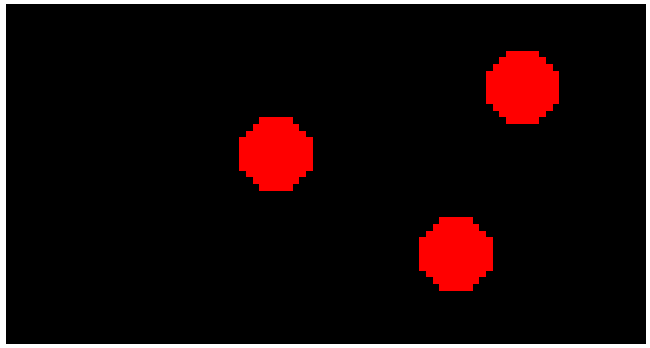
Weapons of Mass Destruction:

Nuclear

Biological

Chemical

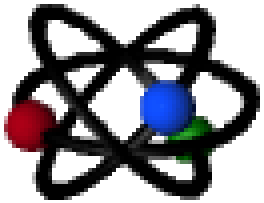


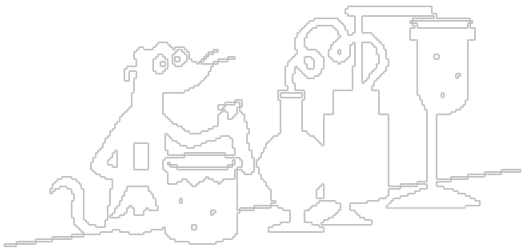
Prof. Lynn R. Cominsky

Department of Physics & Astronomy

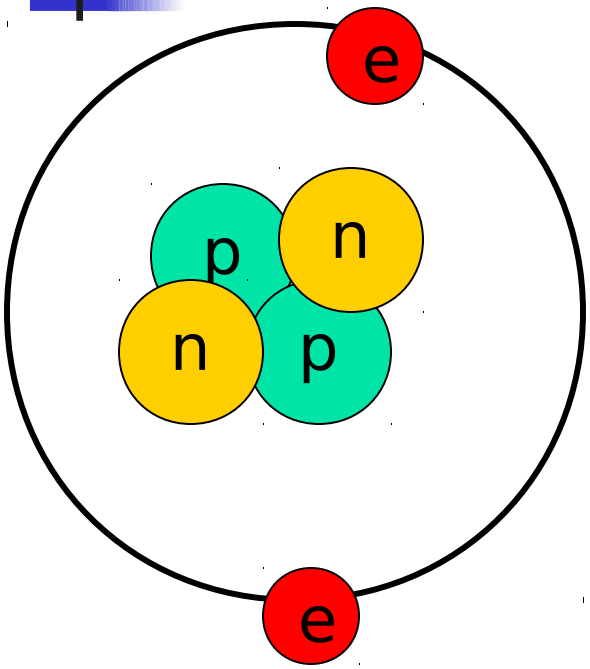
Talk Outline

- Nuclear Weapons
  - Background
  - Fission
  - Fusion
  - Effects
  - Proliferation
- Biological Weapons
- Chemical Weapons





The Helium Atom



^{4}He

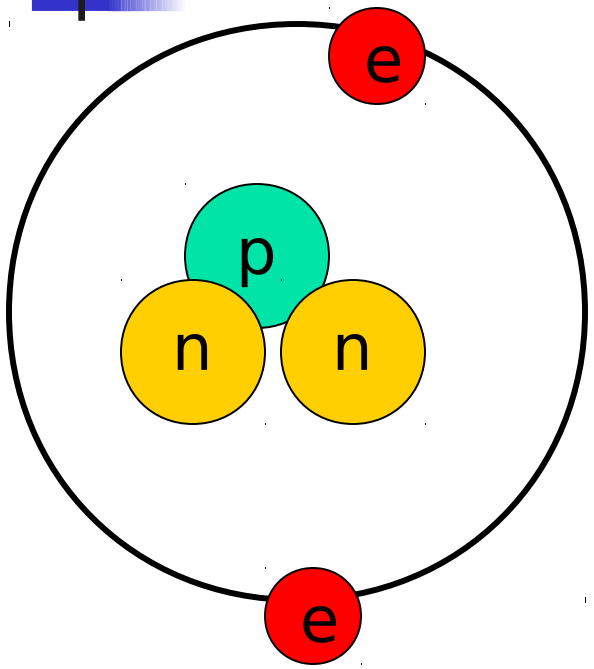
- Two electrons orbiting a nucleus with:

2 protons = Z = atomic number

2 neutrons = N

- Total mass = A = Z+N
- Singly ionized Helium is missing one electron = $^{4}He^{+}$
- Doubly ionized Helium is missing both electrons = α particle = $^{4}He^{++}$

Isotopes and Elements

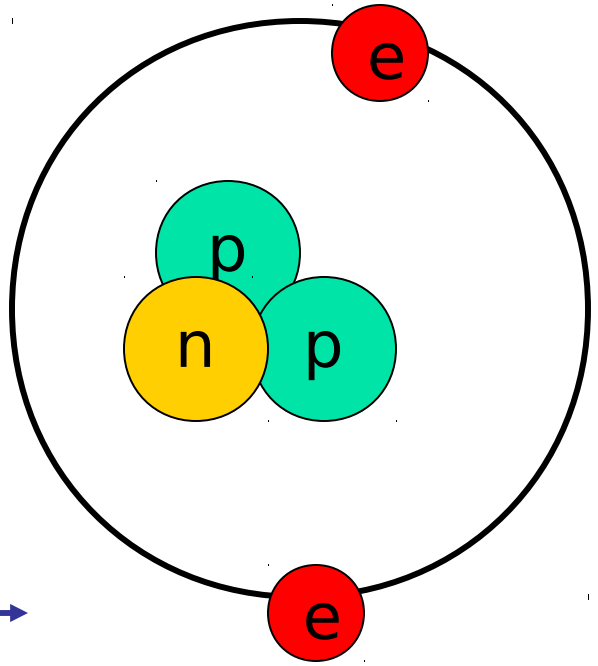


- If Helium loses one of its protons, it becomes a different element

^{3}H

- If Helium loses one of its neutrons, it becomes an isotope

^{3}He

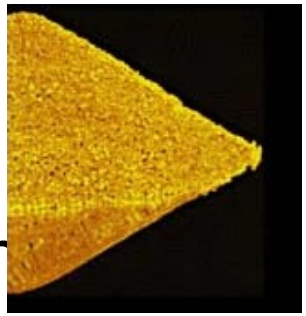


Materials

- Tritium = ^{3}H = very heavy Hydrogen (1p + 2n), used in fusion weapons
- Deuterium = ^{2}H = heavy Hydrogen (1p + 1n), used in fusion weapons
- Uranium: ^{238}U is >99% in nature ^{235}U is ~0.7% in nature – major ingredient in fission weapons
- Plutonium: ^{239}Pu is not found in

Uranium processing

- Uranium is mined as ore from open pits or deep shaft mines, often with the help of extracting solutions
- At nearby mills, ore is crushed and U is extracted, leaving behind radioactive tailings
- Extracted U is then leached (with sulfuric acid) forming a concentrate known as “yellowcake” (aka Uranium oxide U_3O_8)
- Yellowcake is then turned into UF_6 gas, which can be cooled to a solid for easier transport

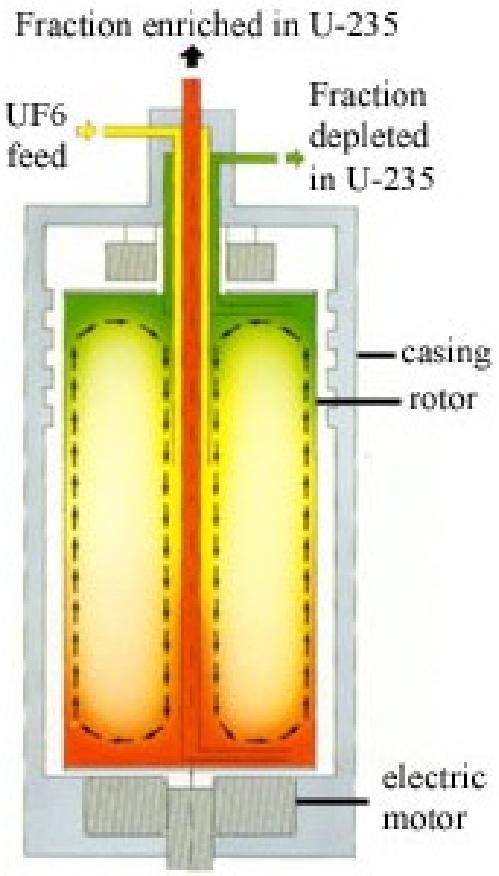


Enriching Uranium

- Naturally occurring Uranium must be enriched to >90% ^{235}U in order to make fission weapons (or to ~5% for nuclear power plants)
- Enrichment methods
  - Gas centrifuge (now being used in Iran and found in Iraq after 1st Gulf War)
  - Gaseous diffusion (used in USA)
  - Electromagnetic isotope separation – (unexpectedly found in Iraq after 1st Gulf War)

