From Quarks to the Bomb

Basic Science → Science Policy

Jerry Gilfoyle, University of Richmond

"The Periodic Table"

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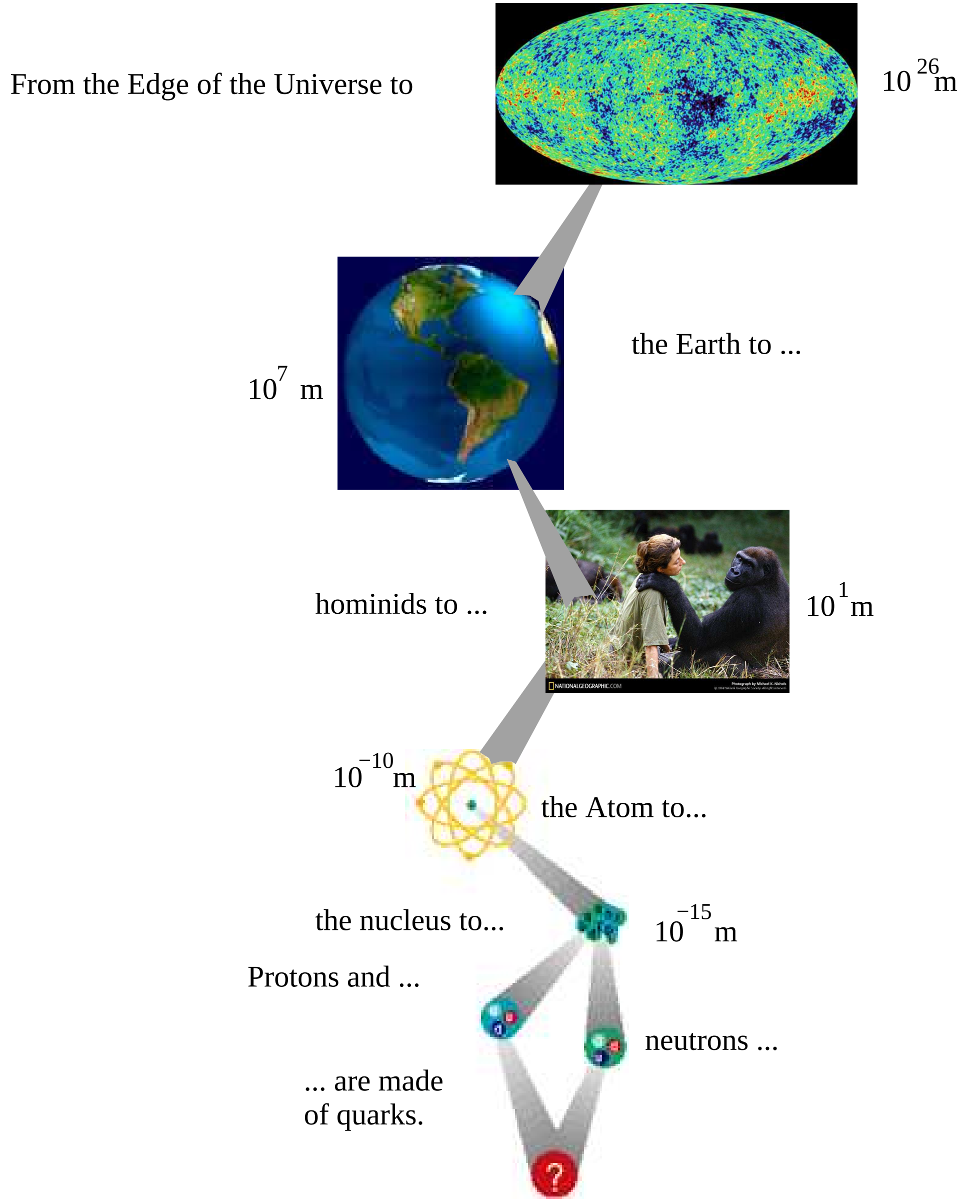
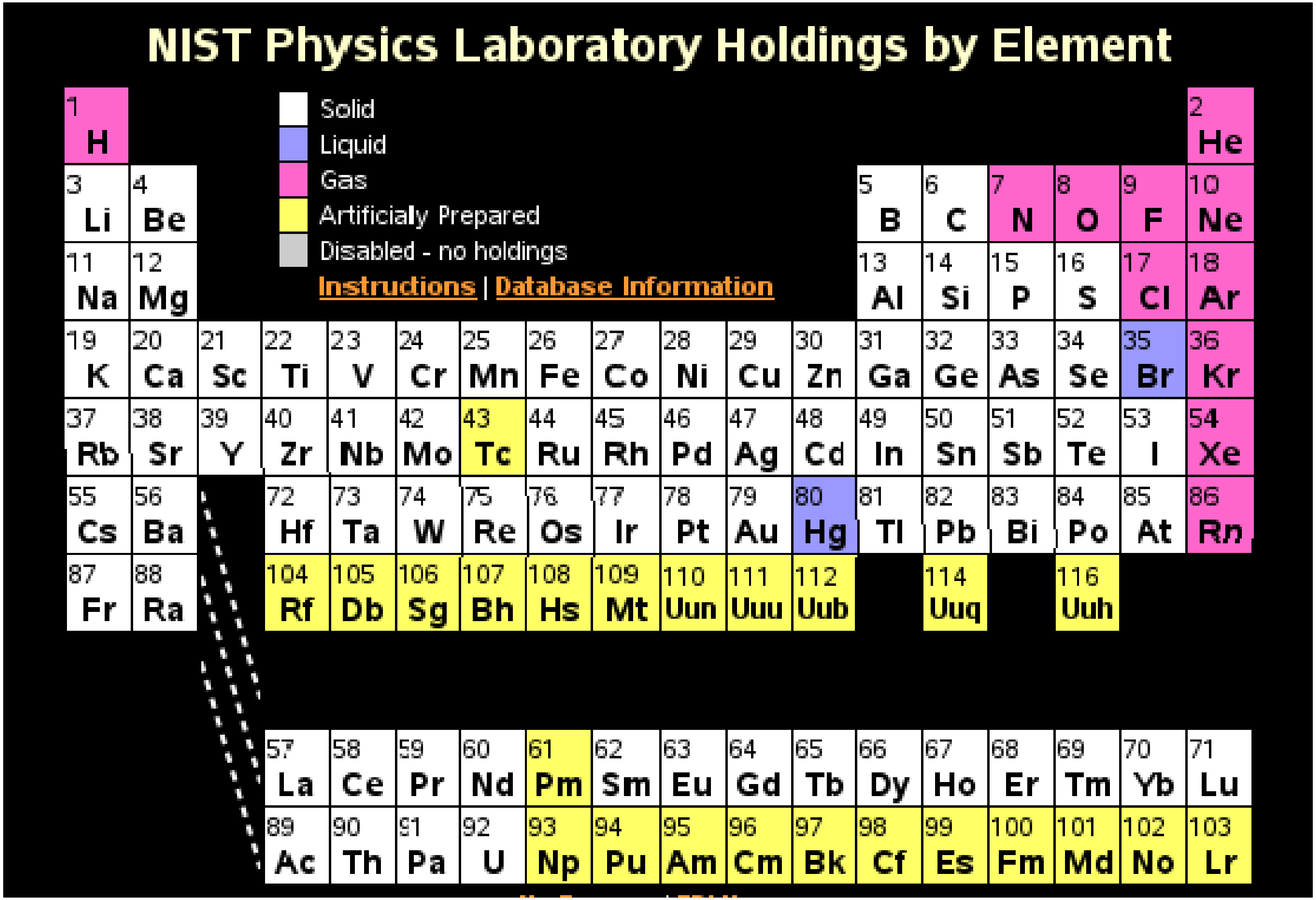
Outline:

