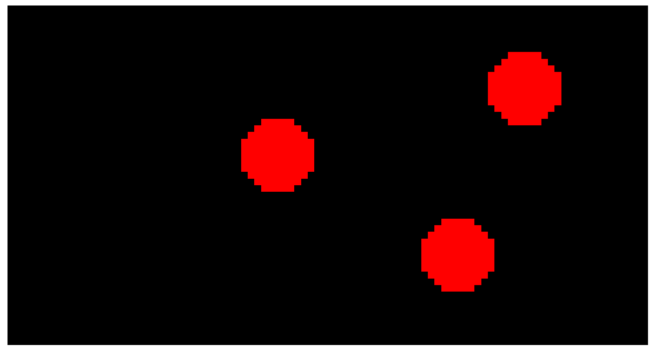
Science of War (and Peace)



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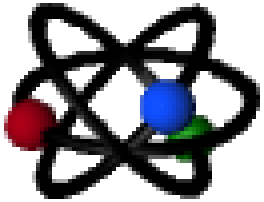
Talk Outline

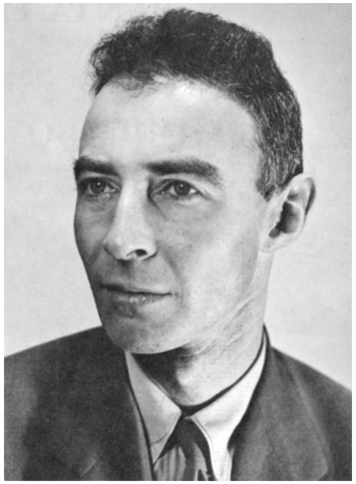
- Different sides of science
- Atoms for War
  - A bit of history
  - Fission
  - Fusion
  - Effects
- Atoms for Peace
  - Enrichment
  - Proliferation
  - Current state of affairs with Iran



Science – it’s not good or bad

- “The good thing about science is that it's true whether or not you believe in it.”

  -- Neil deGrasse Tyson



- “ When you see something that is technically sweet, you go ahead and do it and you argue about what to do about it only after you have had your technical success. That is the way it was with the atomic bomb.”

  -- J. Robert Oppenheimer

Science does not discriminate

Science	War	Peace
Chemistry	Chemical weapons	Pharmaceuticals
	Chemical Explosives	Demolition
Biology	Biological weapons	Botox, vaccines
Physics	Nuclear weapons	Nuclear power
	Sensors	Astronomy
	Guidance systems	GPS
	Ballistics	Hobby rocketry
	Strategic Defense	Lasers
Computers	Cryptography	Encryption security
	Spy satellites	Remote sensing
	Cybersecurity	Secure websites

Atoms for War – some history

- World War II coincided with advances by physicists in understanding the inner workings of the atom
- These physicists understood that it was possible to release huge amounts of energy by breaking apart or smashing together nuclei of atoms – far more than can be released in chemical reactions, which rely on electrons

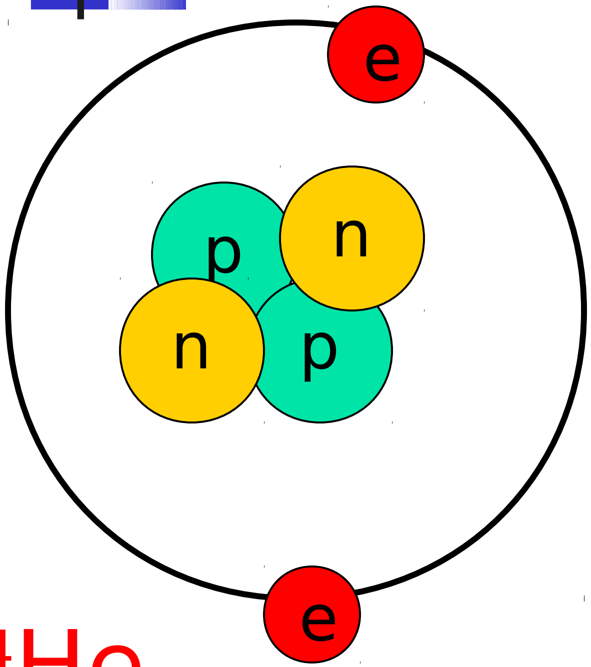
WWED?

