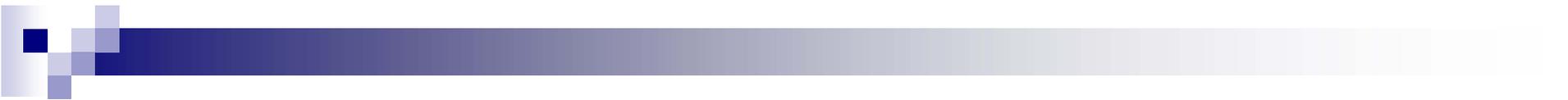


# The Physics of Terrorism and Counter-Terrorism

Prof. Kevin McFarland  
Physics 100  
Spring 2004



# Physics and Terrorism?

- Why is what you've learned about in Physics 100 relevant to terrorism?
  - Terrorist threats:
    - How to release energy quickly
    - Nuclear and radioactive (“dirty”) weapons are among those most potentially destructive
      - How could a terrorist build a nuclear weapon?
  - Counter-terrorism:
    - Non-destructive imaging is a major tool in preventing access to potential weapons
    - Understanding and detecting threats of radiation



# Relative Threats of Energy Release

- This is not a biology course, and I'm not a biologist, so I can help little with understanding infectious diseases and bioterrorism
  - we will, however, talk about destruction of biological organisms with radiation
- I do understand, however, how to release energy in a confined space
  - This is an obvious form of property destruction and mass murder

# Explosive Energy Release



Alfred P. Murrah Federal Building  
Oklahoma City, OK, April 19, 1995  
Fertilizer-Fuel Truck Bomb



Coordinated Train Bombings  
Madrid, Spain, March 11, 2004  
Chemical High Explosives in  
Luggage

# Massive, Slow Energy Release



World Trade Center Attack on South Tower  
United Airlines Flight 175. ~60 tons of fuel.  
Initial Blast Leaves Tower Intact. Exploded fuel is much less than 60 tons.  
But subsequent Fire Weakens Structure; Tower Collapses 62 Minutes Later

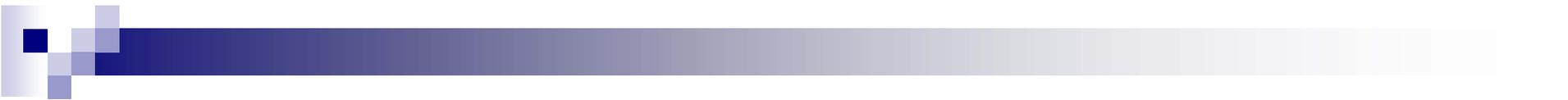
# Stored Energy

object	Calories in one gram	compared to TNT
gasoline	10	15
chocolate chip cookies	5	8
bullet (moving at speed of sound)	0.01	0.015
methane gas (CH <sub>4</sub> )	13	20
battery (flashlight)	0.01	0.015
battery (computer)	0.1	0.15
hydrogen gas (H <sub>2</sub> ) for fuel cell	26	40
TNT by convention*	1 (see footnote *)	1.5
real TNT (trinitrotoluene)	0.651	1
modern High Explosive (PETN)	1.06	1.6
Nitroglycerin (in dynamite)	1.59	2.44
meteor (at 30 km/sec)	100	154
uranium-235	20,000,000	30,000,000

} chemical  
 ← kinetic  
 } chemical  
 ← kinetic  
 ← fission

\*For weapons limitations treaties, 1 gram of TNT is defined as have 1 Cal.  
 Thus, for example, an explosion that releases an energy equivalent  
 of one ton of TNT will be a million Calories, i.e. a megaCalorie.

Chart Courtesy Richard Muller, LBL



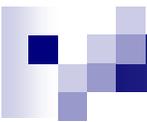
# Conclusions about stored energy?

- Gasoline (& methane, H<sub>2</sub>, oils, fertilizers) store tremendous amounts of energy
- What is the different between chocolate chip cookies, gasoline and dynamite as weapons?
  - different methods of liberating energy
  - high explosives: easy to detonate
  - gasoline, methane: must mix with air and ignite
  - chocolate-chip cookies: require additional work in order to release energy
- Nuclear and kinetic energy can be much larger
  - but harder to obtain and release...

# Releasing Energy of Gasoline

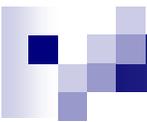
- Blu-82 “Daisy-cutter” Bomb, used in Afghanistan
  - 7.5 tons of gasoline (that’s 1,500 gallons)
  - equivalent to 112 tons TNT = *1% of Hiroshima bomb*
  - parachute deploys from fuel core, spraying gasoline into air which can then be ignited
  - much larger initial explosion than crashing Boeing 767





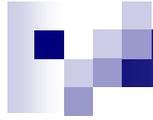
# A Few (non physics) Words about Terrorist Threats

- Al Qaeda is a very serious terror threat, but we should understand the nature of the threat
- 9/11 Hijackers were not sophisticated
  - Mohamed Atta (pilot of AA Flight 11, North Tower WTC) applied for a USDA loan to help buy a crop duster in spring 2000
  - Zacarias Moussaoui made it very clear to his flight instructors that he didn't care about landing 767s
- By contrast, domestic terrorists (Timothy McVeigh, Anthrax mailer?) leave very few clues
- Lesson: One can make tremendous headway against terrorists threats by eliminating the obvious
  - are immigrants/visitors to US the right group on which to focus?

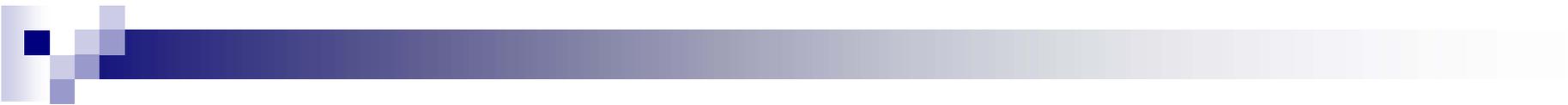


# More (non physics) Words...

- Are passenger airplanes as a bomb delivery vehicle a likely next method of attack in the US?
  - lesson of UA Flight 73 (crashed near Pittsburgh in struggle between passengers and hijackers) is...?
- Are there other vulnerabilities?
  - small planes or cargo planes
  - cargo containers on ships or trains
  - common al Qaeda techniques:
    - trucks or boat bombs (fuel mix)
    - luggage or personal bombs (high explosives)
    - plane as the target (the “shoe bomber”)
  - “value added” targets, e.g., stores of radioactivity



# The Case of Airport Security: What is the technology? Should we feel safe?



# The problem...

- 1.8 Million commercial passengers per day
- 87000 Flights per day
  - 30000 commercial passenger planes
  - 25000 private planes
  - 5000 military flights
  - 2500 air cargo planes
- How do you screen every passenger, bag and element of cargo?
  - Two tiered strategy: “superficial” screening and detailed screening of a small fraction



# Airport Detection Tools

- Metal detectors
- X-rays
- More sophisticated alternatives, like NMR Imaging or Cosmic Ray Imaging
- Chemical Detectors



# Non-destructive Imaging

- What are the potential weapons we want to identify?
  - Metals (knives, guns) on airplanes, at public gatherings
  - Explosives on airplanes, in buildings
  - Biological weapons (viruses, spores, toxins)
  - Radioactive materials for “dirty bombs”
  - Fissionable materials for nuclear weapons



# Metal Detectors

# Why do we want to detect metals?

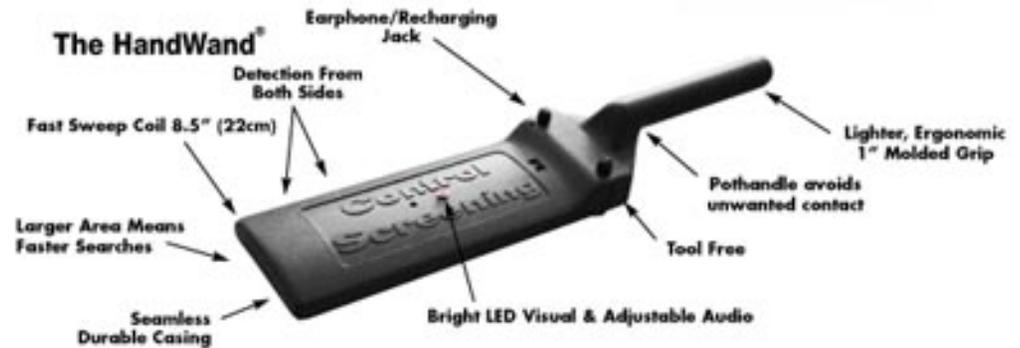
- Metals are special materials because of their strength, ability to withstand stress and conduct electrical signals
  - Guns and knives use metal, primarily because of the first two properties
  - But we detect the third property, usually
- There are other materials with good structural properties... e.g., ceramic
  - Here's a ceramic 8" Sashimi knife you can buy for \$690 on amazon.com (There are less expensive models.)
  - There are also ceramic/plastic guns. I could not find a source on amazon or e-bay.