1. Hunting for Quarks:
   Motivation and Method
2. Nuclear Non-proliferation:
   Science Meets Politics
3. Science and Policy Careers

Hunting for Quarks - What Do We Know?



The Periodic Chart



What Do We Know?

- The Universe is made of quarks and leptons and the force carriers.

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+	80.39	+1
W bosons		
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

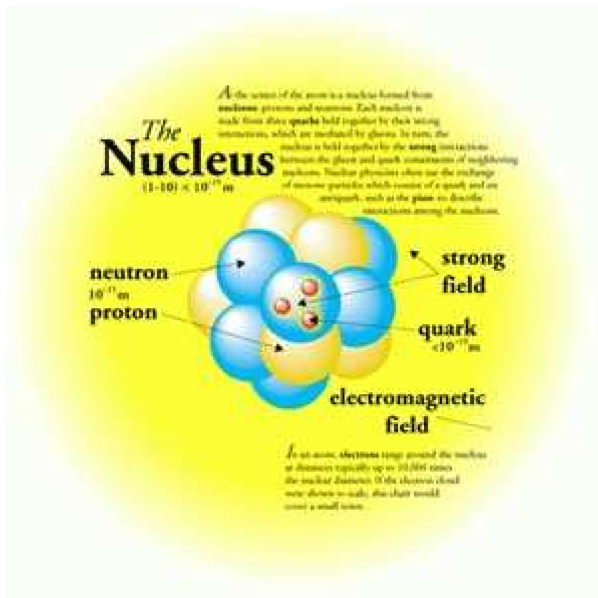
Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