- By 1939 many prominent (mostly Jewish) physicists had fled Europe and resettled in the USA
- Albert Einstein signed a letter to President Roosevelt alerting him to the terrible potential of weaponizing nuclear reactions
- But until Pearl Harbor in 1941, the USA did not invest much in this research

Manhattan Project

- After 1941, the US began to race Nazi Germany to develop nuclear weapons
- Manhattan Project was really located in Los Alamos, NM
- Most of the funding went to build factories that could produce the materials needed to make the bombs
- The first successful test was Trinity on 7/16/45 in Alamogordo, NM

Nuclear physics vs. Chemistry

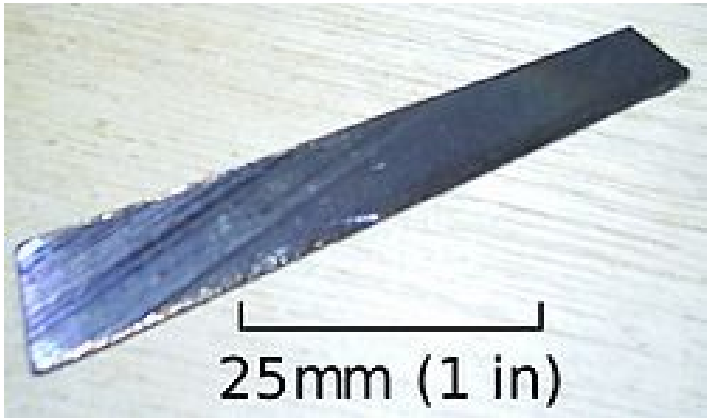


^{4}He

Helium Atom:
2 electrons (e)
2 protons (p)
2 neutrons (n)

- Chemistry: change the number of electrons → typical energies involved are a few electron Volts (eV)
- Nuclear physics: change the number of protons or neutrons in the nucleus → typical energies involved are millions of eV

Isotopes of Uranium



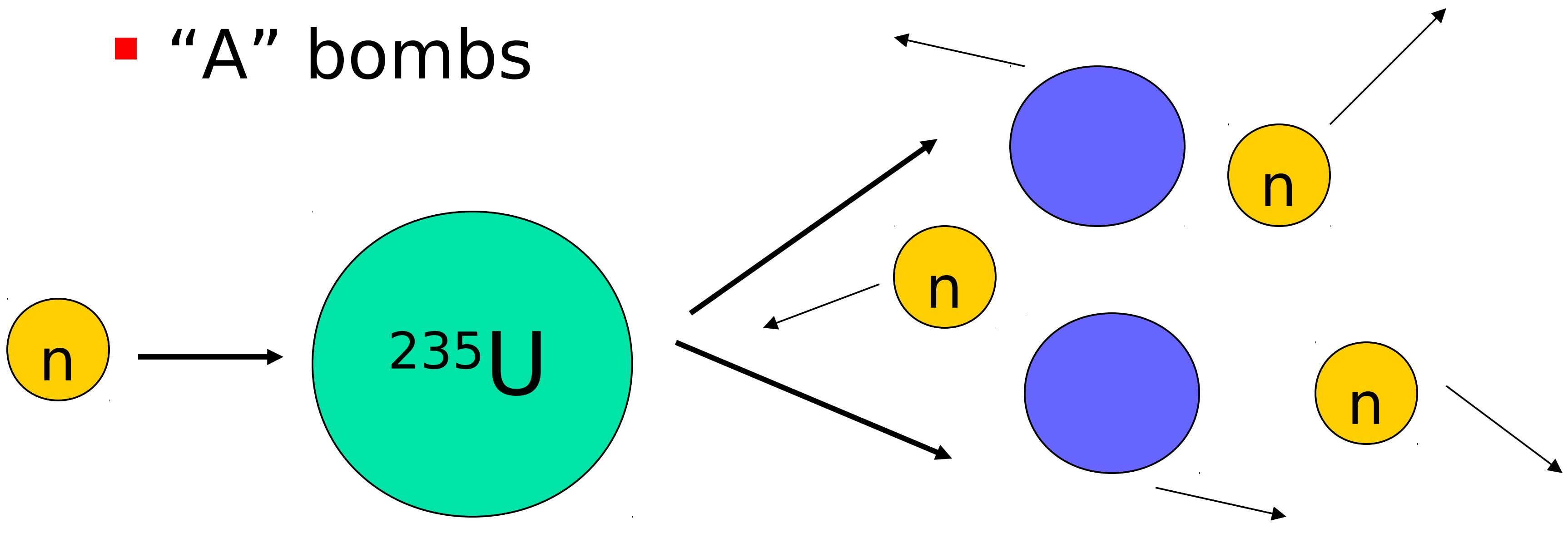
10 g of ^{238}U

- Uranium: ^{238}U is >99% in nature. Uranium has 92 protons, and ^{238}U has 146 neutrons.