Gas centrifuge

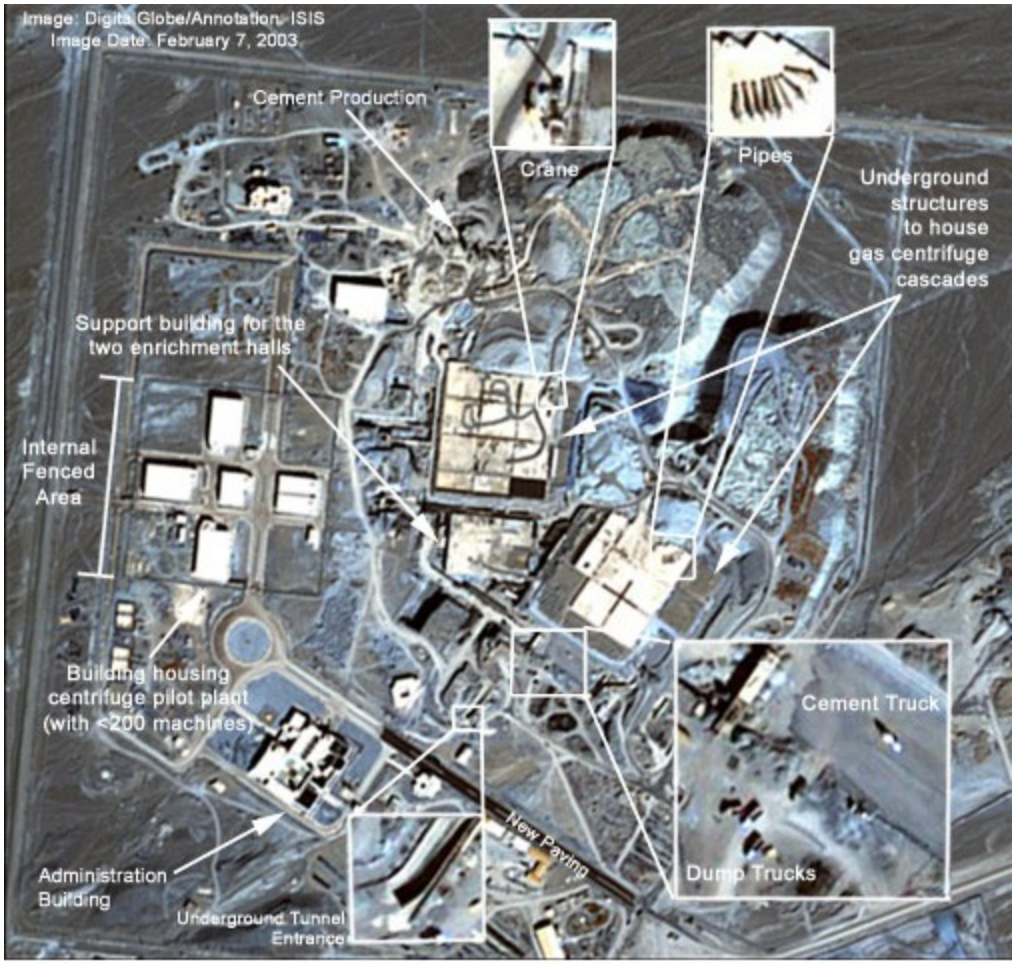
- Uses successive stages to isolate isotopes by weight – lighter mixture is sent on to the next stage, heavier mixture is sent back to the previous stage
- Requires thousands of successive stages to create weapons grade ^{235}U



Enriching Uranium in Iran

- As of 2003, Iran was developing an extensive, underground enrichment facility for Uranium
- Most of the centrifuges are underground, in order to withstand aerial attack – only 1-2% would be needed to make sufficient quantities of highly enriched U for a weapons program
- Iran's stated goal for this facility is production of sufficient low-enriched U to generate 6000 MW electricity through

2003 Image of Natanz, Iran



NATANZ, IRAN

INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY

IMAGE CREDIT: DIGITALGLOBE
DATE OF IMAGE: 7 FEBRUARY 2003

8/28/09 Update on Iran and U

- On 12 August 2009, 4592 centrifuges were being fed with UF_6 and an additional 3716 centrifuges had been installed.
- IAEA has estimated that, between 11/18/08 and 7/31/09, 7942 kg of UF_6 was fed into the cascades and a total of 669 kg of low enriched UF_6 was produced
- All the materials being produced at Natanz remain under IAEA containment and surveillance. The results of the environmental samples taken at Natanz indicate that the cascades have been operating as declared (i.e. less than 5.0% ^{235}U enrichment).
- Known stockpiles of low-enriched ^{235}U are sufficient to fuel one bomb if further enriched (which would take 2-3 months). Enough for a second weapon will be produced by 12/09.

New enrichment facility in Iran

- On 9/25/09, Pres. Obama announced that Iran had been building a new enrichment plant in a mountain near Qom, that had not been disclosed to the IAEA. The evidence was obtained by US, UK and France.
- The new plant is believed to have 3000 more centrifuges, but is not yet operational.
- As of 10/1/09, Iran had offered to send some of its low-enriched ^{235}U out of the country and to allow inspection of the new plant on 10/25/09.
- Iran has also been reported to be testing detonators and has repeatedly successfully tested missiles with 2000 km range.

Ahmadinejad visits Natanz 4/08

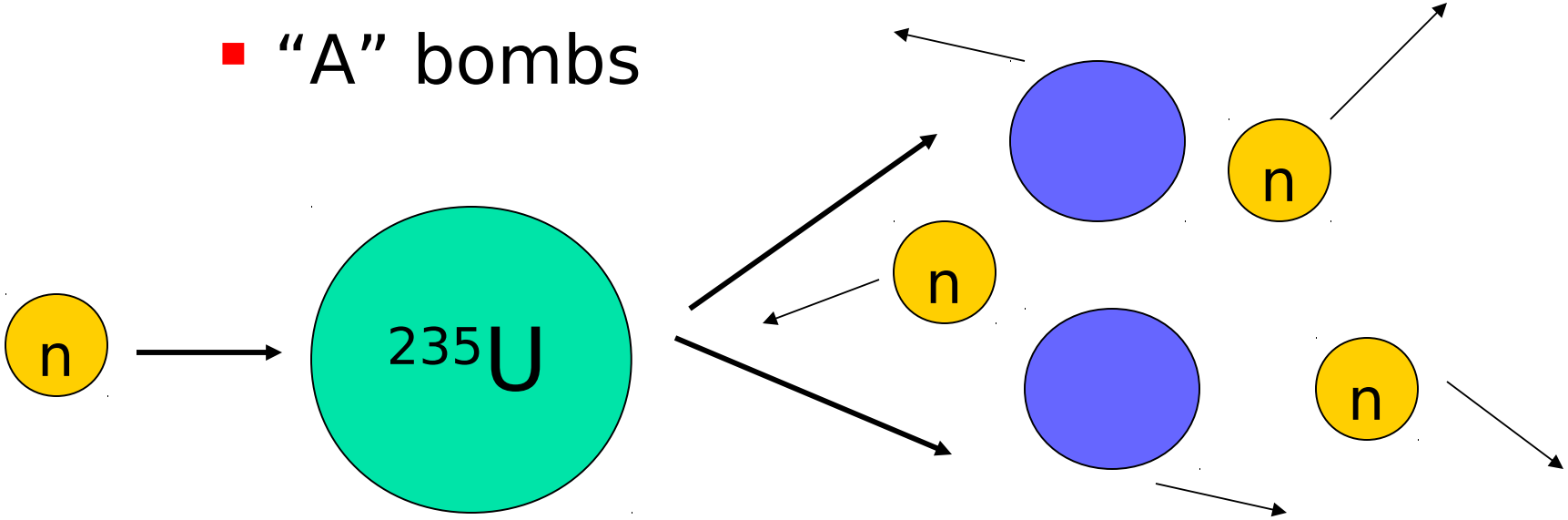
- Strolling among the P-1 centrifuges

Ahmadinejad visits Natanz 4/08

- Inspecting the new IR-2 centrifuges

Fission Weapons

- Fission
  - releases energy in elements heavier than Iron
  - Bombard U or Pu with neutrons, they split into fragments, releasing energy
  - “A” bombs



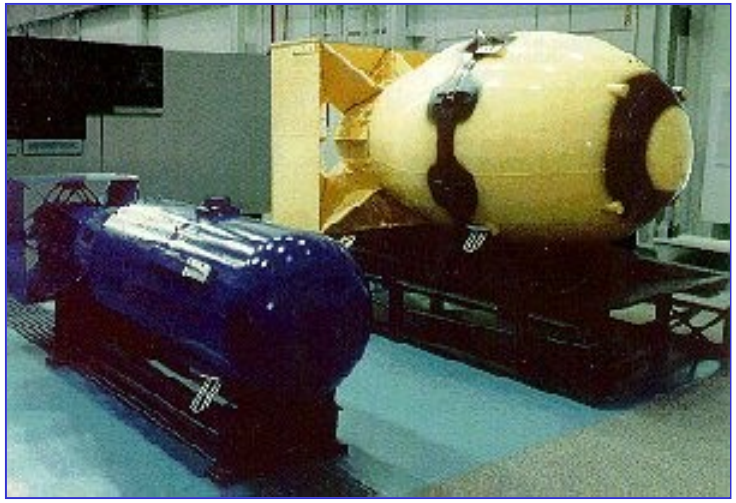
Critical mass → chain reactions

- When a large enough mass of either ^{235}U or ^{239}Pu is assembled, a self-sustaining chain reaction results after the first fission is produced.
- The minimum (“critical”) mass of fissile material that can sustain a nuclear chain reaction depends on the density, shape, and type of fissile material, as well as the effectiveness of any surrounding material (called a reflector or tamper) at reflecting neutrons back into the fissioning mass.
- Depleted U is often used in the tamper

The first “A” bombs

- Trinity – Gadget (7/16/45)
  - Alamagordo test range in New Mexico
  - 20 kTon yield
- Little Boy (8/6/45)
  - Hiroshima
  - 15 kTon yield
- Fat Man (8/9/45)
  - Nagasaki
  - 20 kTon yield