# Where are metal detectors at work in airports?



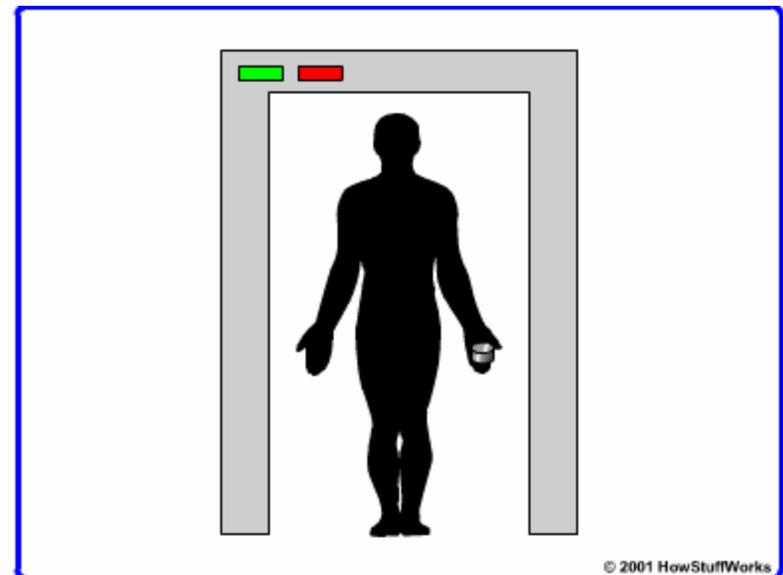
Walk-through model from Perkin-Elmer



Hand-held model from ControlScreening

# How do they work?

- Best large-scale metal detectors use a technology called “pulse induction”
  - think of how a light reflects from metal. Here a **magnetic pulse (red)** is **reflected (blue)** from metal
  - the reflection is detected in a sensor
- The pulse is why people with pace-makers should NOT go through metal detectors...



# Why did this not stop the 9/11 Hijackers?

- Until the hijackers attempted to take control of the plane, they had actually broken no laws
- It was legal until after 9/11 to bring knives with blades less than 4”



- Metal detectors were set at a threshold incapable of finding a box cutter or razor blade
  - so that your pocket full of change wouldn't set it off
  - too many “false positives” mean screeners ignore signals or raise thresholds. This is human nature.



# X-rays

# You baggage, but not you, goes through an X-ray machine

- What can X-rays do?
- Early commercial application illustrates...



**CERTIFICATE**

SHOE-FITTING TEST DATA FOR \_\_\_\_\_

**1. ANKLE ROLL**    GOOD     FAIR     POOR

**2. WEIGHT DISTRIBUTION**

40%  
60%

RIGHT WAY

WEIGHT DISTRIBUTION TEST

70%  
30%

WRONG WAY

LEFT                      RIGHT

\_\_\_\_% BALL            \_\_\_\_%

\_\_\_\_% OUTER           \_\_\_\_%

\_\_\_\_% HEEL            \_\_\_\_%

**3. X-RAY FITTING TEST**

RIGHT WAY

X-RAY TEST

WRONG WAY

LEFT                      RIGHT

GOOD                     

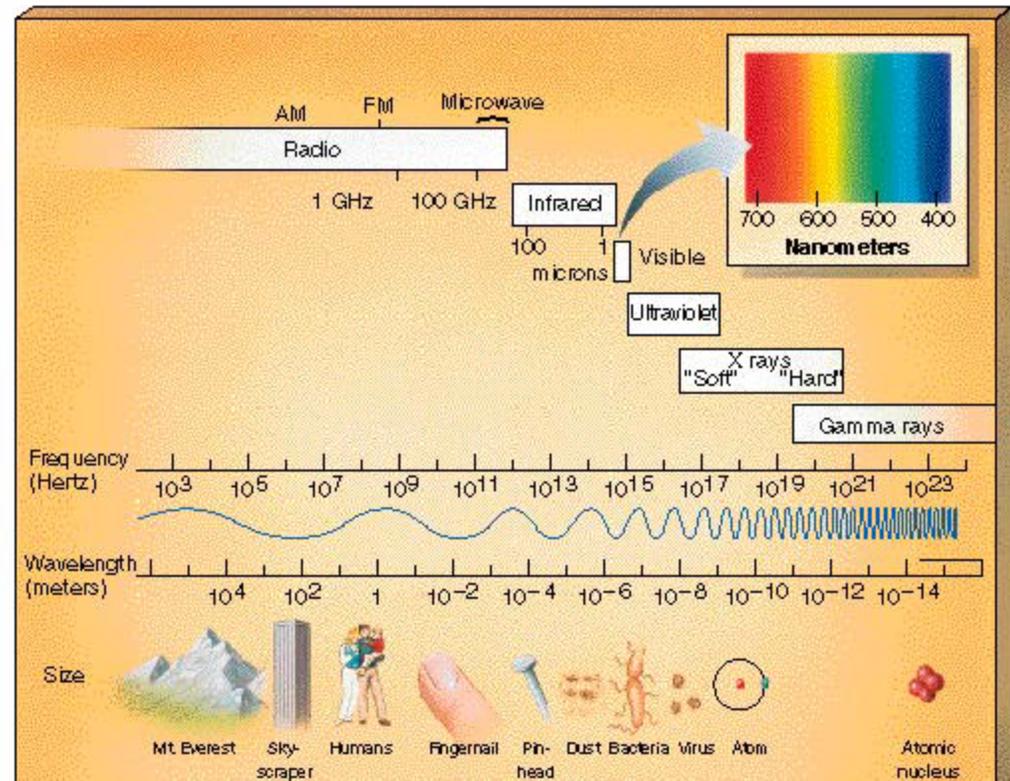
FAIR                       

POOR                       

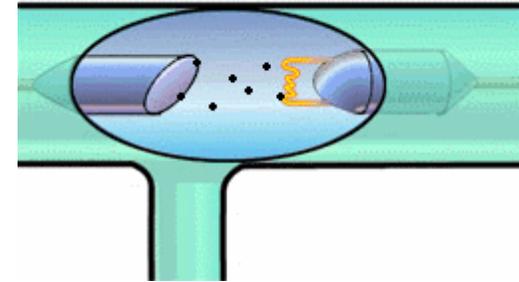
**This scientific way of approaching the problem of poorly-fitted shoes eliminates guesswork. Now you can see for yourself!**

# What are X-rays?

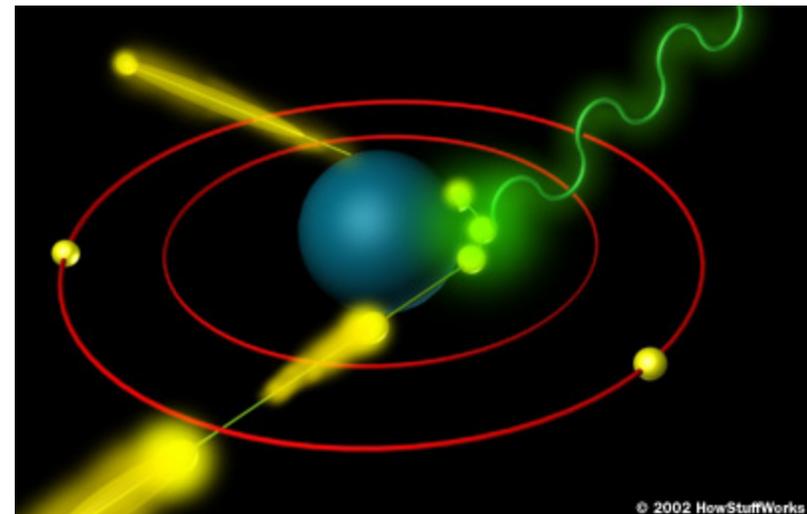
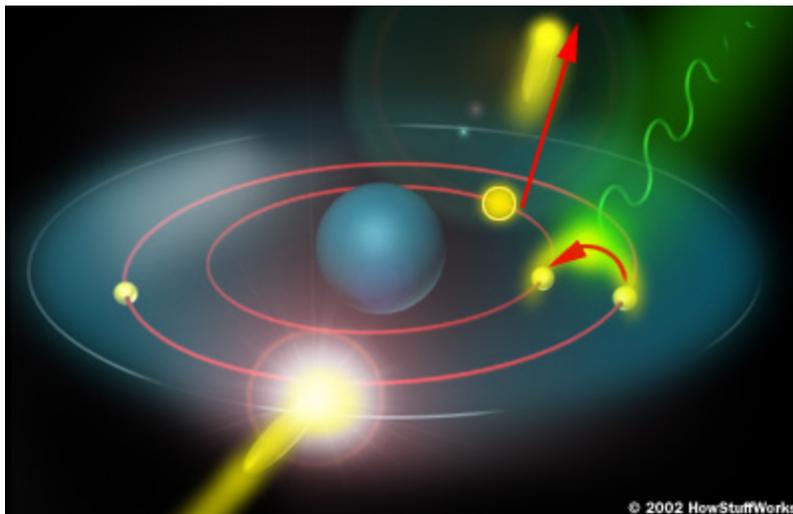
- From high energy part of electromagnetic spectrum
- Wavelength of X-rays are roughly the size of an atom
  - ~1000 times smaller than visible light



# Making X-rays

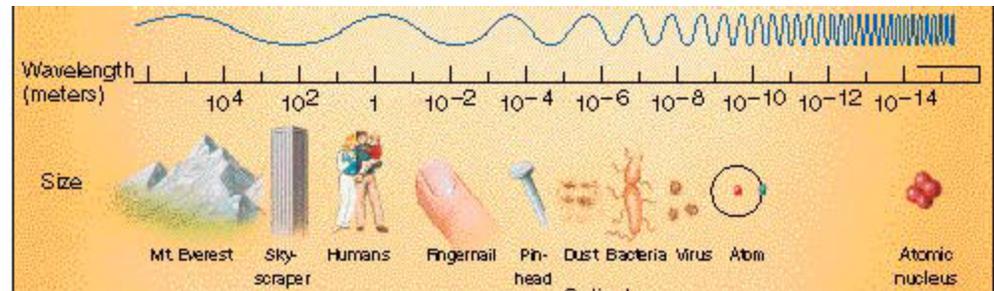


- It's “easy” to make X-rays by bombarding a heavy element with electrons
  - knock an electron out of orbit
  - “bremsstrahlung”... accelerate electron, it radiates



