then throw three feet of dirt on top. It's the dirt that does it. If there are enough shovels to go around, everybody's going to make it."

      Thomas K. Jones,
      U.S. Deputy Undersecretary of Defense, Strategic and Theater Nuclear Forces
      Reagan Administration, 1982

- “Mutual assured destruction” as a strategy to prevent nuclear war



  - Maybe, but only if never employed! Is that a good strategy?
  - Deterrence is valid, but brinkmanship is very dangerous.
  - Launch on warning?
    - Increases chances of destroying the world via mistakes and misunderstandings
  - Doomsday Machines?
    - In case of enemy attack, “doomsday machine” is launched automatically
    - Once launched, cannot turn back
  - It is arguable that dropping a nuclear weapon would constitute a “crime against humanity” and civilization.
    - Unless of course civilization ceases to exist.

- Disarmament?
  - Ratification of Strategic Arms Limitation/Reduction Treaties…STILL an issue!!!
- Bottom Line:
  - *Humans must be a little crazy.*

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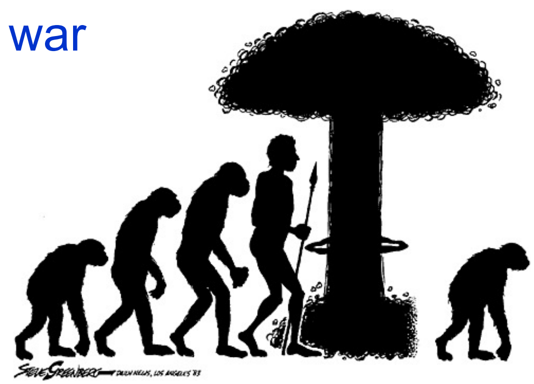

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Are we safe now?

- 1990s to present: No more USSR.
  - Whew! Now we are safe….we hope, although there are still several 1000 nuclear weapons left
  - And nonproliferation is proving to be extremely difficult
  - Enough to cause Nuclear Winter? Probably yes
- However…world came close at least twice to thermonuclear war:
  - Cuban Missile Crisis 1962, Reagan Administration early 1980s
- This hammer has been hanging over our heads for >70 years

- Such tensions are reflected in the culture.
  - Enter "Dr. Strangelove"

"Dr. Strangelove, or How I learned to Stop Worrying and Love the Bomb"

- Stanley Kubrick director w/Peter Sellers, George C. Scott, Slim Pickens
  - George C Scott gives a masterful performance, Peter Sellers plays 3 roles
- Released 1964, <2 years after Cuban Missile Crisis….
  - …where we came "this close" to nuclear exchange with USSR
- A comedy? A nightmare? Or a statement about sanity.
- Dr. Strangelove: takeoff on Nazi scientists captured/brought to US after WW2
- No cooperation from US military
- American Film Institute:
  - ranked 26th all time best American movies, 3rd all time best comedies
- Academy Award nominations, BAFTA Award winner Best Film 1964
- There are discussions of "gaps". This goes back to the 1950s political debate about falling behind the Soviets, tag line is "missile gap"
- You will see some familiar things:
  - For instance: irrational and crazy conspiracy theories were alive and well 60 years ago
  - How insanity can plausibly exist at the highest levels of government
- Enjoy (if you can). (Movie ends with a great song!)