- The atomic nucleus is made of protons (*uud*) and neutrons (*udd*) bound by the strong force.
- The quarks are confined inside the protons and neutrons.
- Protons and neutrons are NOT confined.



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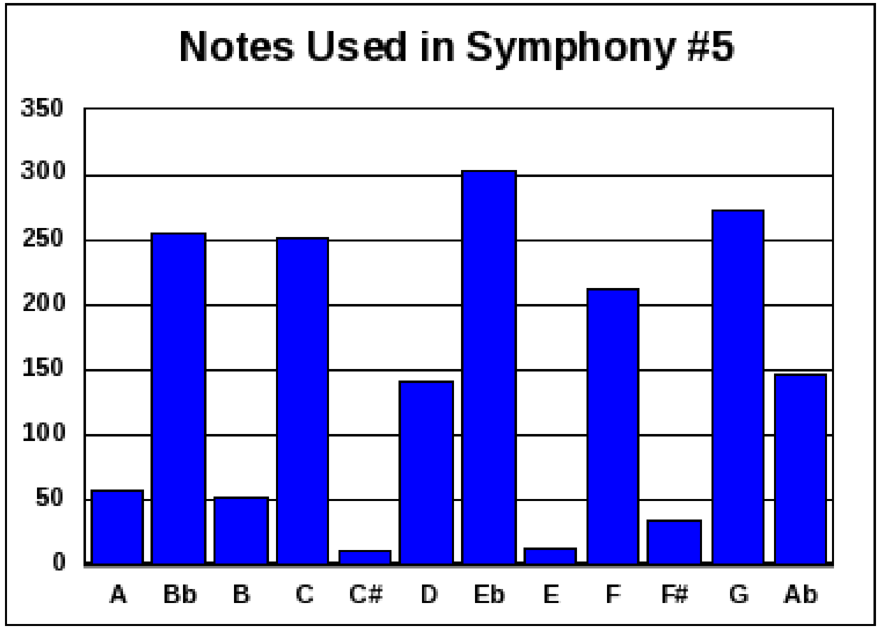
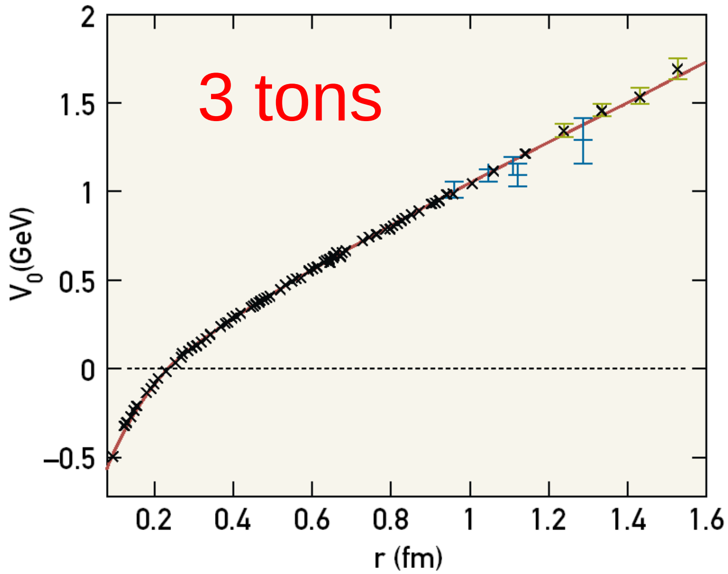
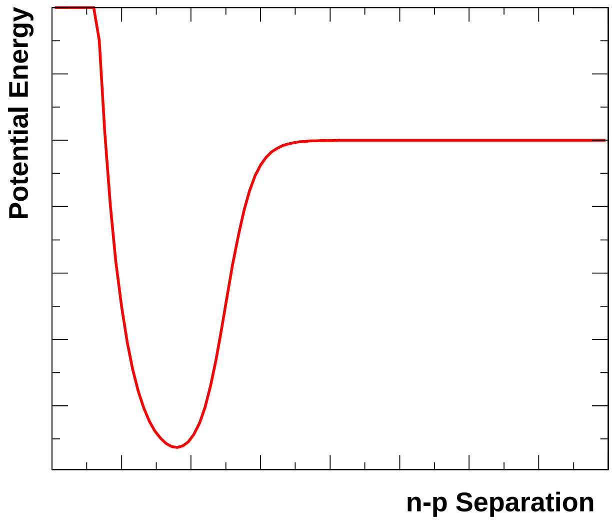


What is the Force?