Museum display in NM

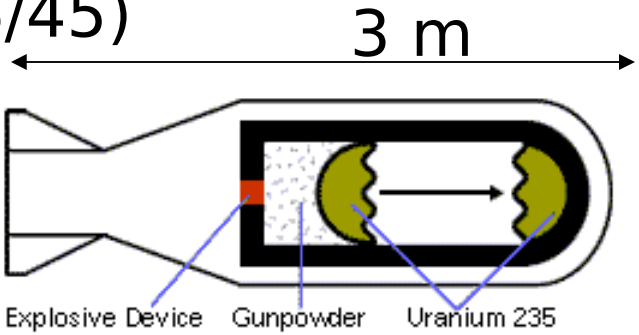


How to make an “A” bomb

- Use >90% ^{235}U
- Squeeze and confine evenly
- Reflect neutrons back into ^{235}U
- Use initial explosive device to

A-bomb dome

Little Boy (Hiroshima 8/6/45)



http://www.pcf.city.hiroshima.jp/peacesite/English/Stage1/1-3/1-3-3E.html

“Fat Man” style of A-bomb

- High explosives are arranged to form an imploding shock wave which compresses the fissile material to supercriticality

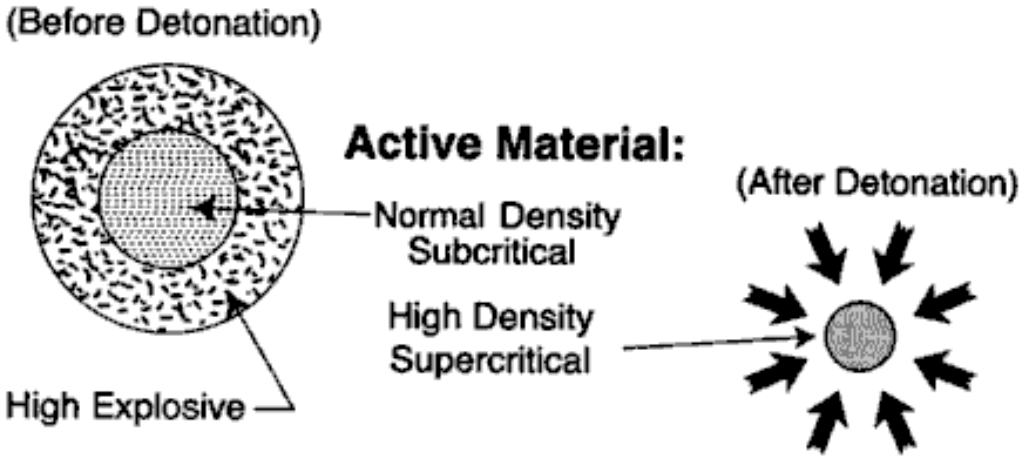
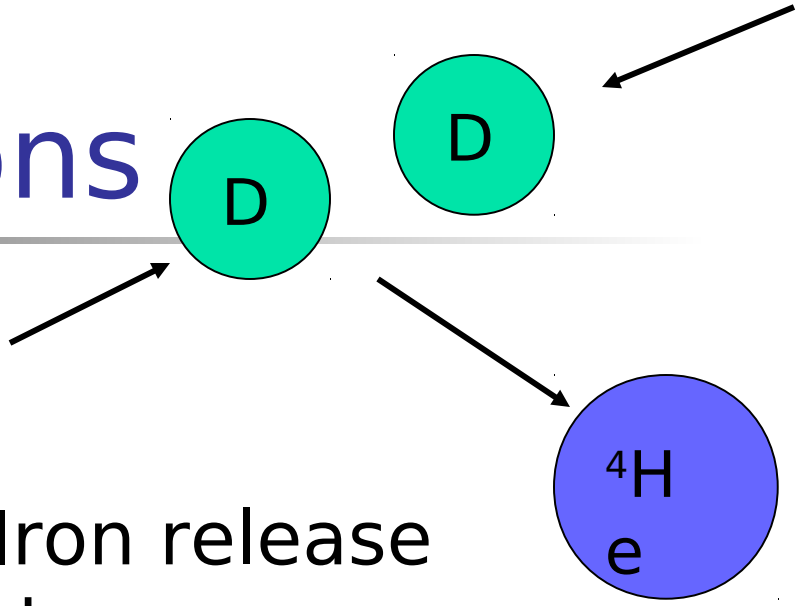


Figure 2-VIII. Implosion Assembly Principle

- Burst of neutrons from generator is timed for moment of maximum compression

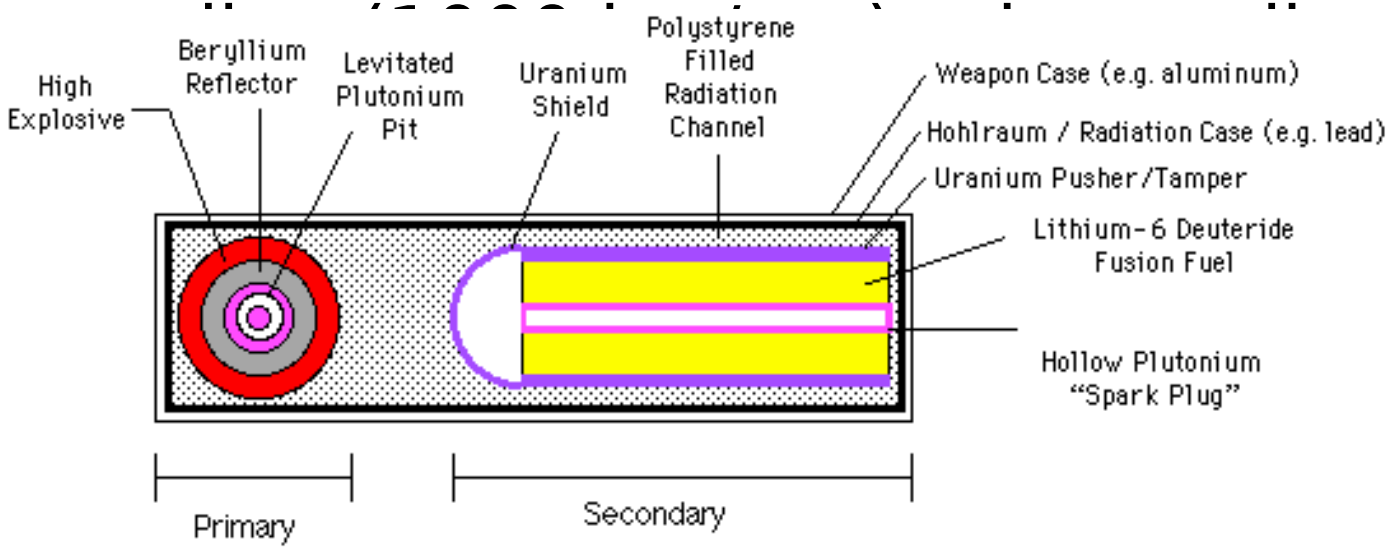
Fusion Weapons



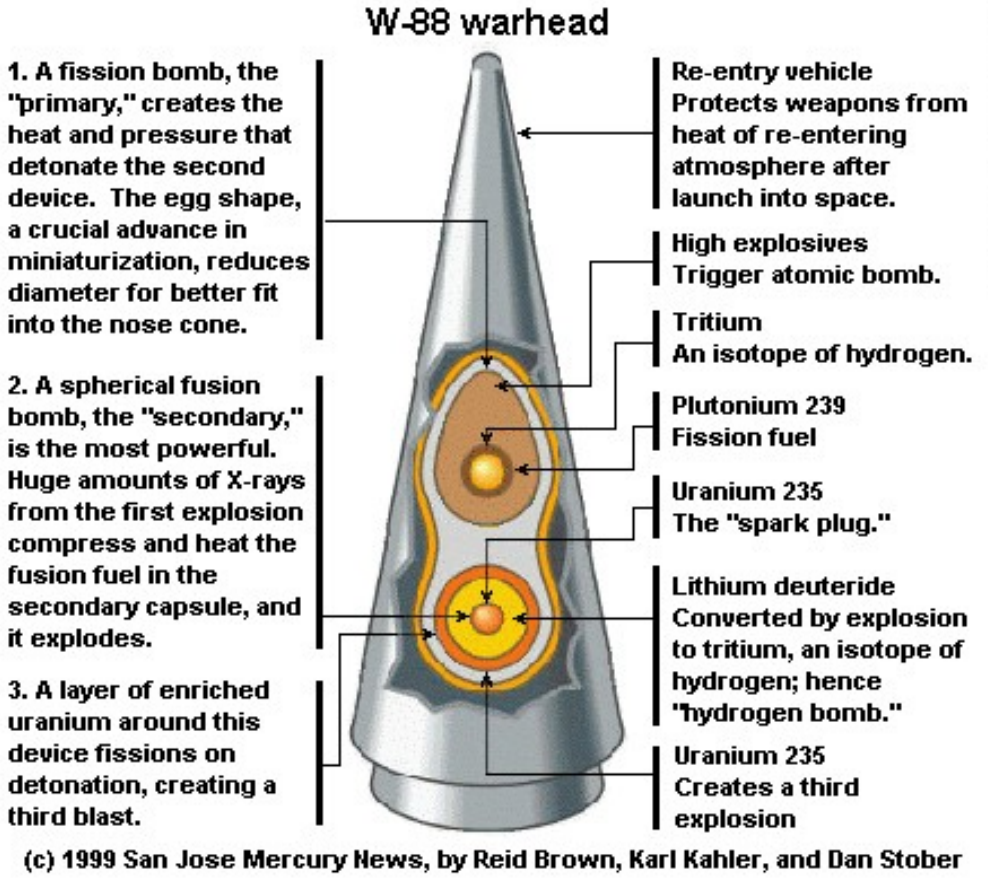
- Fusion
  - Elements lighter than Iron release energy when combined
  - Deuterium, Tritium, Lithium
  - Reactions that occur inside Sun
  - “H” bombs
- Thermonuclear Reactions
  - Heat from reaction increases reaction rate, so less fuel is needed → “efficient” bomb