- ^{235}U is ~0.7% in nature but is the major ingredient in chain reactions. 143 neutrons.

Fission Weapons

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



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

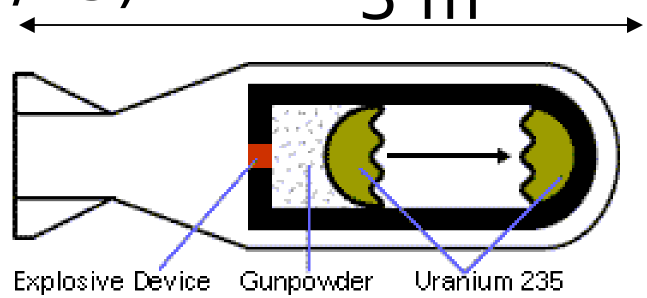
How to make an “A” bomb

- 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)

3 m



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

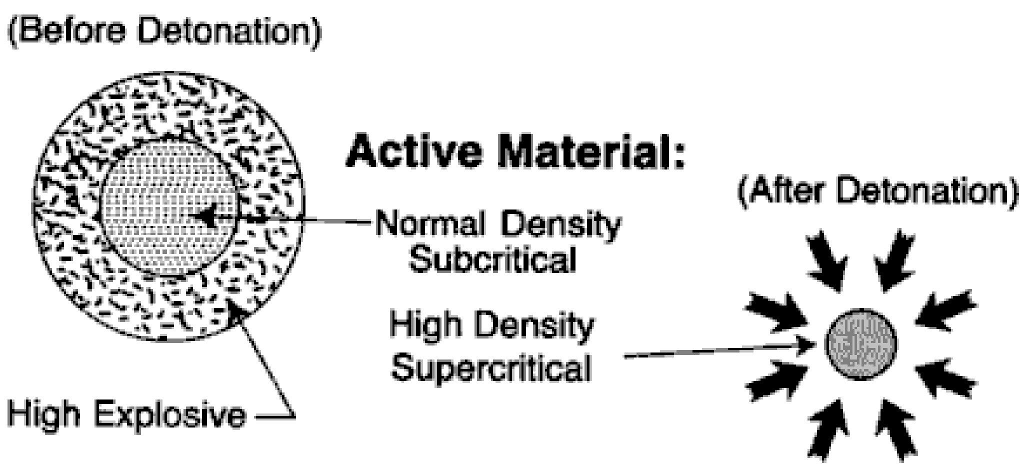
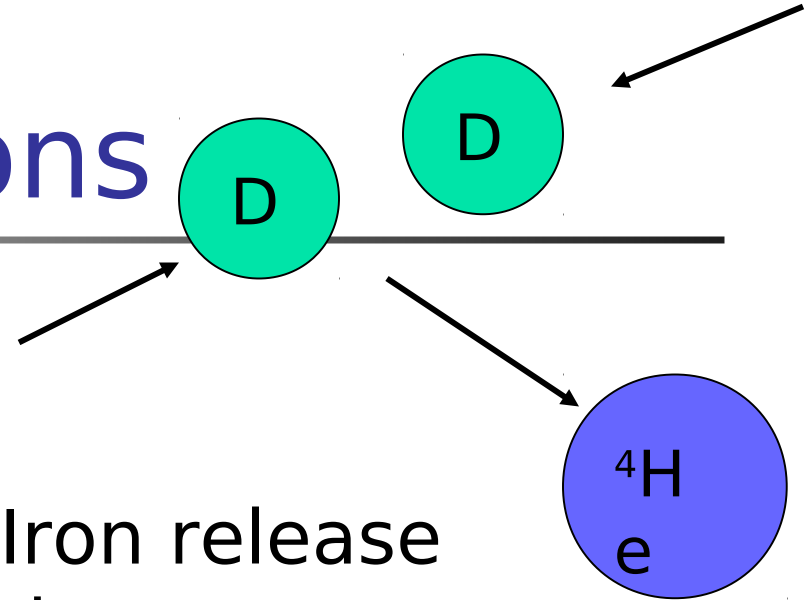