- Quantum chromodynamics (QCD) gets the force among quarks and gluons right at high energy (Nobel Prize in 2004).

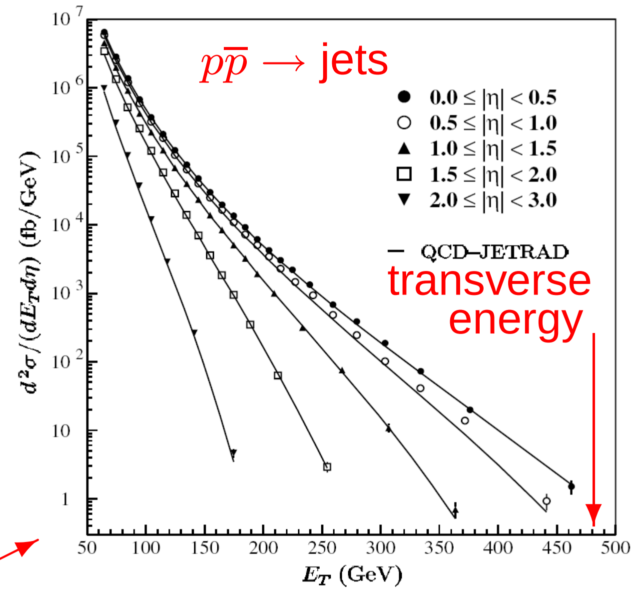
- The hadronic model uses protons and neutrons (nucleons) to describe data at low energy. This ‘strong’ force is the residual force between quarks.





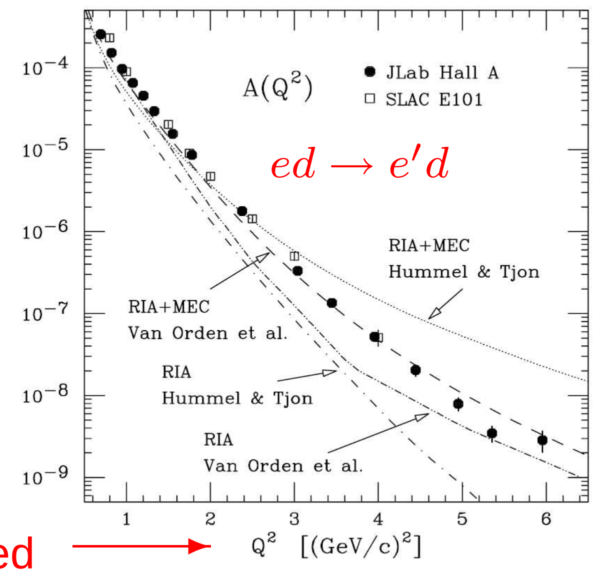
How Well Do We Know It?

- QCD works real goood! (B.Abbott, *et al.*, Phys. Rev. Lett., **86**, 1707 (2001)).



effective target area

- So does the hadronic model (L.C.Alexa, *et al.*, Phys. Rev. Lett., **82**, 1374 (1999)).



4-momentum transfer squared

What Don’t We Know?

- Matter comes in pairs of quarks or triplets.
- We are made mostly of the triplets (protons and neutrons).
- More than 99% of our mass is in nucleons.

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- How much does the proton weigh?

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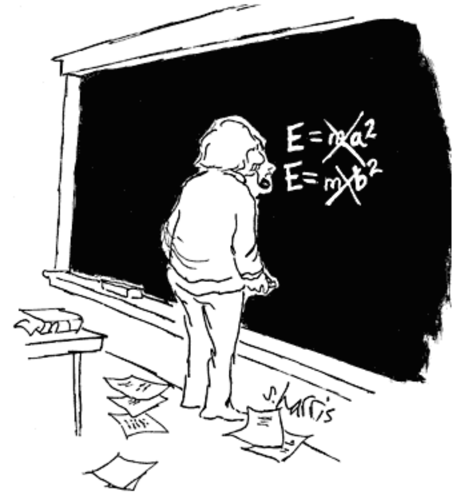
$$= 0.939\ GeV/c^2$$ OOOPS!!!????