# Why can you see bones on an X-ray picture?

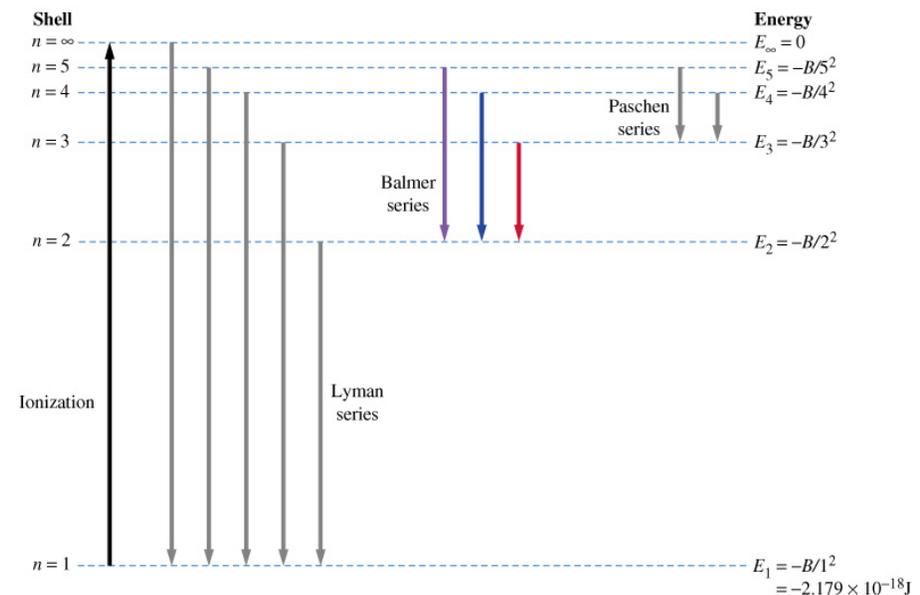
- Let's look at the electromagnetic spectrum again



- In radio waves (few meters), photons can't excite atoms, so they pass through material
- In visible light, lots of atomic quantum transitions to absorb light in hydrogen, oxygen, carbon. You are not transparent!

# Why can you see bones (cont'd)

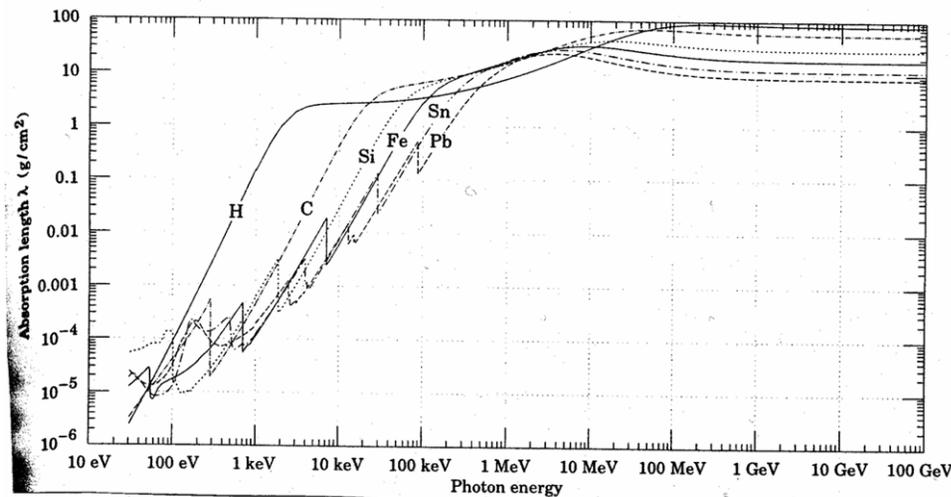
- But in X-rays... most of the time they have too much energy to make transitions! How can that be?
- Hydrogen binding energy is only the energy of a UV photon
- Photons near an atom are absorbed best ONLY if they can make an electron jump from one energy level to another



- Binding energy of atom goes as  $Z^2$  ( $Z = \#$  of protons)

# Absorption of X-rays in matter vs. X-ray energy

23. Passage of particles through matter 169



- Scales of energy and absorption are logarithmic.
- Observe a very sharp edges in the graph. Energies where the absorption is very effective. This is where inner electrons in heavy materials go to outer electrons
- The higher Z is, the higher energy these edges are

# So what is a medical X-ray?



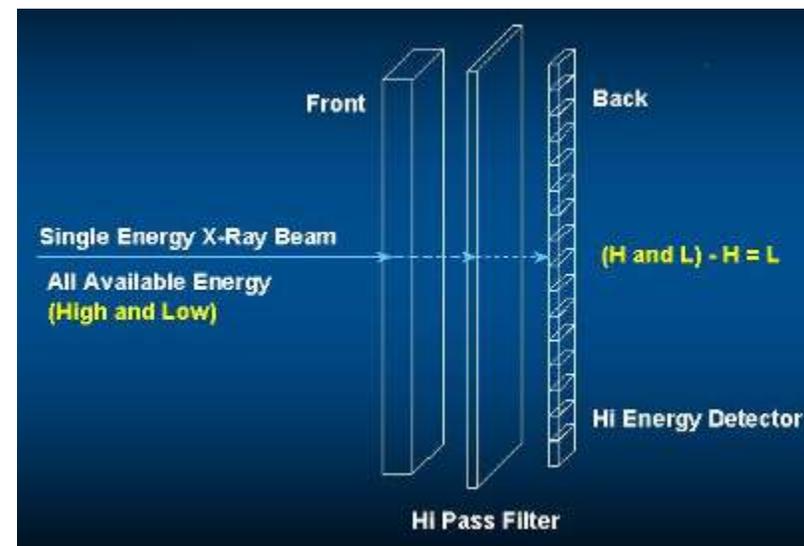
- Soft tissues are transparent to X-ray. Calcium in bones absorbs it
  - X-rays are detected on film. This is a negative, so black means X-rays hit the film at that point. White means the body absorbed the X-rays

# So the strategy is...

- Measure absorption of different energy X-rays to identify the composition of different materials!

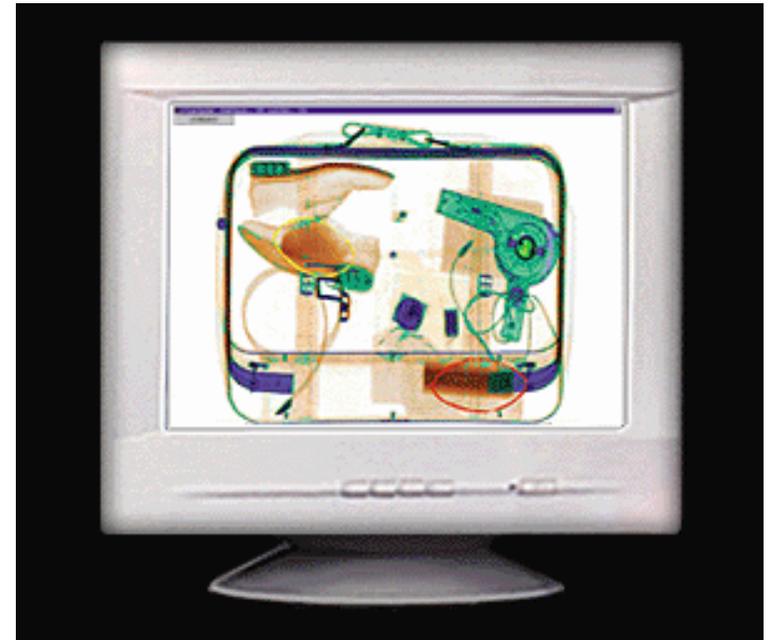


Perkin-Elmer Handbag Scanner



Dual-range scanner. Looks at high energy and low energy X-rays at same time.

# What the machine gives...



- Orange=organic material (H, C, O)
- Purple is metal (absorbs higher energies)
- Green is inorganic... intermediate Z of atoms

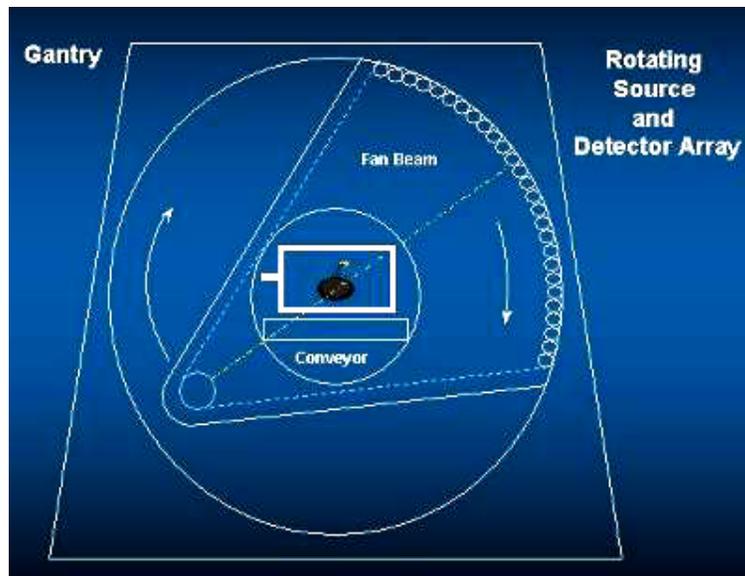
# Checked Bags get special treatment

- Larger scanner with higher X-ray power and higher energy X-rays
  - allows for identification of more materials in denser, thicker objects
- And if your name shows up on one of those CIA or FBI lists...



# CT (Computerized Tomography) X-ray Scanners

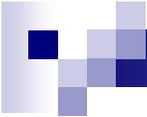
- Maps out in 3-D the density profile of your bag
  - identifying different materials (organic, inorganic, metals) with X-rays...