The "secret" of the H-bomb

- At the high temperatures of a fission bomb 80% or more of the energy exists as soft X-rays
- The X-rays heat a polystyrene channel, causing plasma which can compress and ignite the second (fusion) stage before the e[illegible]upts it



Fusion weapons

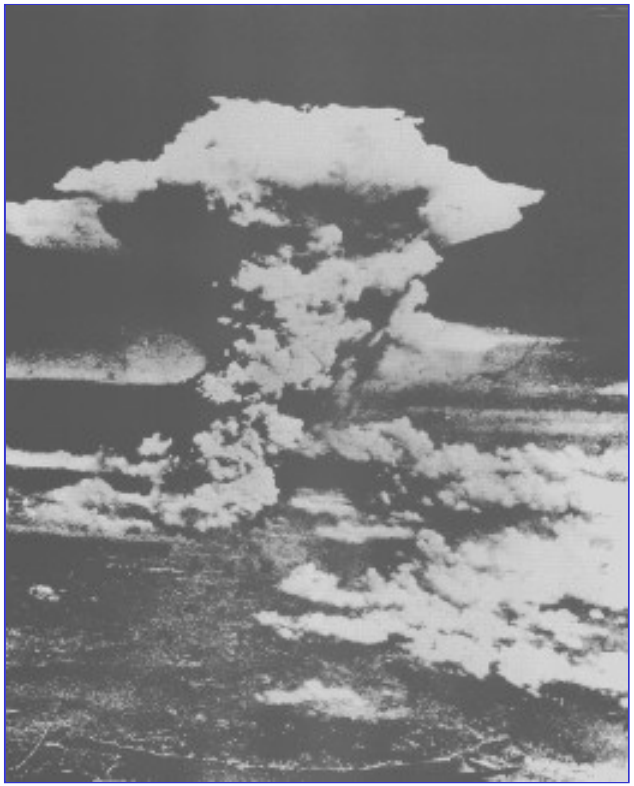


Published due to Wen Ho Lee case

http://www.fas.org/sgp/eprint/morland.html

Why is an atomic bomb so much worse than a TNT bomb?

- Amount of heat and light energy released is 1000 times greater
- Explosion is accompanied by invisible, penetrating and harmful radiation
- After explosion, radioactive fallout remains and continues to damage living things for days → weeks → years



Ground level view of Hiroshima cloud

Physical Effects of Nuclear Weapons

- Thermal
  - Fireball → Firestorms
  - Mushroom Cloud
- Initial (prompt) Radiation
  - Alpha particles ($^{4}He^{++}$)
  - Beta particles (e^{+} and e^{-})
  - Gamma-rays (γ)
  - Neutrons (n)

Trinity

Bridge in Hi

Physical Effects of Nuclear Weapons

Hiroshima buildings

- Pressure Blast Wave
  - Buildings collapse
- Fallout
  - Radioactive fragments which stick to air particles or dirt that is sucked up mushroom stem
  - 80% falls back down in first day
  - 90% falls back down in first week
  - 10% lasts weeks → years

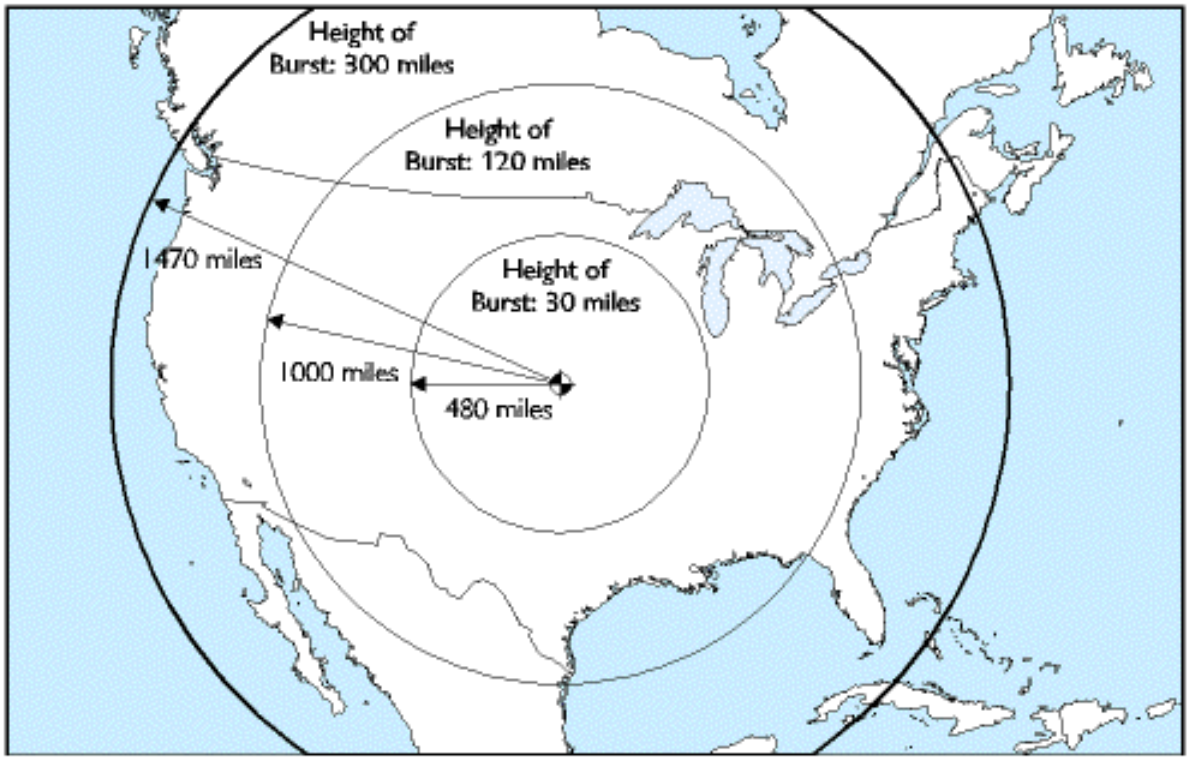
Nagasaki victim

Google Nuclear Weapon Effects Calculator to try it out on your city!

Physical Effects of Nuclear Weapons

- Electromagnetic Pulse
  - Strongest for very high bursts
  - γ–rays ionize air → electrons
  - Electrons create large currents in air
  - Currents are picked up by power lines
  - Power surges shut down grid, destroy attached electrical devices
- 1.4 Mton airburst in 1962 knocked out lights in Hawaii over 1000 miles away

Electromagnetic Pulse Effects



Area Effected by an Electromagnetic Pulse, by Height of Burst

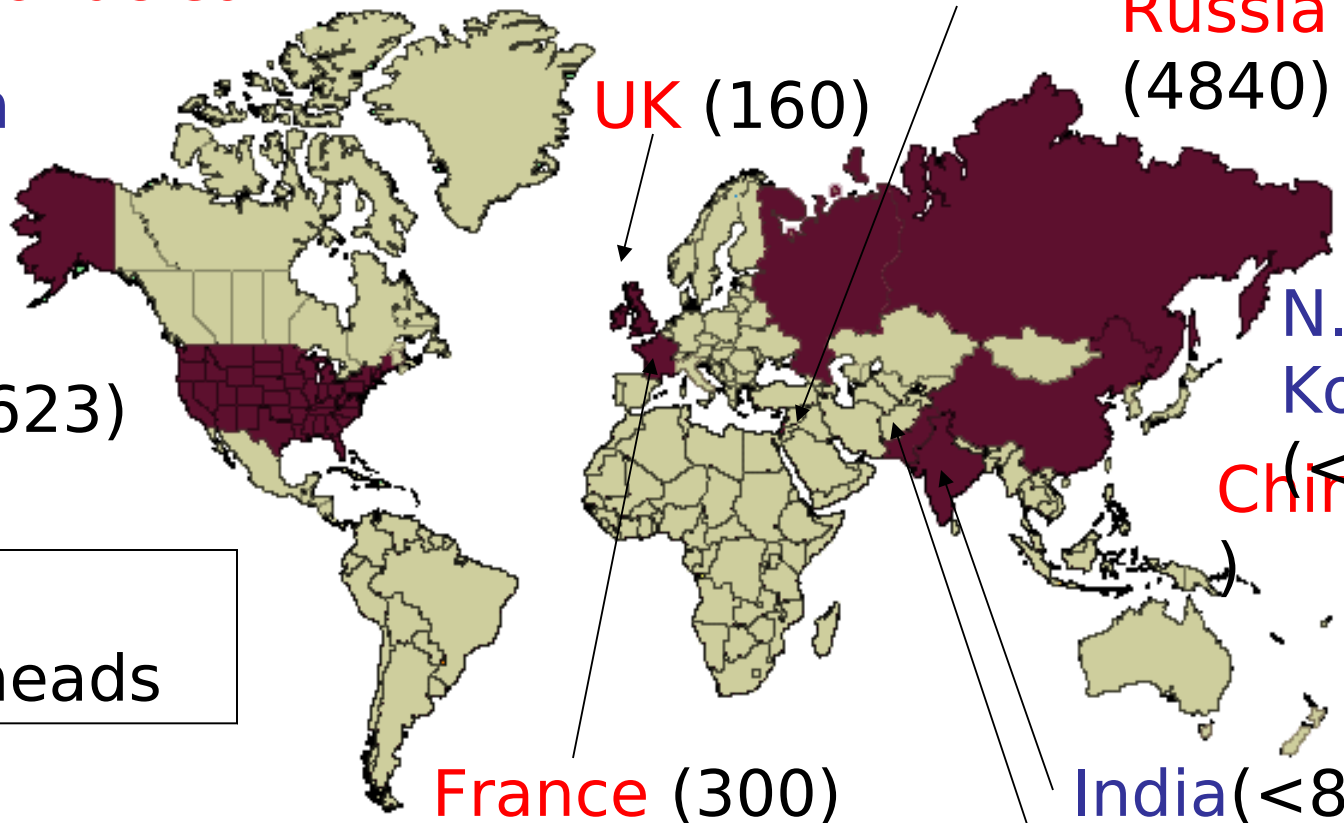
Source: Gary Smith, "Electromagnetic Pulse Threats," testimony before the House National Security Committee, July 16, 1997.

http://www.fas.org/nuke/intro/nuke/emp.htm

How big are the weapons?