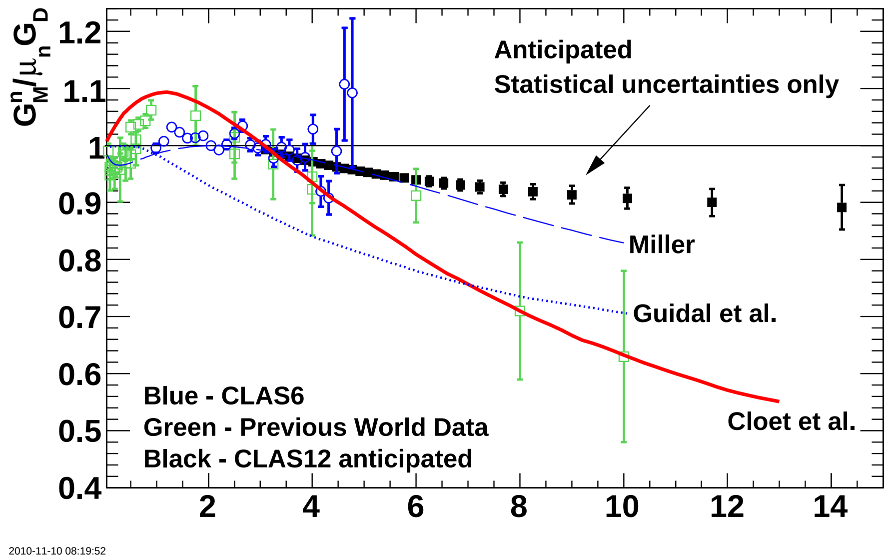
What's Up? Or Down?

- The strong force produces an intense field that stores a huge amount of energy. Remember the 3 tons.
- That intense, high-energy field has mass!



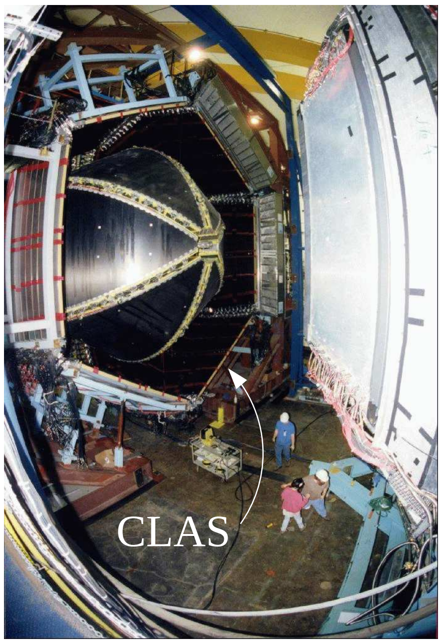
$$\longrightarrow \quad E = mc^2$$

- We know the missing mass is in there, but don't yet have a working theory.
- Maybe soon (after the 12 GeV Upgrade at Jefferson Lab)!



How Do We See Inside a Nucleus?

- High-energy electrons can throw a diffraction pattern when they shine on atomic nuclei.
- Need a big accelerator!
- And a big detector!
- And lots of help.



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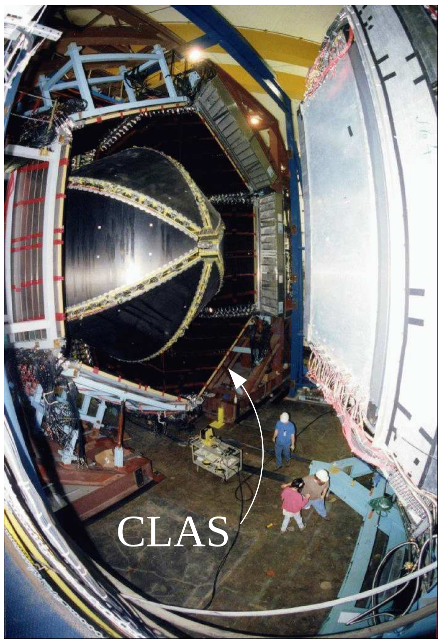