- “Tomography” basically means making a complex map
  - easier for computer to recognize suspicious structures because you can take a slice or see in 3D

# CT of a Human Abdomen





# Where should you keep your film?



- Handbag scanners have very low dosage
- CT scanners have to expose for much longer to make a 3D map and have to use higher power X-rays to penetrate through thick bags
- So never check your film.
  - Thin lead bags, by the way, are not very effective protection against luggage CT scanners
  - And even if it did hide the contents, it may single your bag out for “special treatment”

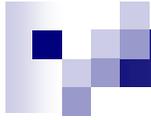
# Chemical Detection



Low-tech solution is very effective



Chemical sniffers or “trace detectors” can identify very low levels of explosives (or fertilizer or other household products)

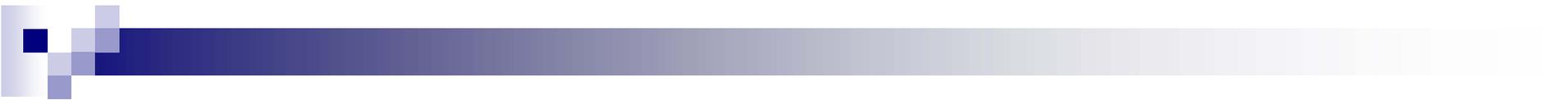


# Nuclear Magnetic Resonance

# NMR and MRI Scanners

- **NMR**= Nuclear Magnetic Resonance. This is what physicists call this...
- **MRI**= Magnetic Resonance Imaging.
  - This is the name doctors give this. (To avoid using the word “nuclear?”)



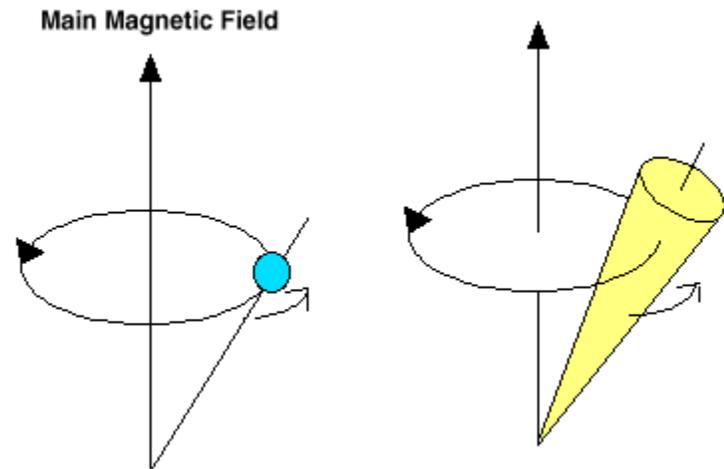


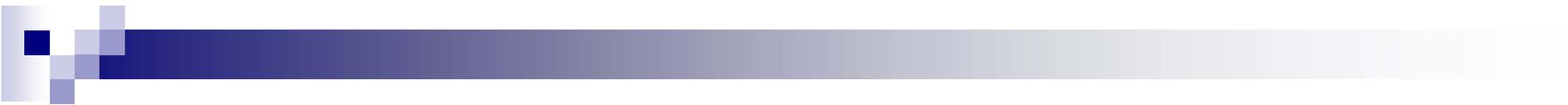
# What makes nuclei magnetic?

- Remember that we showed currents could create magnetic fields?
  - each nucleus has little currents in it (from “spin” of quarks, from orbits)
  - So each one is a little bar magnet
- Now imagine you put that nucleus in a magnetic field?
  - Can see this alignment of the little magnets, but it is a very very tiny signal

# The detection technique is very clever...

- This nucleus' magnet will “precess” around the field from an external magnet
- It's a lot like the way a top that is slightly off center will slowly spin around
- This precession has a frequency that can be excited with radio wave pulses and “echoed” back
- Can locate individual types of material by position also to build up a complete map





# Chemical Identification

- Nuclei are inside atoms, inside molecules
- The location of the electrons distorts this nuclear resonance effect
  - Can actually identify particular chemical species!
  - This is the ultimate non-intrusive detector for explosives, etc.
- Unfortunately, we're not there yet for using this technology in luggage scanning...

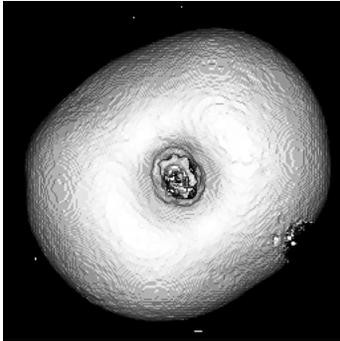
# NMR Technique

- Requires a very large magnetic field to align spins
- This can be dangerous and cumbersome!
  - Here is a fully loaded pallet jack that got too close to an NMR machine. Oops.
  - Don't keep your keys in your pocket!

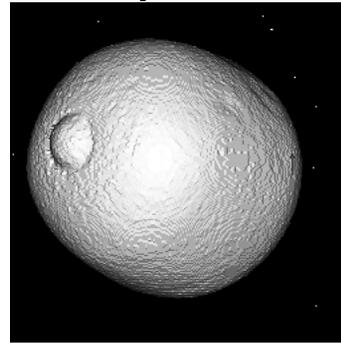


# MRI Pictures

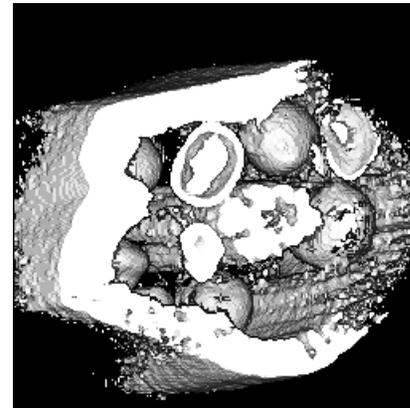
Cherry



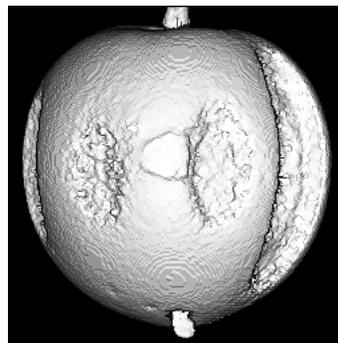
Grape



Okra

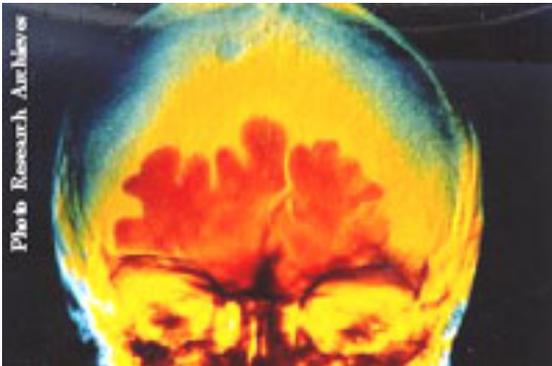


Tomato



# More MRI Pictures

Sinus

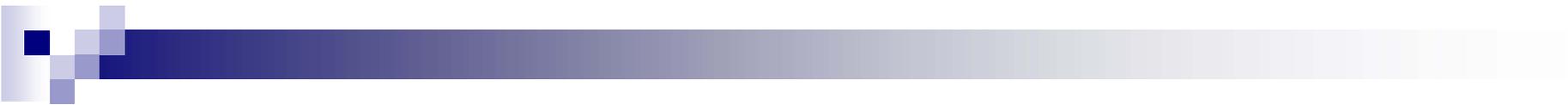


Brain



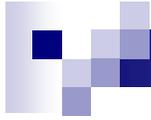
Lungs





# Next time...

- Radioactivity and Human Effects
  - Using radioactivity to fight bioterrorism
  - “Dirty Bombs”
- Nuclear proliferation
  - Nuclear Weapons and Terrorism