Figure 2-VIII. Implosion Assembly Principle

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

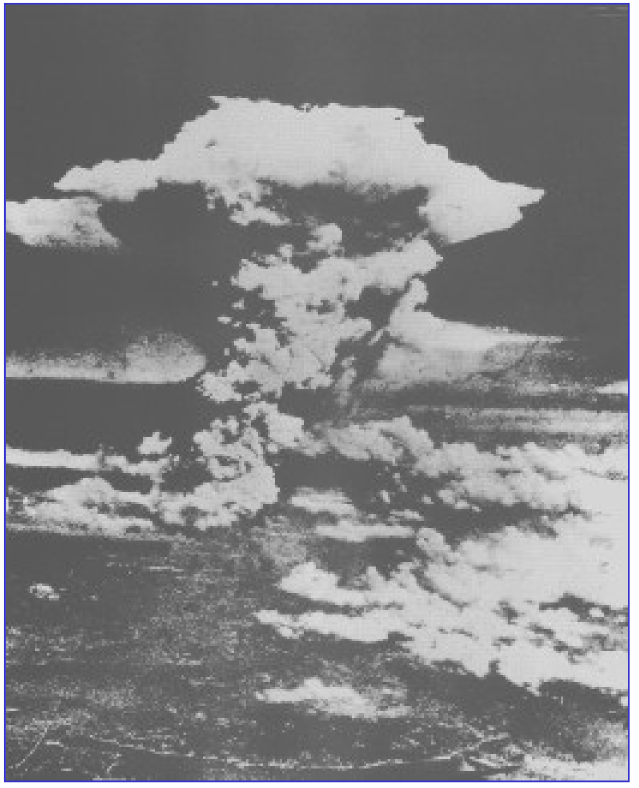
Fusion Weapons



- 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

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)

Trinit

Bridge in

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

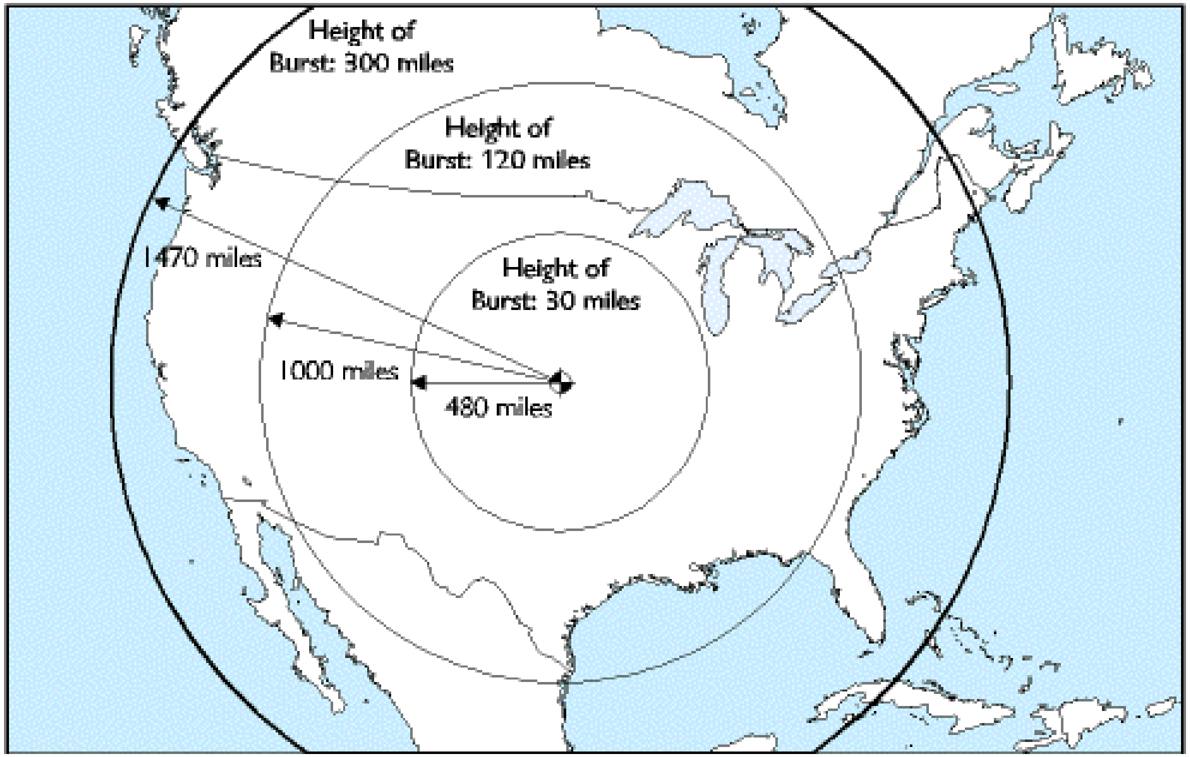
Google Nuclear Weapon Effects Calculator to try it out on your city!