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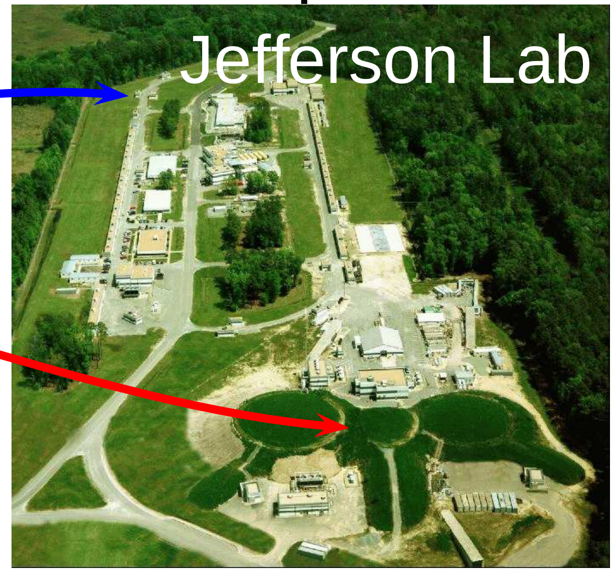

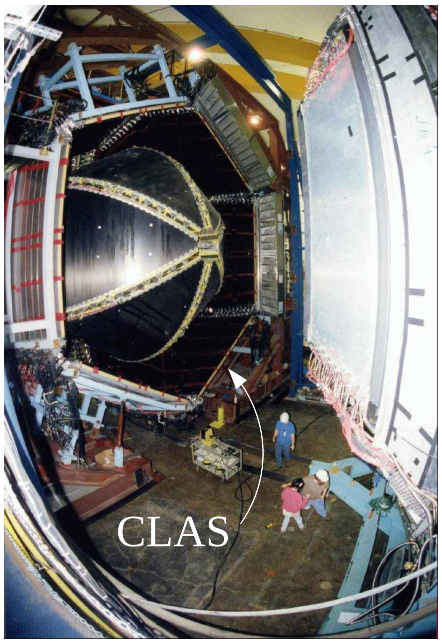

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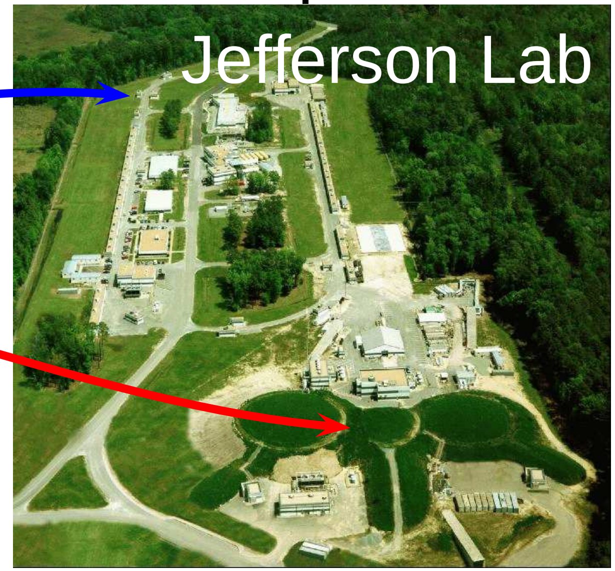