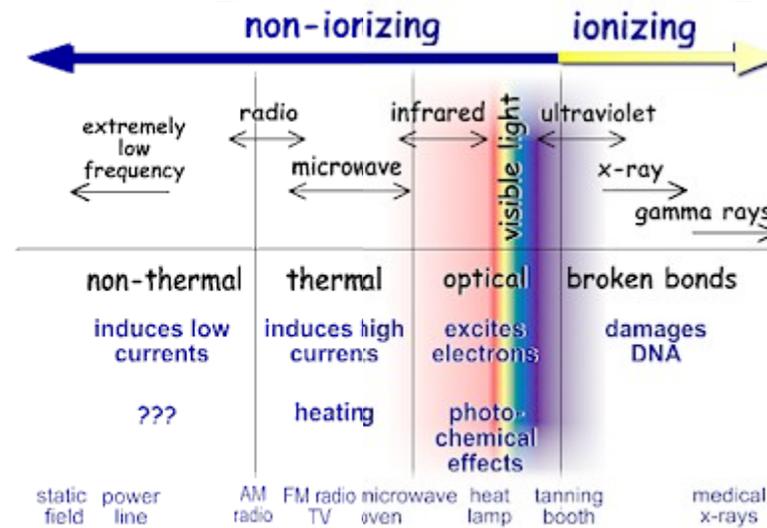


# Radiation and Biological Systems

# Biological Harm from Radiation

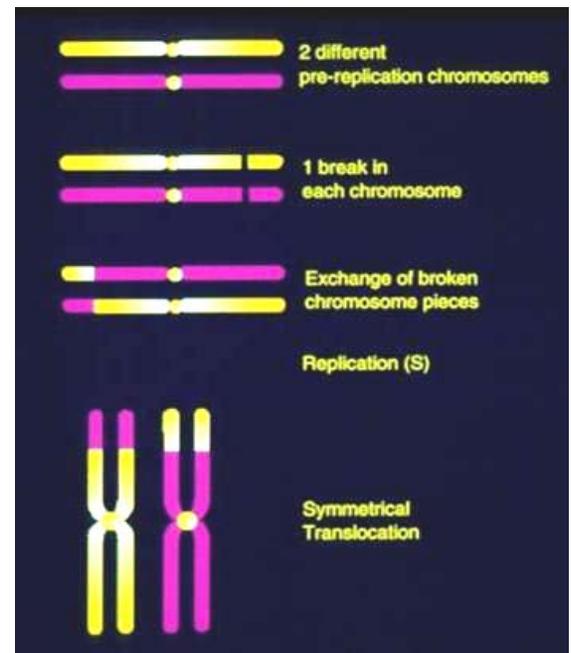
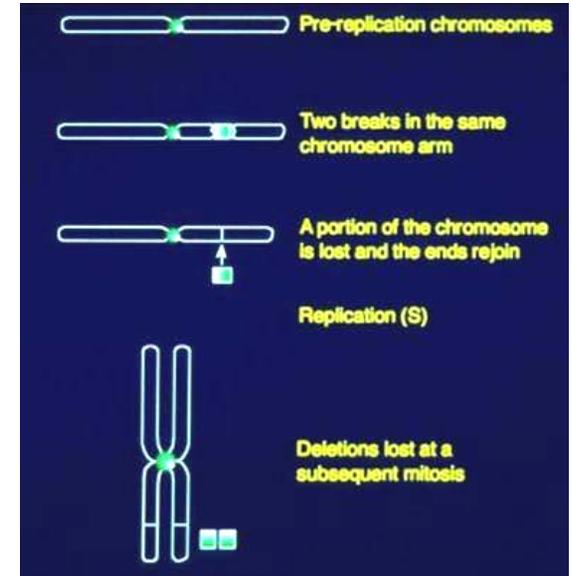
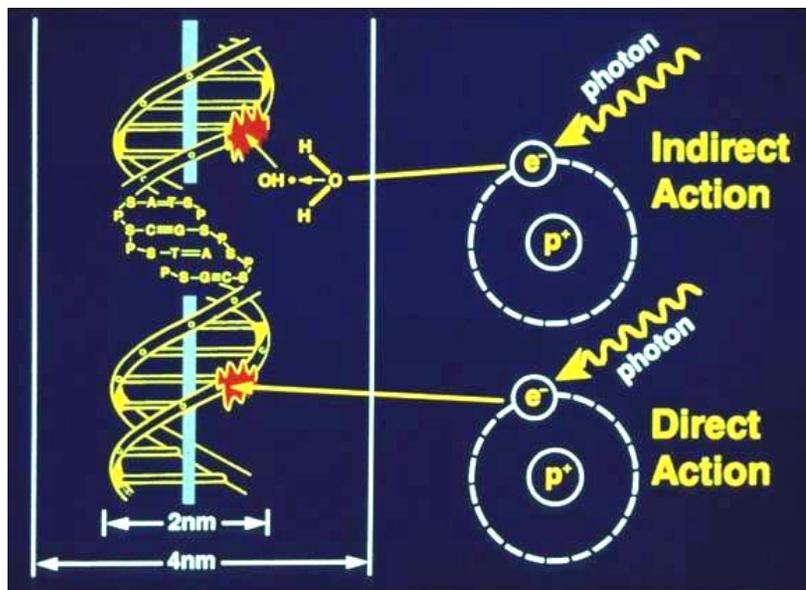
- A priori, all forms of electromagnetic radiation (radio, microwaves, light, ultraviolet, X-rays,  $\gamma$ -rays) and particle radiation could be harmful
- A useful distinction is ionizing vs non-ionizing radiation

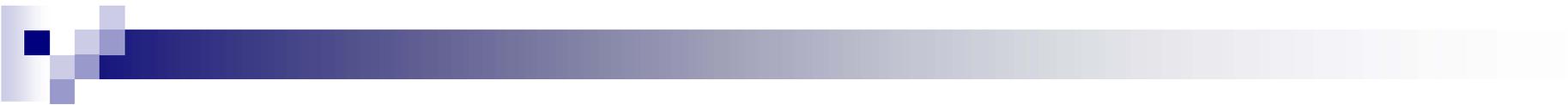
- Ionizing radiation can remove an electron from biological material that it strikes



# How does Ionizing Radiation Damage Cells?

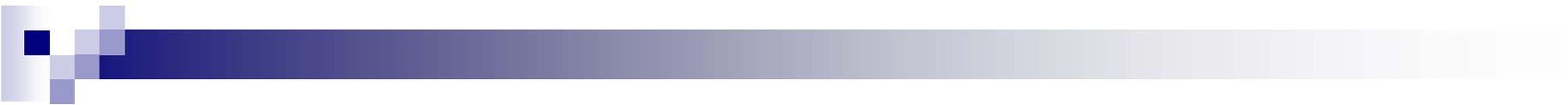
- One cause: DNA chemical bonds break, leading to deletion or substitution of genetic code
  - Mutations in DNA or cancer formation





# Massive Doses: “Acute Radiation Poisoning”

- Here the effect is primarily massive cell damage leading to cell death
  - Most deadly is loss of cells that create red blood cells in bone marrow and the cells that line the intestinal walls
  - Symptoms: red and white blood cell counts decrease, vomiting, diarrhea, loss of hair, weakened blood vessels, spontaneous internal bleeding

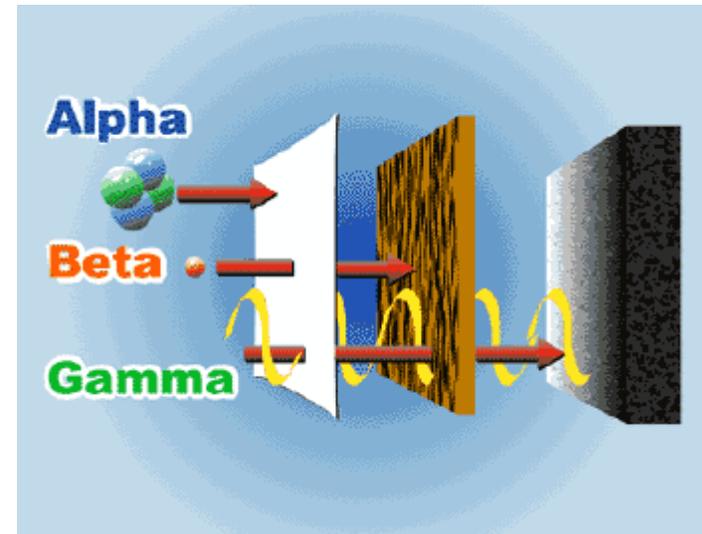


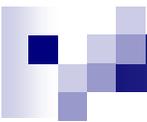
# Measuring Radiation Doses

- Units of deposited energy
  - 1 Gray (Gy) is one Joule energy absorbed in one kg
  - Replaces old unit called the “Rad” (100 Rad = 1 Gy)
- Unit of biological effect
  - Includes a “damage factor”
    - $\gg 1$  for alpha particles and neutrons which can do more damage to atoms
  - 1 Sievert (Sv) is parallel of 1 Gray
  - REM (Roentgen Equivalent to Man) is parallel of Rad. Most doses still given in mrem (milliREM)

# Shielding Ionizing Radiation

- Remember the different properties of particle and EM radiation...
  - Alphas don't go through skin, so greatest danger is ingestion or inhalation of source
    - High risk if resident in body chemistry
    - E.g,  $^{90}\text{Sr}$  will replace calcium in your bones
  - Beta easily shielded from outside (walls)
  - Gammas and X-rays require heavy metals like lead



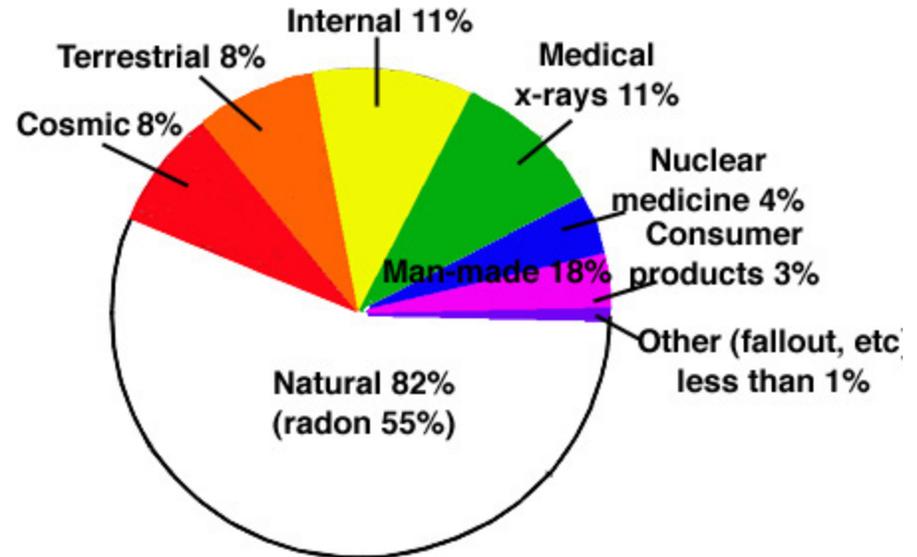


# What are Effects of Different Doses?

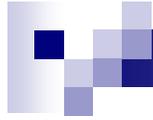
- We understand, unfortunately, the effect of massive doses of radiation from Hiroshima, Nagasaki and Chernobyl victims
  - 10,000,000 mrem causes death within hours
  - 1,000,000 mrem causes near certain death within 30 days
  - 400,000 mrem is “LD50” dose (50% of people exposed die)
  - >100,000 mrem will see acute radiation sickness symptoms
  - 25,000 mrem causes a 1% cancer death rate
    - “natural” cancer death rate in US is ~20%, for reference
  - Your annual dose is probably ~350 mrem
- The “linear hypothesis” is that cancer rates are proportional to dose. It is plausible, but not well studied.