Nagasaki victim

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

Nuclear Weapons are Scary!

- Most of the lasting effects are due to radiation, so are odorless and colorless
- Genetic damage and cancers can take 20 or more years to develop
- A single bomb can kill 100,000 people and destroy an entire city
- It does not take much nuclear material to create a big explosion
- However, it does take considerable

How big are the weapons?

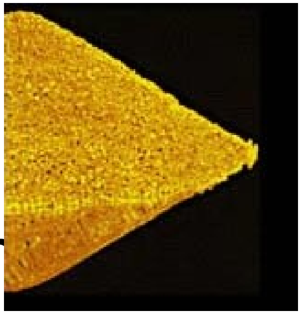
- 1 kTon = 1000 tons = 2,000,000 pounds of TNT equivalent
- ~2 pounds of ^{235}U → 20 kTons
- Today’s warhead is 100-200 kTons
- Largest underground burst: 4.5Mtons
- Largest airburst: 58 Mtons
- Over 1700 known tests since 1945

Atoms for Peace

- After the horrors of Hiroshima and Nagasaki, Eisenhower launched ‘Atoms for Peace’ in 1953
- The goal was to “solve the fearful atomic dilemma… to find the way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life.”
- This program built the first nuclear reactors in other countries including Iran

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

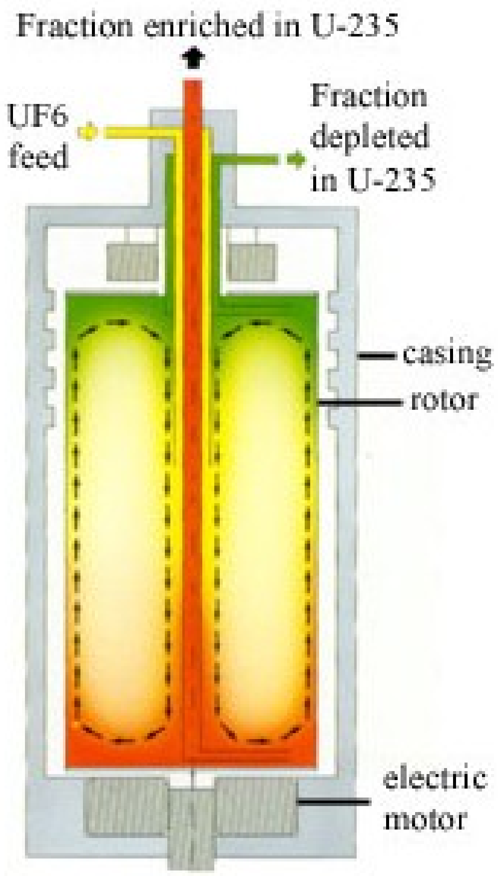
- Naturally occurring Uranium must be enriched to >90% ^{235}U in order to make fission weapons (or to ~5% for nuclear power plants)
- Enrichment methods
  - Gas centrifuge (now being used in Iran and found in Iraq after 1st Gulf War)
  - Gaseous diffusion (used in USA)
  - Electromagnetic isotope separation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

Iran - key to Mid-east peace?