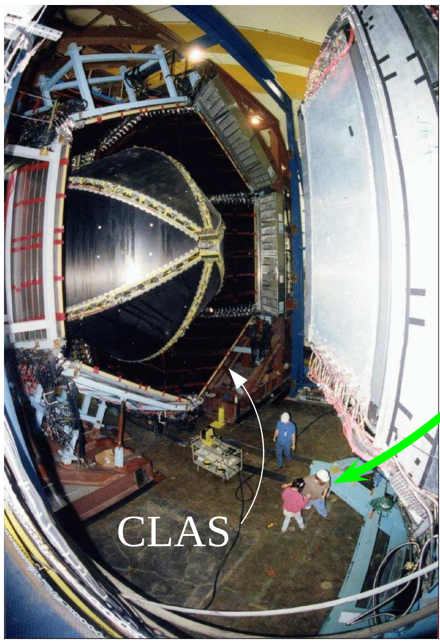

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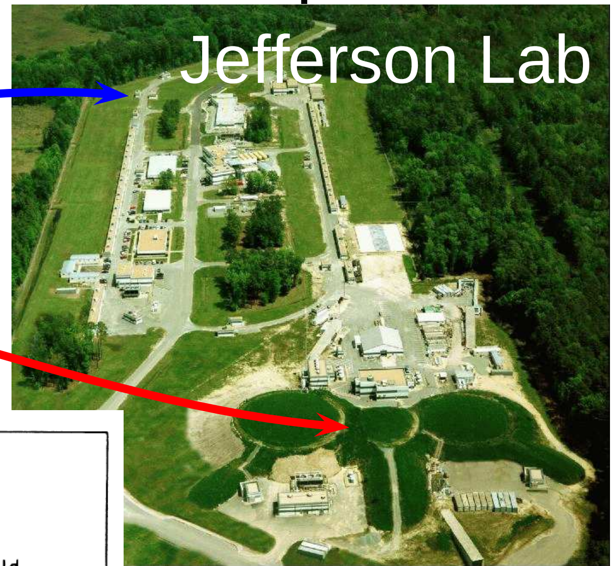
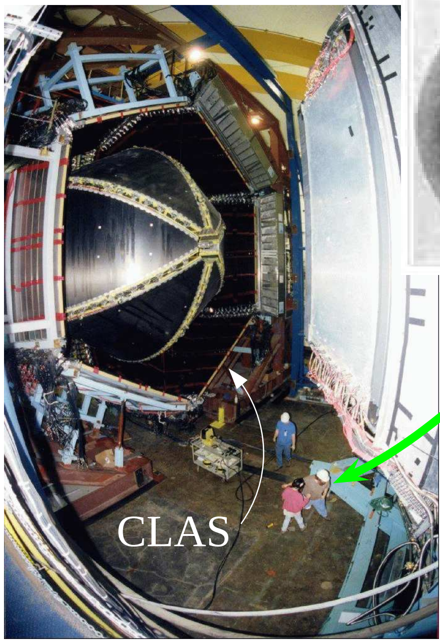
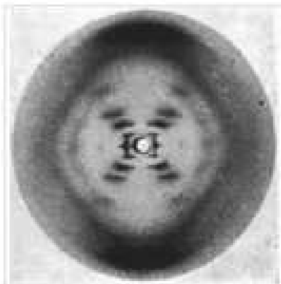
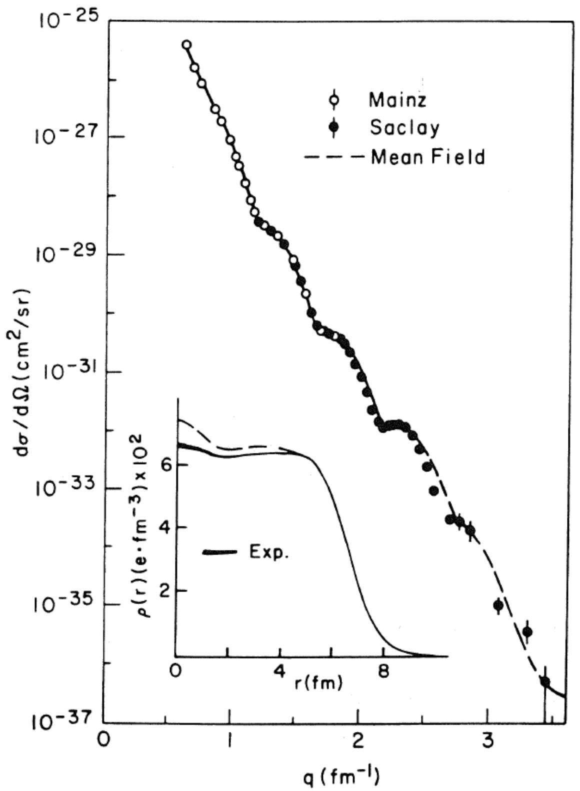
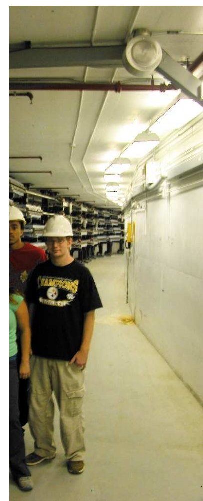