# Your radiation dose...

- Here is a rough breakdown of sources for an average American
- Other doses:
  - Additional dose of person within 10mi of Three Mile Island accident, 8mrem
  - Flying 100K miles, 50mrem
  - Hand-washing a family's worth of original orange Fiestaware, 50mrem
  - Cosmic Rays in Denver, 80mrem

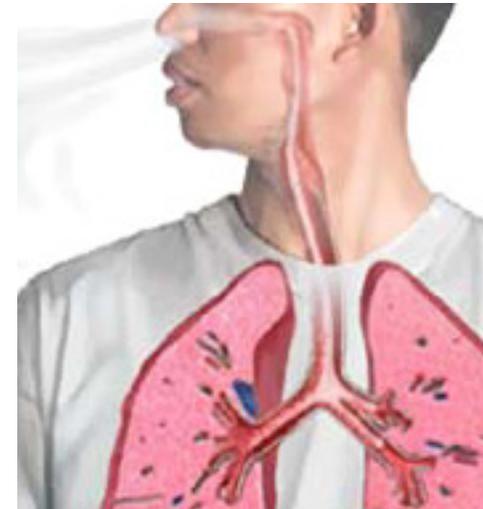
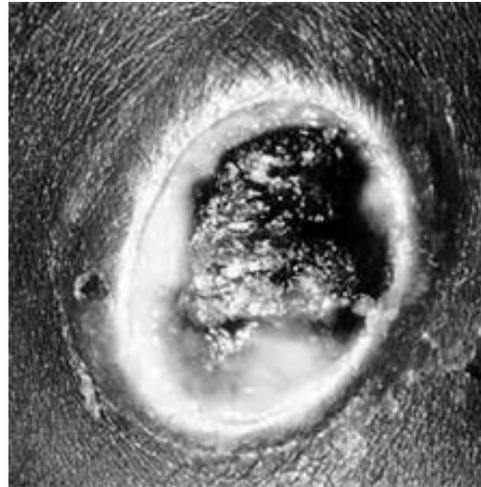
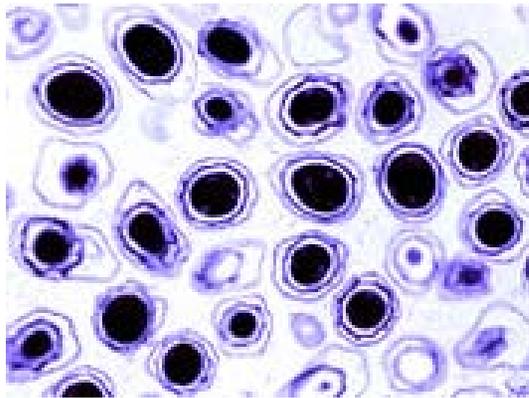


The average dose of radiation an average American receives in one year (360mrem/yr.).  
After Sinclair, 1987.

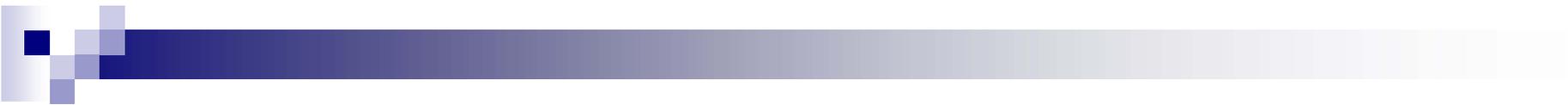


# Anthrax as a Case Study in the Use of Radiation

# Anthrax, a Bacterial Disease

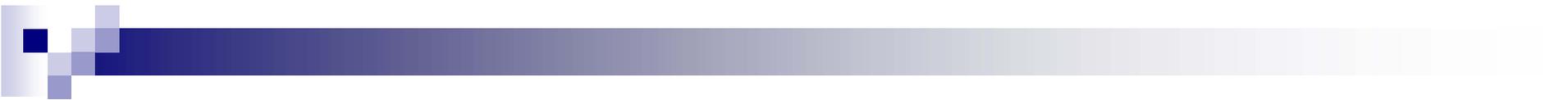


- Contracted mainly by exposure to infected sheep
  - not human to human
- Incubation period 2-6 weeks but spores can lie dormant for decades. Spores are a possible biological weapon
- Cutaneous (most common): usually curable
- Inhaled: usually fatal.



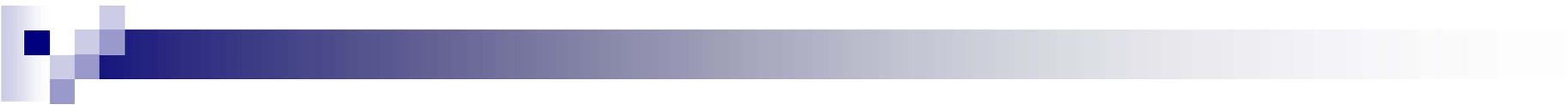
# Irradiation to Kill Anthrax Spores

- If DNA in spores cannot replicate, then Anthrax bacteria cannot infect a victim
  - What dose? Turns out that the only comprehensive study (at least non-classified) from a Bulgarian Veterinary journal suggests about 2 MegaREM
  - Ground beef irradiation, for comparison, is 0.1-1 MegaREM and spices are up to 3 MegaREM
  - Note that this is about 40000 times the LD50 dose
- Concern: don't want to mutate anthrax to create a more infectious agent so “overkill” is necessary



# How to deliver this radiation

- For mass irradiation of materials (food or mail) need it to be fast and focused in a limited area
- Also cannot create secondary radiation (new radioactive isotopes)
  - Radioactive (gamma-ray) source
    - Can deliver large dose deep into material
    - But emits in all directions. Difficult to shield/handle. No “off”
  - Miniature electron beam accelerators
    - Focused beam, but can't penetrate far into material
    - Thought to be best solution for mail
    - But lots of reports of burned, yellowed mail
    - Don't send film or seeds! ☺



# Current policy of USPS

- A lot of paper mail going to Washington DC only is still being irradiated
  - Done at a special facility in New Jersey
- Best to email your congressperson or senator...
- Is this effective?
  - How well is needed dose studied?
  - If I wanted to deliver biological material, why wouldn't I just put wrap it in copper or lead?
    - That would stop the electron beam effectively... although not gamma rays

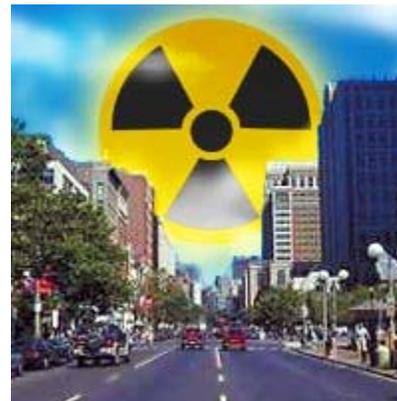


# Dirty Bombs

# What is a “dirty bomb”?

- A dirty bomb uses a low level conventional explosive to distribute radioactive material over an urban area

- Destructive effect is primarily the radiation rather than the blast itself



- Little is required to build one, except a source of radioactive material

# How to obtain massive amounts of radioactive material

**December  
2001**



The Georgia radioactive device and its containment bucket with handles

**Lja, Georgia** -- Three woodcutters discover two heat-emanating containers near their campsite in the remote Abkhazia region of the Caucasus. Hoping to use the containers as a heat source, the men drag them back to their tents. Within hours they become ill with nausea, vomiting, and dizziness, and leave the site to seek treatment at a local hospital. Later, the men develop severe radiation burns on their backs. The International Atomic Energy Agency (IAEA) dispatches a team to recover the containers, but severe weather prevents them for more than a month from reaching the campsite and securing the materials. When the IAEA team finally reaches the containers in February 2002, they discover that each one, previously used in Soviet-era radiothermal generators, contains 40,000 curies of strontium, an amount of radiation equivalent to that released immediately after the accident at Chernobyl.

**September  
1987**



The destruction of a contaminated Goiaina home

**Goiaina, Brazil** -- A scrap-yard worker pries open a lead canister that was scavenged from an abandoned cancer treatment center and dumped at the yard five days earlier. Inside the canister the man is delighted to find a sparkling blue powder; he has no idea the powder is radioactive cesium. Curious residents living near the junkyard pass the canister from home to home for nearly a week. All told more than 200 people are exposed to the cesium. The incident -- a radiation disaster second only to Chernobyl in size and scope -- causes the deaths of four people, including a six-year-old girl who rubbed the powder over her body and hair so that she glowed. The radioactivity contaminates soil, businesses, and homes, 85 of which are leveled during the cleanup process.

Courtesy PBS Nova Web Site

# How to obtain massive amounts of radioactive material

**November  
1995**



The cesium-filled package uncovered in a Moscow park

**Moscow, Russia** -- In the first-ever attempt at radiological terror, a group of Chechen rebels contacts a Russian television station and boasts of its ability to construct a radioactive bomb. The rebels alert the press that they have buried a cache of radiological materials in Moscow's Ismailovsky Park. In the very spot where the rebels indicated it would be, authorities find a partially buried container of cesium. Neither the Chechens who planted it there nor the original source of the cesium are ever identified.