- Iran is currently negotiating over its nuclear enrichment program with US, Germany, UK, France, Russia and China
- Iran is supporting Iraq and Assad in Syria against ISIS forces
- Will US allow Iran to continue to enrich Uranium in exchange for help against ISIS?
- Or will we continue to undermine their enrichment program through cyber-physical or other types of attacks?

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

- Iran has developed an extensive, underground enrichment facility for Uranium at Natanz
- 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

Ahmadinejad visits Natanz 4/08

- Inspecting the new IR-2 centrifuges

To Kill a Centrifuge

- In 2010, news reports indicated a new type of malware had been uncovered. (An older, less effective version was later discovered dating back to 2007)
- “Stuxnet” penetrated Windows computers, then took aim at specific programmable logic controllers made by Siemens and resident in Iranian enrichment centrifuge systems that were IR-1 models
- Reports indicate that up to 10% of Iranian centrifuges (~1000) were destroyed by varying the rotational speeds while playing back a loop that indicated normal operations were occurring

From Langner’s report

- “Stuxnet will not be remembered as a significant blow against the Iranian nuclear program. It will be remembered as the opening act of cyber warfare”
- “Stuxnet started as nuclear counter-proliferation and ended up opening the door to proliferation that is much more difficult to control: The proliferation of cyber weapon technology.”

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

Feb. 2013 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

Nuclear Non-Proliferation Treaty

- NPT indefinitely extended since May 1995, confirmed again in 2000, reviewed most recently in May 2010
- Now signed by 189 countries
- N. Korea ratified in 1985 then withdrew in 2003. In 2006 and 2009, it conducted nuclear tests.
- Israel, India and Pakistan are still not signatories.
- Iran remains a signatory but has been in violation for many years now. Issues in 2014 include:
  - suspicious experiments with high explosives
  - studies on neutron initiators
  - experimentation with high explosives
  - calculations on nuclear detonation yields

Current dealings with Iran

- Interim nuclear accord is in effect through 11/24/14
  - Iran has diluted or converted to oxide form its stock of 20 percent enriched UF_6
  - In return, Iran gets a suspension of restrictions on its automotive and precious metal sectors as well as waivers for foreign purchasers of Iranian oil.
  - Plus, Iran will receive an additional $2.8 billion in frozen assets

While negotiations continue...

- Iran claims it wants to raise its LEU quantities to 190,000 units per year (from current 7000) using new IR-8 machines
- Iran is continuing to use IR-1s to create up to 2.4 tons of LEU during 2014
- Iran is continuing to manufacture IR-2 and newer models of more efficient centrifuges
- Estimates are that it could create enough HEU within 2 months to make 7 bombs (at any time it chooses to enrich

Some hopeful signs

- New START (STrategic Arms Reduction Treaty) signed April 8, 2010 by Obama and Medvedev – and then ratified by Senate and put into force on Feb. 5, 2011
  - Limits deployed strategic nuclear warheads to 1,550
  - Limits deployed and non-deployed ICBM, SLBM, and heavy bombers to 800.
  - Limits deployed ICBMs, deployed SLBMs, and deployed heavy bombers to 700
- For the first time in a long time, US and Russia are slowing vertical proliferation

More hopeful signs

- 2014 Nuclear Security Summit in the Hague, the Netherlands (3/26-27/14)
  - Concrete agreements between 58 world leaders to prevent terrorists from acquiring nuclear materials that could be used for weapons (HEU and Plutonium)
  - New agreement to improve security of radioactive material that could be used for “dirty bombs”
  - Improvements in the exchange of information and international cooperation
  - This is the third bi-annual summit

Words of wisdom?

- “To be prepared for war is one of the most effective means of preserving peace.” -George Washington

- “Peace cannot be kept by force; it can only be achieved by understanding.”

  - Albert Einstein

Additional Resources

- Carnegie Endowment for International Peace http://www.ceip.org/
- To Kill a Centrifuge

http://www.langner.com/en/wp-content/uploads/2013/11/To-kill-a-centrifuge.pdf

- Federation of American Scientists http://www.fas.org
- Verification report about Iran

http://fas.org/pub-reports/verification-requirements-nuclear-agreement-iran/

- Iran Watch (Wisconsin Project) http://www.iranwatch.org/
- Union of Concerned Scientists http://ucsusa.org
- Nuclear Security Summit 2014 http://www.nss2014.com/en