- 1 kTon = 1000 tons = 2,000,000 pounds of TNT equivalent
- ~2 pounds of ^{235}U → 20 kTons
- Today's warhead is 100-200 kTons
- Largest underground burst: 4.5Mtons
- Largest airburst: 58 Mtons
- Over 1700 known tests since 1945

Who has nuclear weapons?



http://en.wikipedia.org/

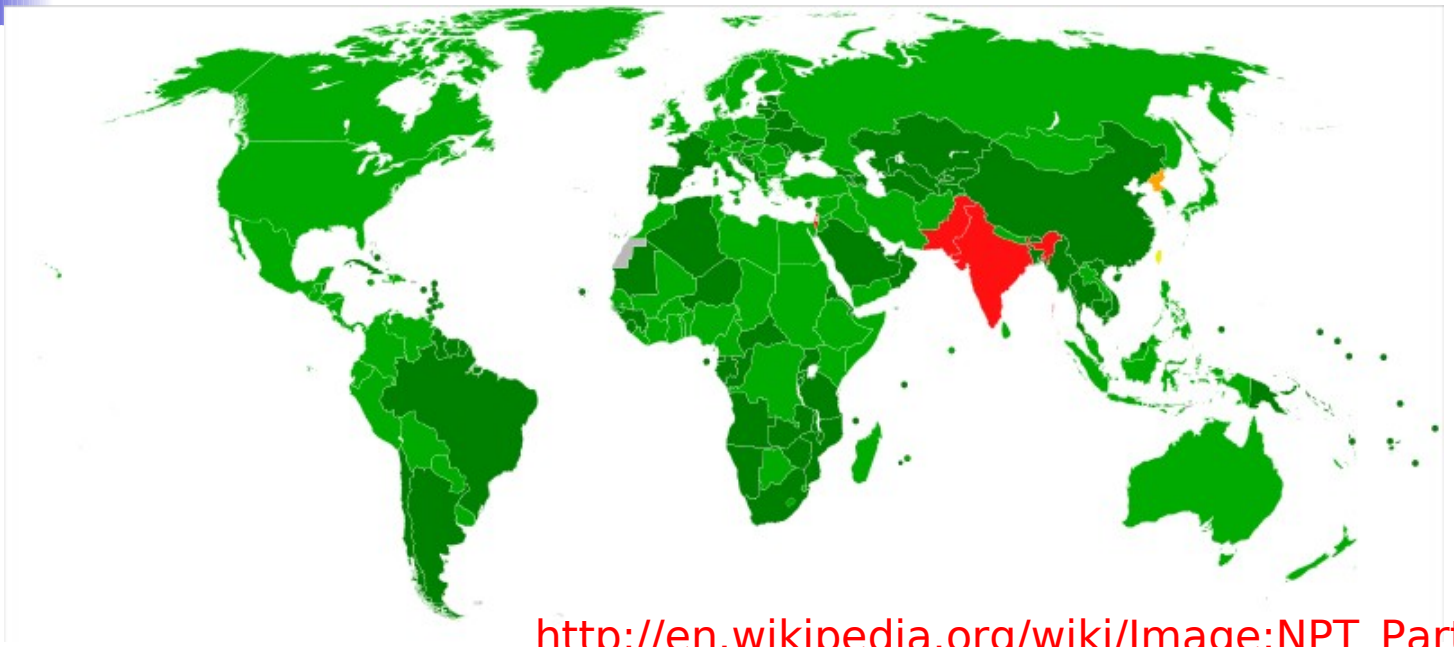
Nuclear Non-Proliferation Treaty

- Vertical – development of new weapons by the “Big 5”
- Horizontal – spread of weapons to other countries
- “Haves” agree not to spread weapons, materials or technology to “have-nots” – also, to stop vertical proliferation
- “Have-nots” agree not to try to acquire weapons from the “haves,” and will accept inspection and regulation of “peaceful” nuclear technology by IAEA- this stops horizontal proliferation

Nuclear Non-Proliferation Treaty

- NPT indefinitely extended since May 1995, confirmed again in 2000
- Now signed by 189 countries
- N. Korea ratified in 1985 then withdrew in 2003. In 2006, it conducted nuclear tests.
- Israel, India and Pakistan are still not signatories.
- Iran remains a signatory but is in violation according to 2007 IAEA report which is disputed.

July 2008 Non-proliferation Treaty Map



http://en.wikipedia.org/wiki/Image:NPT_Participation.svg

- Signed and ratified
- Acceded or succeeded
- Unrecognized state but abiding by treaty
- Withdrawn
- Non-signatory

2006 North Korean Nuclear Test

- On October 10, 2006 North Korea reported its first underground nuclear test, indicated by a small (~4th magnitude) earthquake
- Estimates are that this blast measured only ~0.5 kilotons – very small compared to other first weapons tests
- Likelihood is that it was a “fizzle” or even a conventional weapons blast – only time will tell if radio-isotopes emerge.
- IAEA believes that N. Korea has enough weapons-grade Pu for 6 bombs

2009 Update on North Korea

- In 4/09, N. Korea launched a long-range missile, but the third stage did not work. Estimates are that they will be able to deploy mobile ICBMs that can survive a US first strike within 5-7 years.
- On 5/25/09, N. Korea successfully conducted a second underground nuclear test, about the same as Hiroshima (~15 kTons).
- In 7/09, N. Korea launched surface to ship cruise missiles, and also ballistic missiles. All of their successful tests have involved short or medium-range missiles.

Yongbyon nuclear facility

- Read more at:
  http://www.iht.com/articles/2008/09/25/asia/25korea.php
- http://www.pbs.org/newshour/indepth_coverage/asia/northkorea/nuclea

Blowing up cooling tower in June 2008

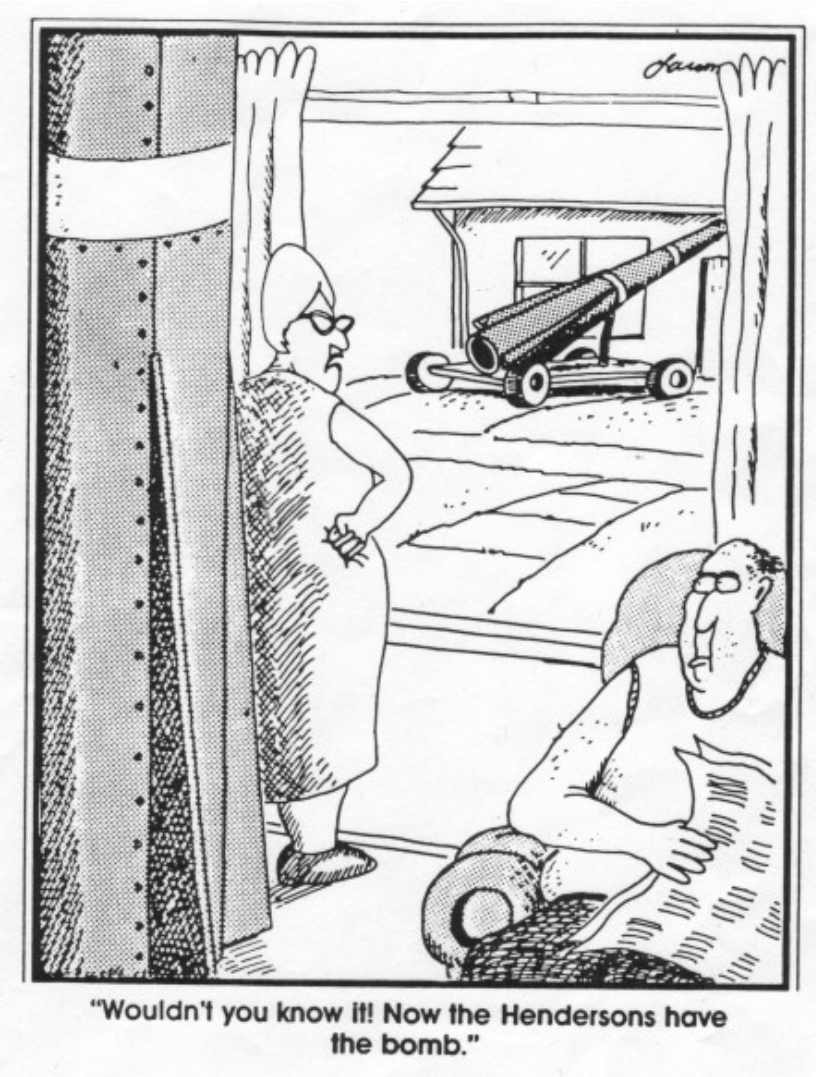
Are we in danger from N Korea?