**March  
1998**



Cesium tubes similar to the ones missing from Greensboro

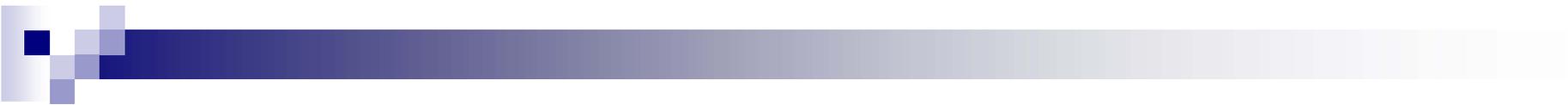
**Greensboro, North Carolina** -- Nineteen small tubes of cesium go missing from a locked safe in Moses Cone Memorial Hospital. Each only three-quarters of an inch long by one-eighth of an inch wide, the tubes were being stored for use in the treatment of cervical cancer. Though local, state, and federal officials scour the city using sophisticated radiation-sensing equipment, the cesium is never recovered. Authorities believe whoever stole the cesium tubes -- for the loss is officially listed as a theft -- may have been trained to handle the material, since unprotected contact with the tubes could have caused serious injury or even death. After the loss, the hospital takes steps to better secure its nuclear assets.

Courtesy PBS Nova Web Site



# The Lesson of Our Boy Scout...

- It's not hard to obtain (or even create your own) radioactive isotopes
  - they have common industrial applications
  - sources can be purchased relatively easily
  - control of radioactive materials is not always stringent
  - neutron sources (alpha emitter plus light element) can create more radioactive (short-lived) materials
- This is a very different statement than saying that it is easy to create fissionable materials



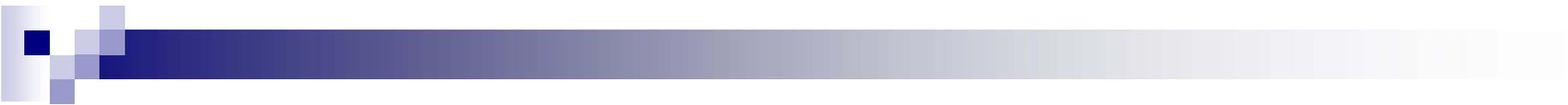
# Why is a dirty bomb difficult?

- Apparently it isn't obtaining the materials...
- I would classify the problems that must be solved to carry out a dirty bomb attack as threefold
  - dispersal of sufficient radioactivity
  - safe handling
  - avoiding detection

# Dispersing Material

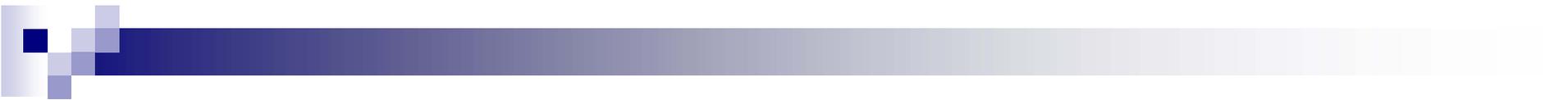
- The basic problem is that to make an impact a terrorist would have to spread material over a wide area
  - that by itself is not hard but not insurmountable
  - drop material by an airplane (flight restrictions?) or send the material up into the wind (unpredictable?)
- Wide area implies a high concentration of the material
  - so to spread material over  $5 \text{ km}^2$  in lower Manhattan, for example
  - need a concentration factor inside the delivery vehicle of  $(5\text{km}/2\text{m})^2 \sim 10^7$
  - ten million!





# Concentrated Dirty Bomb Material

- Now let's remember what we learned about radiation...
  - Near term fatal dose is a few million mrem
  - 1% cancer risk increase over a lifetime increase requires a 25,000 mrem dose
- There is a bad mismatch here
  - Let's say a terrorist takes a few hours to assemble a bomb
  - And that people in the dirty bomb zone would be exposed to the full final concentration for a day, and then to residual radioactivity at 1% of the full concentration for a few years
    - note that the latter is the biggest effect
    - why 1%? most of radioactive material is likely to be removed
      - if you are in a dirty bomb attack, close your windows, throw away your clothes and take a shower as soon as you can!



# Concentrated Dirty Bomb (cont'd)

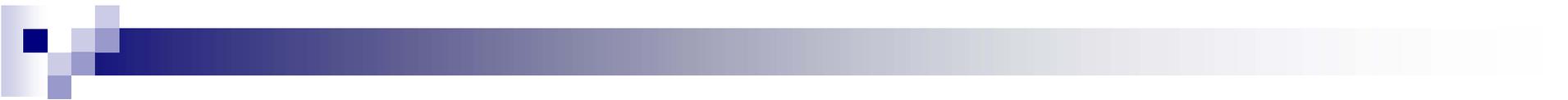
- So for terrorist to deliver a 1mrem dose (your natural dose over a day), she will expose herself to a short-term lethal dose
  - any higher than 1mrem, and she likely can't survive to detonate
- OK, so imagine the terrorist is sophisticated in the handling of the radioactive material
  - you can line the carrier vehicle with 2cm of lead which would cut down the exposure by a factor of 100 (once the material is inside the lead!)
  - 2cm of lead to line a truck or a plane is a few tons. Possible...
  - So now the terrorist can deliver a 100mrem dose and survive long enough to detonate the bomb
- You get the idea... this is not a simple problem.
- This is not to say that a sufficiently sophisticated terrorist could never manage it however.

# Historical Lessons

- Hiroshima and Nagasaki are thriving cities
  - the unspeakable devastation was short-term
- Chernobyl accident as an example
  - the 40000 people closest to the plant received doses, on average, of 45,000 mrem
    - from our numbers, each will have an increased cancer risk of about 1.8%
      - 720 additional cancer deaths
    - worldwide (fallout) about 24000 additional deaths
    - compare the natural cancer rates in those two groups
      - 8000 of the closest people; 1 billion worldwide
  - Chernobyl was a tragedy. But if we understand the harm of radiation correctly, is this the world's biggest health problem?
    - there is a significant “if” in that previous sentence

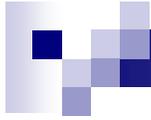


today's view from center of Hiroshima blast



# My conclusion

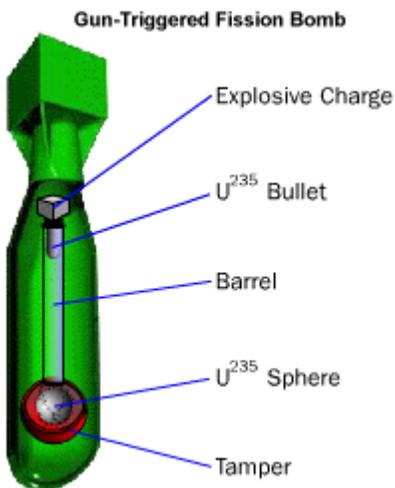
- Threats of a dirty bomb are real, but...
- The primary damage, I believe, would be psychological
  - Low-level radiation is not well understood
    - By public for sure! Scientifically? Probably...
  - Panic leads to overreaction
    - People killed trying to evacuate?
    - Economic devastation of area?
    - Self-imposed cleanup standards that are as devastating as the attack itself?



# Terrorism and Fission Bombs

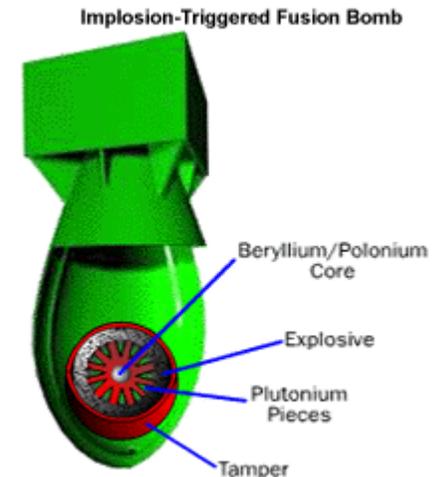
# Building a Bomb from Fissionable Materials is Easy

- As we mentioned in class last week, there are two suitable isotopes
  - $^{235}\text{U}$  and  $^{239}\text{Pu}$
  - Critical mass is 15kg for  $^{235}\text{U}$  and 5kg for  $^{239}\text{Pu}$



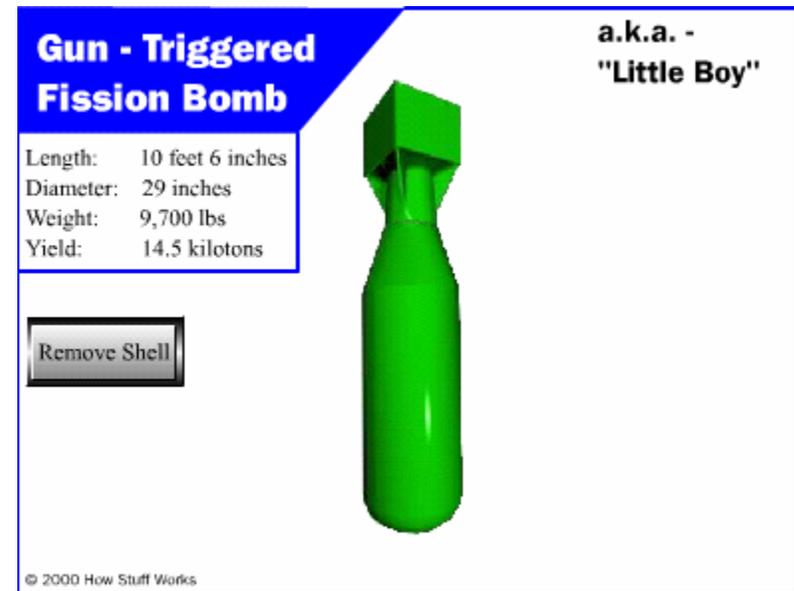
■ Two basic detonation techniques

- “gun” method
- implosion



# Gun Detonation

- This one is so simple, it hurts
- Make critical by adding slug to center
- Need a neutron source released just slug is in sphere to kick-start fissions
- Yield can be increased by adding dense “tamper” to compress shock and reflect neutrinos ( $^{238}\text{U}$  works)
  - ~1-2% efficiency is typical



- Hiroshima bomb was this design
- Cannot work with  $^{239}\text{Pu}$
- Design can't be scaled up to more material

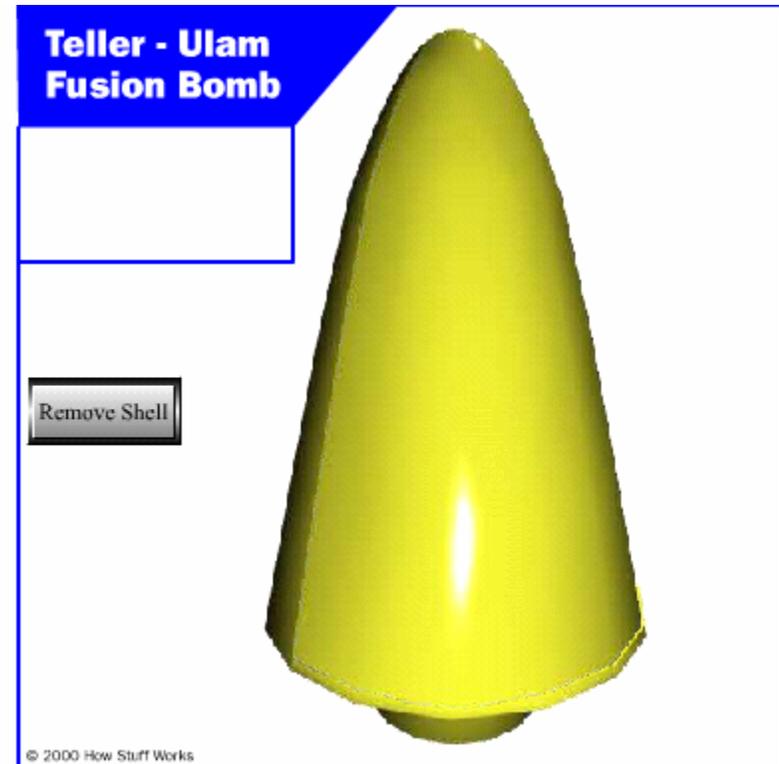
# Implosion Detonation

- Much harder to build
- Critical mass is constructed by imploding a shell of material
- Shielded neutron source in center
- Also benefits from a tamper
- Yield is much higher, ~15%
- This would be a much more difficult device for a terrorist organization to build... higher risk of device failing
- Only design that works for  $^{239}\text{Pu}$
- Can't be "scaled up". (Material in shell goes critical)



# How are bigger bombs built?

- Well, leave it to the military... there are ways
- Using the fission to ignite a fusion source can make much larger explosion.
- Not limited by critical mass
  
- This is almost certainly too sophisticated for most governments, let alone terrorists.



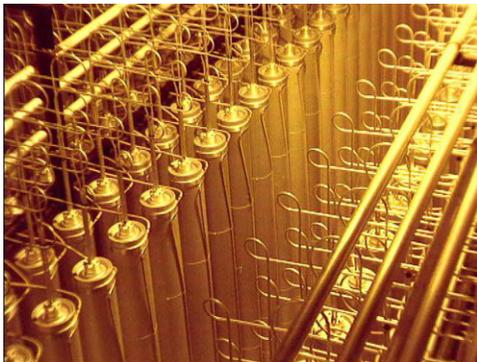


# Summary of Bomb Types

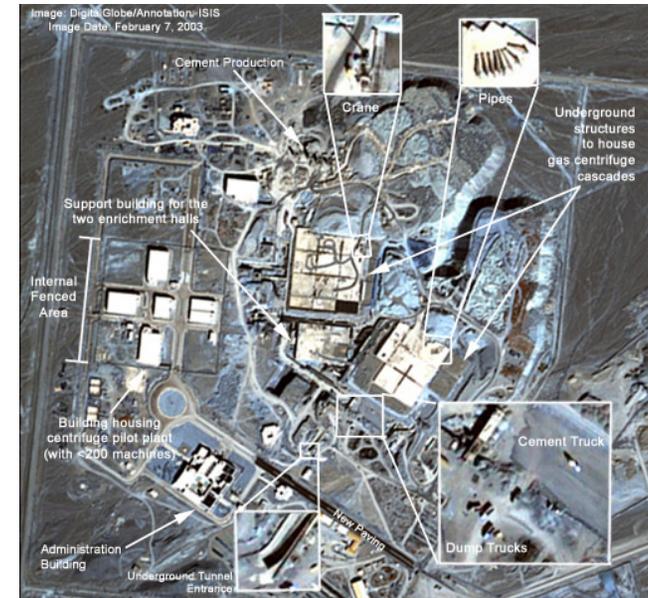
- Terrorist bomb would almost certainly be a fission device
  - based on gun ignition
  - yield would be “low” (Hiroshima)
  - requires large amounts of highly enriched  $^{235}\text{U}$  (HEU)
- Alternatives are possible
  - notably implosion ignition with  $^{239}\text{Pu}$
  - but these are much more difficult

# How Could Terrorists Obtain Fissionable Material?

- Enrich natural Uranium (0.7%  $^{235}\text{U}$ )?
  - remember, this cannot be done chemically. It's a difficult process
  - many governments in the world (US, Russia, China, France, UK, Germany, Netherlands, Japan, Israel?, Pakistan, North Korea?, Iran?) possess this technology



a bank of gas centrifuges at a European facility



**NATANZ, IRAN**  
INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY  
IMAGE CREDIT: DIGITALGLOBE  
DATE OF IMAGE: 7 FEBRUARY 2003  
**THE GAS CENTRIFUGE URANIUM ENRICHMENT PLANT AT NATANZ, IRAN**  
SHOWING DETAILS OF ON-GOING CONSTRUCTION ACTIVITY.

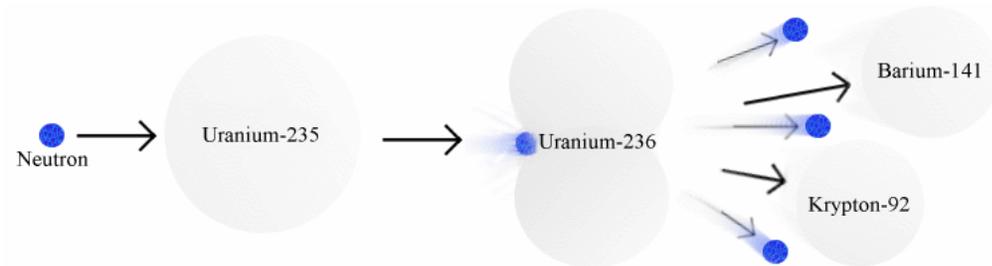


# Obtaining Fissionable Material (cont'd)

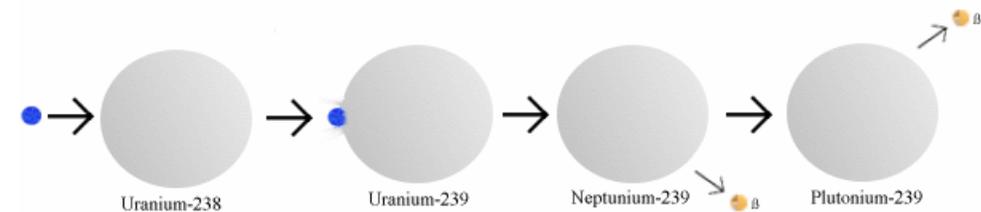
- Could it be stolen?
  - certainly... there is lots of concern over stocks of HEU in the former Soviet Union, particularly outside of Russia
- Could governments sell or give their stock to terrorists?
  - certainly... no public evidence that this has happened
  - we do know that governments have given or sold their technology to allies
    - the US certainly aided Europe in this way
    - strong suspicions that Pakistan has aided North Korea's nuclear program in recent years

# “Breeder Reactors”

- $^{235}\text{U}$  Fission



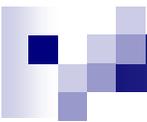
- $^{238}\text{U}$  in a reactor



- All power reactors produce  $^{239}\text{Pu}$ . Reactors can be optimized to produce more of it.

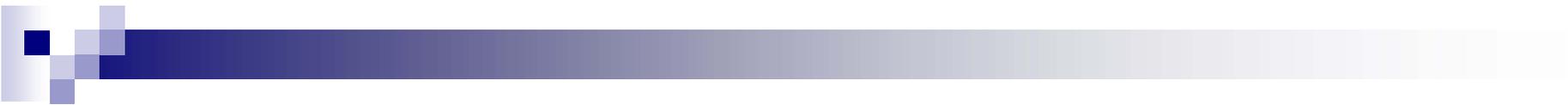
- some of this technology was developed to ensure that we don't run out of nuclear fission reactor fuel...

- There is only so much  $^{235}\text{U}$  on the planet.



# Could Terrorists obtain $^{239}\text{Pu}$ from Reactors?

- This is also a real concern
- Probably terrorists would not be able to build their own breeder reactors
  - reprocessing stolen nuclear reactor waste (chemical separation) is a more likely scenario
- Remember also that a  $^{239}\text{Pu}$  bomb must use implosion technology, so it is more difficult to build
  - $^{239}\text{Pu}$  from reactors also tends to be contaminated with  $^{240}\text{Pu}$
  - $^{240}\text{Pu}$  undergoes some spontaneous fission which emits neutrons. Radiation detectors have a good ability to find neutron emission, so it would be harder to smuggle than  $^{235}\text{U}$ .



# Conclusions

- There are some scary scenarios in the world
  - there are multiple serious threats and clearly people in the world prepared to devote their lives to carrying out atrocious attacks
- My opinion: some of these threats are more serious than others
  - focusing on the wrong threats means we may ignore much more significant threats
  - public education on the outcome of possible scenarios is critical. We should fear “fear itself”.
- US activities on the world stage will have a big impact on our future