- In order to threaten the US, North Korea must have:
  - Working nuclear warhead
  - Working long range delivery system – (still failed)
  - Working electronics triggering for bomb (no evidence yet)
  - Intent to actually bomb another country

  (no clear evidence but entirely possible)

Who still wants nuclear weapons?

- ~~Iraq~~
- Iran – enriching U
- Libya
- Algeria
- Syria
- Chechnya (old USSR?)

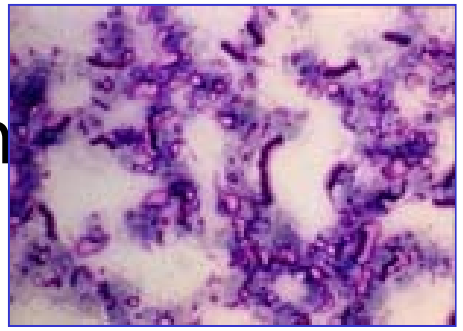


No longer on the “watch” list

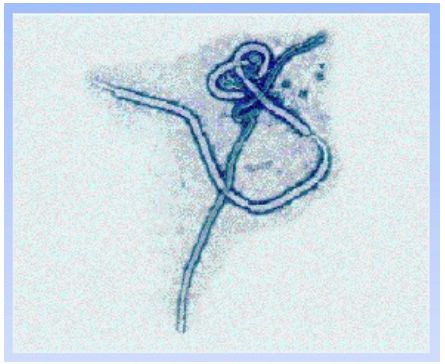
- S. Africa
  - Eliminated 6 weapons in 1991
  - Formal renunciation of use
- Have backed away or renounced use:
  - Argentina
  - Brazil
  - Romania
  - Taiwan
  - Belarus
  - Ukraine
  - Kazakhstan

Types of Biological Weapons

- Bacteria
  - Cause disease by reproducin
  - Single cell organism
  - Typhus, anthrax
- Viruses
  - Multiply only inside host cells
  - Sub-microscopic organisms
  - Ebola, Chikungunya



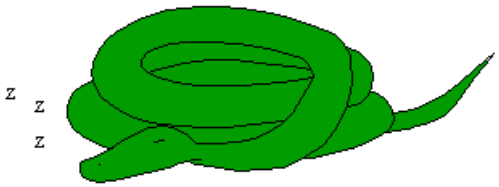
Anthrax



Ebola

Types of Biological Weapons

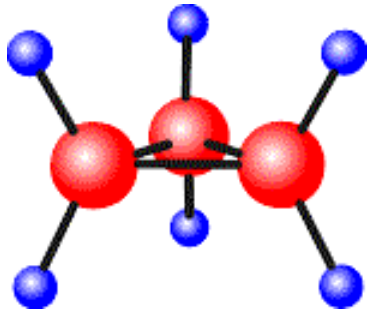
- Rickettsia
  - Larger than viruses
  - Smaller than bacteria
  - From fleas, lice and tic
  - Q-fever



- Toxins
  - Poisons from living things
  - Snake venom
  - Botulinum most lethal known – $<10^{-6}$ g!
  - But some beneficial uses

Types of Chemical Weapons

- Nerve agents
  - Inhibit enzyme that transmits messages from nerve cells to muscles
  - Lethal dose <1-10 mg
- Mustard agents
  - Blistering of skin, lungs
  - Lethal dose >500 mg



- Hydrogen Cyanide (HCN) gas
  - Prevents blood from carrying oxygen
  - Lethal dose > 120 mg

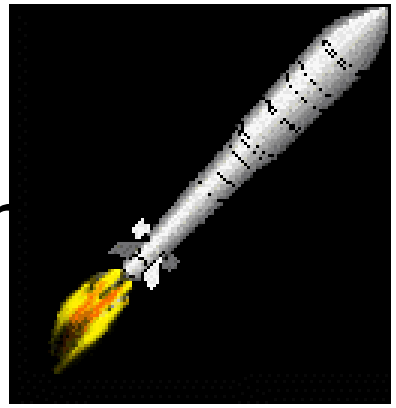
Types of Chemical Weapons

- Tear gases
  - Cause pain in eyes
  - Do not affect horses or dogs
  - Short term effects
- Arsines
  - Mixed with mustard gas
- Psychotomimetic agents
  - Cause temporary psychosis
  - LSD, atropine

LSD

Why Use Chemical or Biological Weapons?

- Cheap
- Easy Technology
- Simple delivery system
  - Artillery shells
  - Rocket launchers
  - Aerosol sprays
- Research into biological weapons continues for treating diseases, developing vaccines, anti-toxins, etc.



Chemical/Biological Weapons Problems

- Chemical weapons largely ineffective
- Biological weapons can’t be stored
- Protection against both is relatively easy on the battlefield
- Both are really “weapons of terror” against citizens or “weapons of intimidation” against soldiers rather than “weapons of mass destruction”

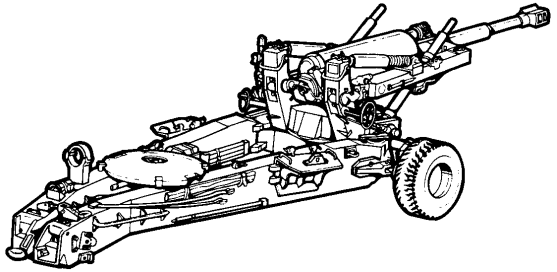
Biological/Chemical Terrorism

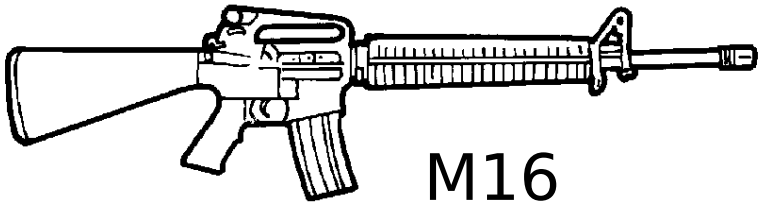
- Since 1900, only ~75 terrorist attacks out of more than 40,000 used Chemical or Biological weapons
- Only 125 people died & ~4000 got sick
- ~20 people died in Japan in the well-publicized nerve gas attacks. This sect also tried to make biological weapons but failed, after spending $1 billion

Major killers in Wars

- Assault Rifles (64%)
- Handguns (10%)
- Landmines (10%)
- Hand grenades, Artillery, Mortars (16%)
- Since 1900: 34 million soldiers and 80 million civilians killed in wars

Howitzer





M16

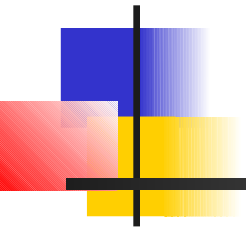
killed 200,000

total.

Additional Resources

- Carnegie Endowment for International Peace http://www.ceip.org/
- Biological and Chemical Weapons Resources http://www.fas.org/main/content.jsp?formAction=325&projectId=4
- US position on BTWC (2001) http://www.fas.org/bwc/news/USPublicPositionsOnProtocol.htm
- CDC Vector Borne Diseases http://www.cdc.gov/ncidod/dvbid/index.htm
- Chemical Weapons Convention http://www.cwc.gov/
- Federation of American Scientists http://www.fas.org
- Iran Watch (Wisconsin Project) http://www.iranwatch.org/

Backup Slides

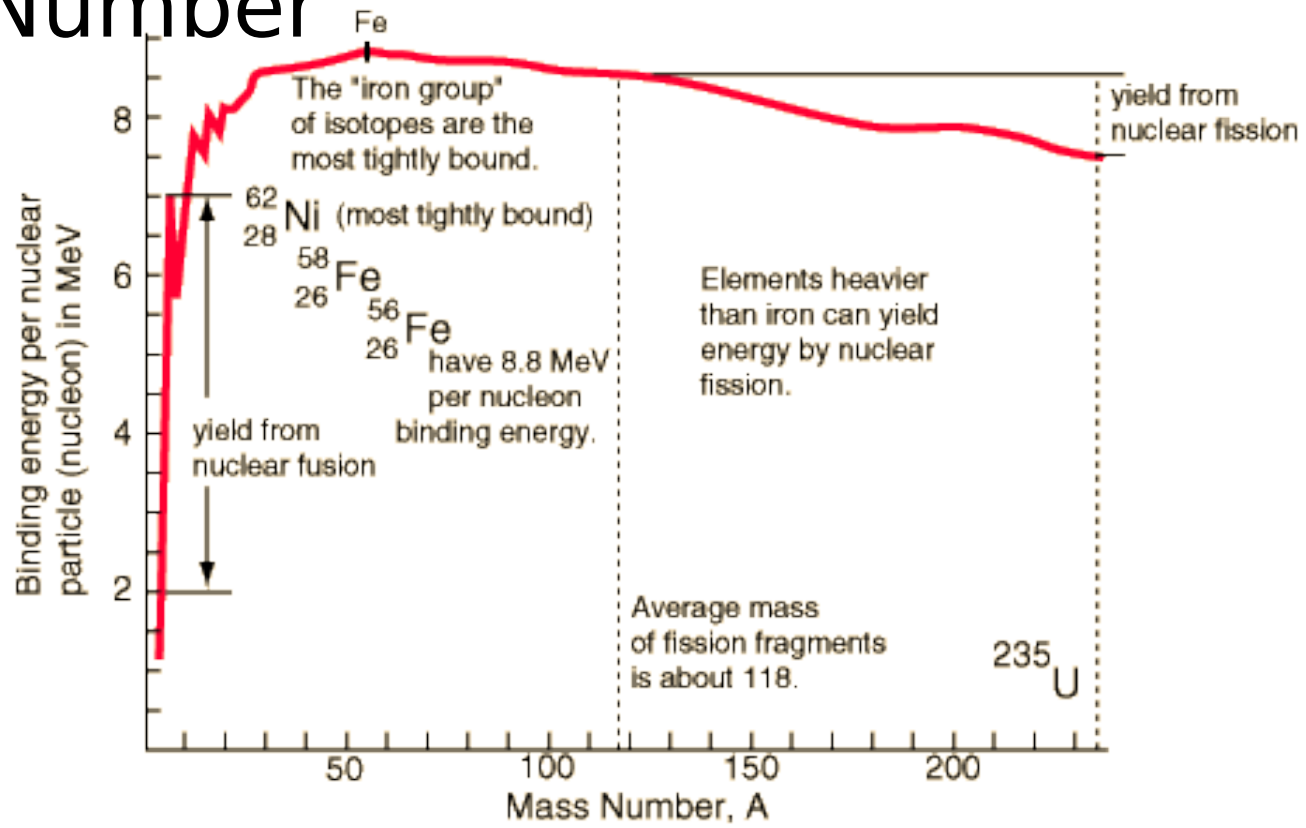


Radioactivity

- Primordial –
  - formed before Earth's creation
  - long half lives – ^{238}U is 4.5×10^9 y
- Cosmogenic – formed as a result of cosmic ray interactions
  - Examples: ^{14}C (5730 y) and ^{3}H (12.3 y)
- Man-made – typically in power plants or accelerators
  - Examples: ^{239}Pu (2.4×10^4 y) and ^{131}I (8 d) and also ^{3}H (12.3 y)

Fission or Fusion?

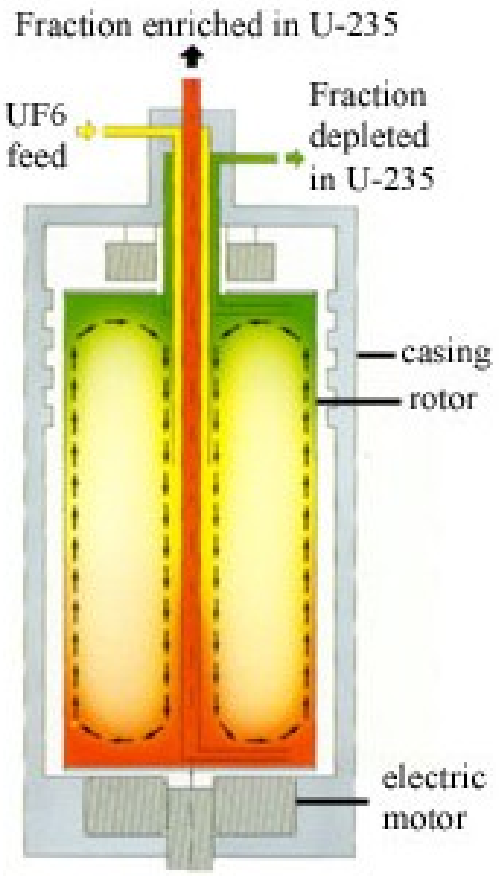
- Nuclear binding energy vs. Mass Number



http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/nucbin.html

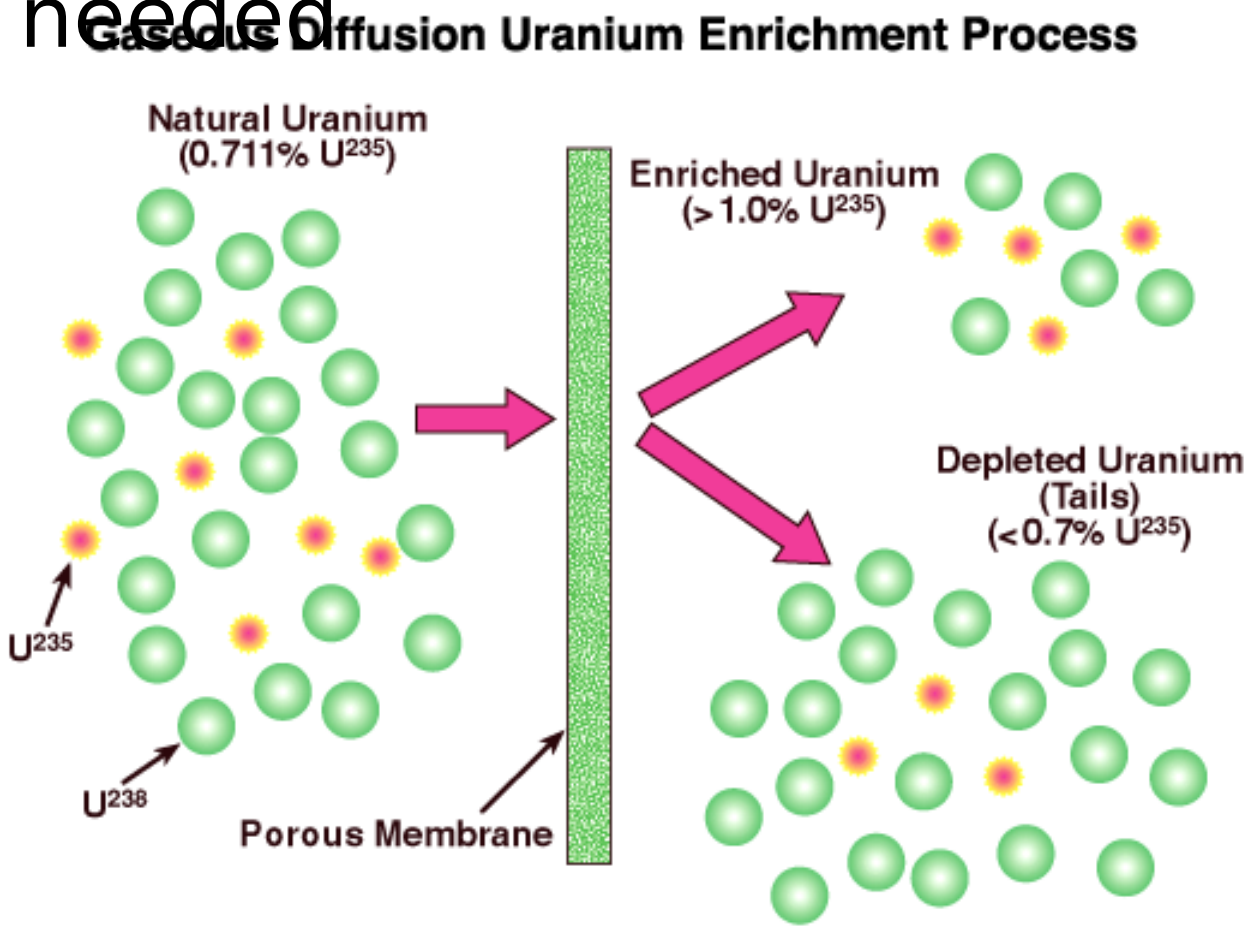
Gas centrifuge

- Uses successive stages to isolate isotopes by weight – lighter mixture is sent on to the next stage, heavier mixture is sent back to the previous stage
- Requires thousands of successive stages to create weapons grade ^{235}U



Gaseous diffusion

- Thousands of diffusion filters needed

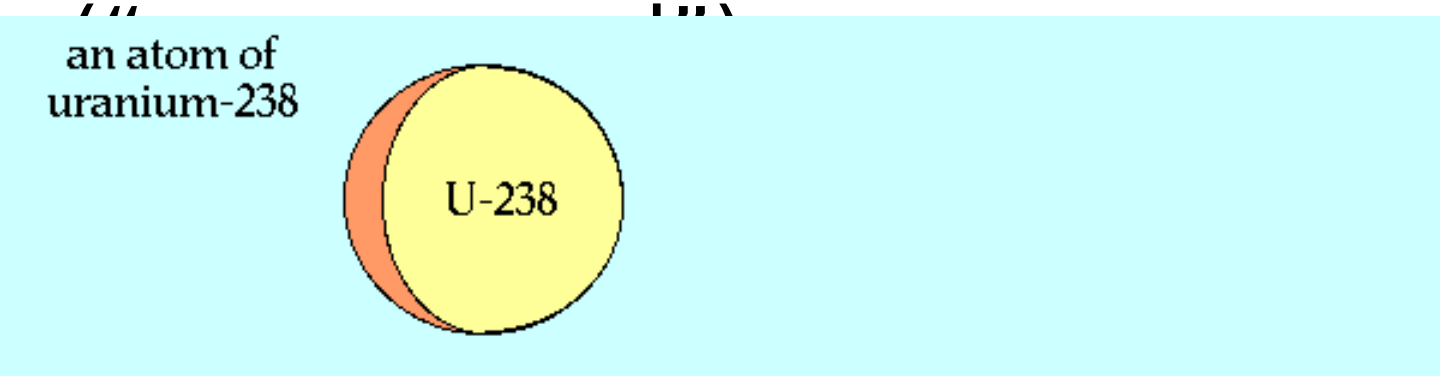


Electromagnetic isotope separation

- Iraq's extensive EMIS program was unknown until its discovery after the Gulf War by UN inspectors
- Several unreported and disguised facilities were found, capable of creating quantities of weapons grade U
- Huge power requirements for EMIS have precluded use in USA – and were thought to preclude use by others

Reprocessing Plutonium

- ^{239}Pu is a waste product in nuclear power reactors, that is intermixed with other spent reactor fuels
- In order to become weapons grade, it must be separated out



Reprocessing Plutonium

- Spent reactor fuel is chopped up, by remote control, behind heavy lead shielding.
- Chopped-up pieces are then dissolved in boiling nitric acid, releasing radioactive gases in the process.
- Pu is chemically separated from the acid solution, leaving large quantities of high-level radioactive liquid waste and sludge behind.
- After it has cooled down for several years, the liquid waste is solidified for ultimate disposal, while the separated

Depleted Uranium

- After isotope separation, the remaining ^{238}U is said to be “depleted” as it is missing ^{235}U – however, ^{238}U is still naturally radioactive
- Uranium is a very dense metal (1.7 x Pb), making it ideal for use in armor and shell casings
- Uranium is pyrophoric – friction causes it to burn
- The USA used depleted Uranium weapons in the Persian Gulf War (1991), in Bosnia (1995), Kosovo (1999) and in Iraq (present war)
- Various health problems have been

Depleted Uranium

- Depleted Uranium can be put into fuel cells in a nuclear reactor and used to produce weapons grade ^{239}Pu
- This is why Israel bombed the French-built OSIRAK nuclear reactor in Iraq in 1981

Targets made of depleted U which will be bombarded by neutrons to make Pu

^{238}U and the first Gulf War

- More than 640,000 pounds of contaminated equipment was left on the battlefields
- US-coalition forces used ^{238}U in
  - Large caliber shells fired from tanks
  - Small caliber shells fired from aircraft
  - Sniper bullets
  - Tank armor in 1/3 (2000+) of tanks

Problems from ^{238}U dust

- After burning, ^{238}U creates fine radioactive and toxic vapor and dust
- More than 50% of these particles are just the right size to be inhaled, where they lodge in the lungs and remain for years
- It is easily carried by the wind, and stays in the air for hours after impact
- It also easily dissolves in water
- Ground contamination allows resuspension into the air and eventual water contamination
- No ground cleanup has occurred in Iraq

Problems from ^{238}U fragments

- Unburned, ^{238}U remains radioactive – is classified as a “low-level” waste, subject to proper disposal and controls
- Fragments corrode with time, creating more dust and contaminated soil
- High levels of radioactivity have been measured from fragments found after the first Gulf War in Iraq, Kuwait and Saudi Arabia

Health problems

- Many US service people were exposed to depleted Uranium during the first Gulf War
- Local populations in Iraq, Kuwait and Saudi Arabia were also exposed
- Particles can be found in the brain, kidney, bone, reproductive organs, muscle and spleen
- Causing kidney damage, cancers of the lung and bone, non-malignant respiratory disease, skin disorders, neurocognitive disorders, chromosomal damage, and birth defects

Weapons design considerations

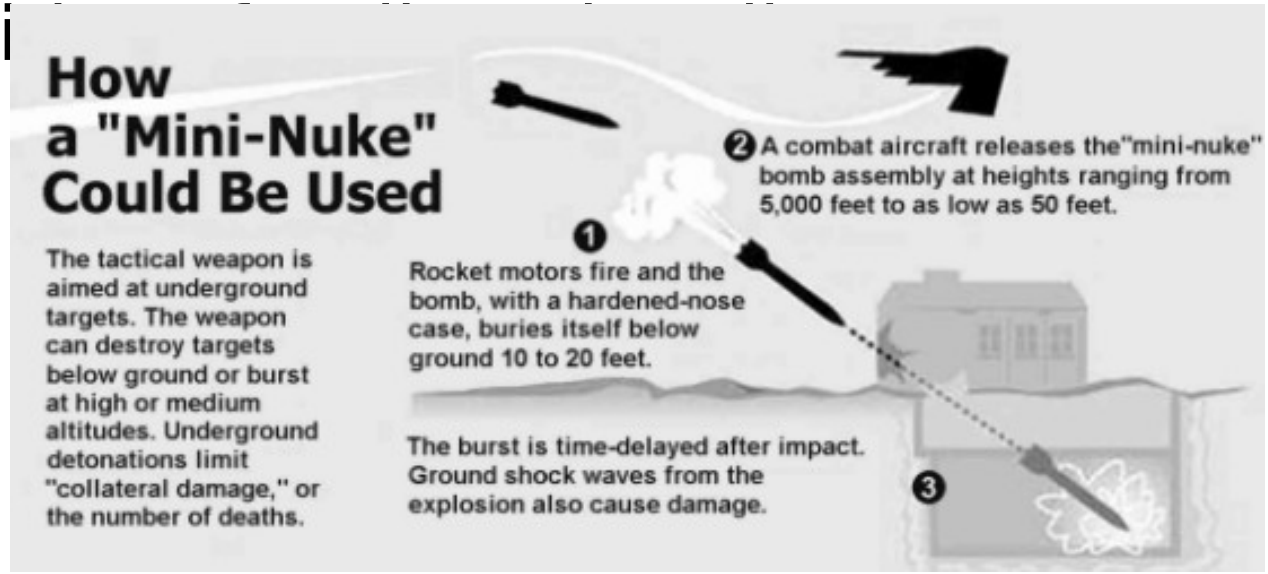
- Fission bombs produce 90% of their output as kinetic energy of fission fragments → fast heat production
- Fusion bombs produce 80% of their output as fast neutrons with <KE> = 14 MeV
- Fast neutrons can produce a fission event of KE=180 MeV, boosting the bomb's "efficiency"
- Most modern weapons therefore consist of at least two stages
  - Primary – fission bomb, often boosted by fusion core produced neutrons
  - Secondary – fusion bomb, with fission "sparkplug" to produce heat that triggers fusion, and extra layers of external fissionable material to boost yield

Other bomb designs

- Neutron bombs
  - Also known as “enhanced radiation” weapons
  - Designed to lower blast wave, thus sparing buildings, but killing people
  - However buildings do become radioactive
- “Clean” bombs
  - Designed with more fusion, and less fission, → more neutrons and less fallout
  - Needed three stages for sufficient

Low Yield Nuclear Weapons

- Designed to “threaten hard and deeply buried targets."
- Despite claims to produce less fallout due to underground explosion, a 5 kTon weapon would produce considerable quanti



Nuclear Weapons Free Zones

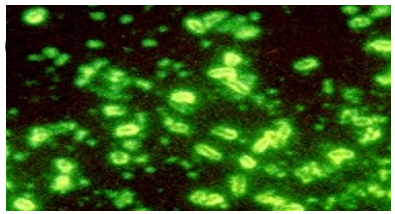
- Latin America and the Caribbean (the 1967 Treaty of Tlatelolco)
- South Pacific (the 1985 Treaty of Rarotonga)
- New treaties underway for
  - Southeast Asia (started December 15, 1995)
  - Africa (started April 11, 1996).

Comprehensive Test Ban Treaty

- Prohibits all nuclear testing
- Opened for signatures in 1996
- Prevents “Big 5” from developing or testing weapons of new design
- Approved by Russian Duma in 4/00
- Rejected by US Senate in 10/99
- Annex 2 has 44 states – those with nuclear research or reactors – 41 states have signed and 33 have ratified as of 10/05 – India, Pakistan, N Korea have not signed. US, China, Israel, Iran among those who have not ratified.

Biological Weapons History

- 1300s: Plague spread by infected



Plague bacteria

- 1760s: Native Americans infected by small pox from British blankets
- WWII:
  - Japanese use POWs for anthrax, cholera “research”
  - US develops anthrax bomb, obtains Japanese research results

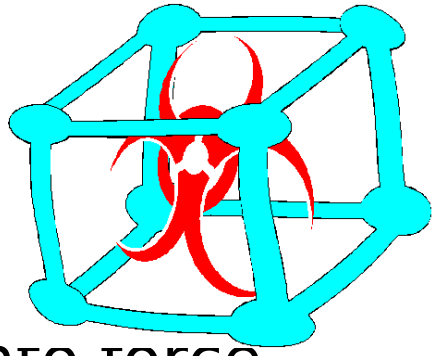
Biological Weapons History

- 1950: US exposes public to “harmless” bacteria (SF) and germs (NYC, DC)
- 1969: Nixon renounced US use, stockpiles and destroys supplies
- 1972: Biological and Toxin Weapons Convention signed and ratified
- 1975: BTWC in force
- 1970s → present
  - US and biotech research continues…

http://www.fas.org/biosecurity/resource/bioweapons.htm

Biological and Toxin Weapons Convention

- 162 signatories pledge to
  - Not develop, produce, stockpile, or acquire biological agents or toxins "of types and in quantities that have no justification for prophylactic, protective, and other peaceful purposes,"
  - Not develop weapons and means of delivery.
  - Destroy stockpiles within 9 months of the conventions entry into force.



- 13 signatories not yet ratified (Aug. 2008)

BTWC Update: Fall 2006

- Discussions still stalemated to add verification provisions to BTWC
- In July 2001, USA officially rejected these provisions, negotiated under Clinton Administration
- Ongoing research projects by USA and others are arguably in violation of the new, strengthened treaty – we do not want these research facilities inspected

http://www.basicint.org/update/BWC0607.htm

Chemical Weapons History

- WWI: Mustard, Phosgene and Chlorine gases used on battlefields
- 1925 Geneva accord prohibits use in battle but development continues
- WWII: Nerve gases made, not used
  - Tabun, Sarin, Soman, VX
- 1968 Open air tests kill sheep in Utah
  - US bans air tests, stops unitary weapons

Not a real dead sheep

Chemical Weapons History

- 1980s:
  - Iraq uses mustard gas vs. Iran, and possibly HCN vs. Kurds, kills > 5000
  - US proposes complete CW ban, but begins funding binary weapons
  - USSR halts production, starts destroying stockpiles
- 1993:Chemical Weapons Convention opens for signatures
- 2000: 172 signatories, 139 ratifiers

Chemical Weapons Convention

- First disarmament treaty to include a time frame for the elimination of an entire class of weapons of mass destruction
- First multilateral arms control treaty to incorporate an intrusive verification regime
- In force since 4/29/97
- Tenth anniversary in 2007
- http://www.cwc.gov/