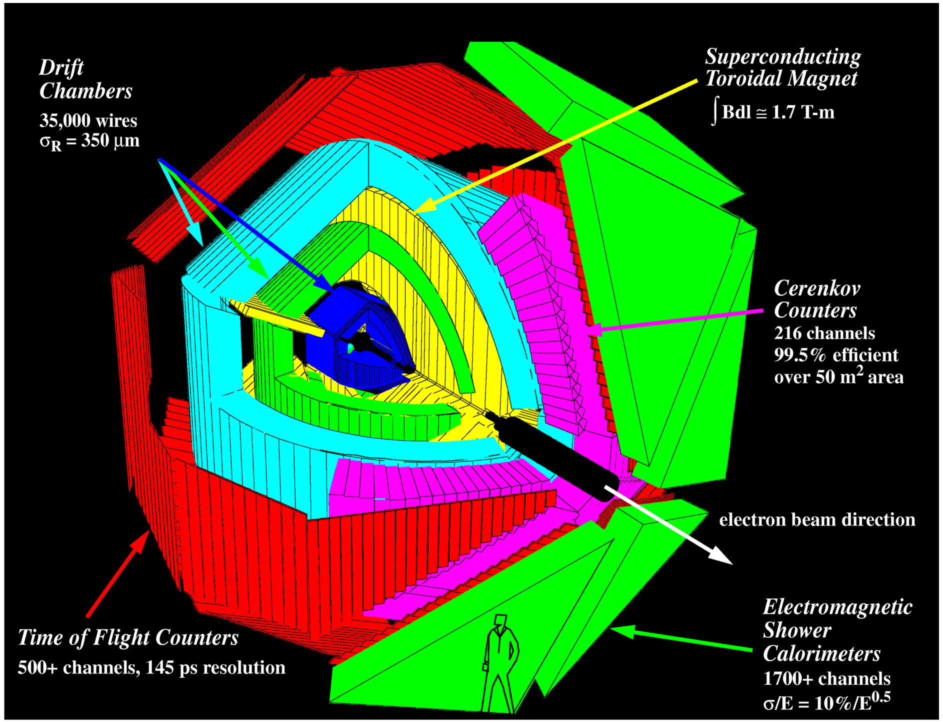


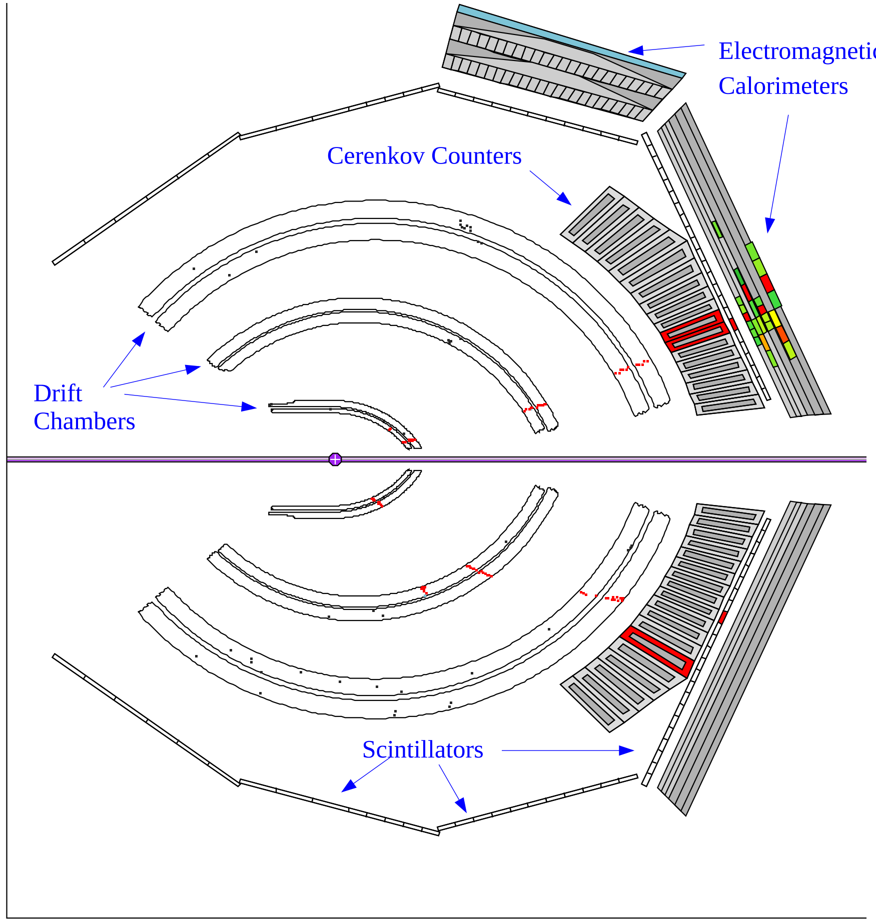






A CLAS Event





Drift chambers - Charged particle trajectories.

Scintillators - Light produced by particles.

Cerenkovs - Separate electrons from pions.

Calorimeters - Energy.

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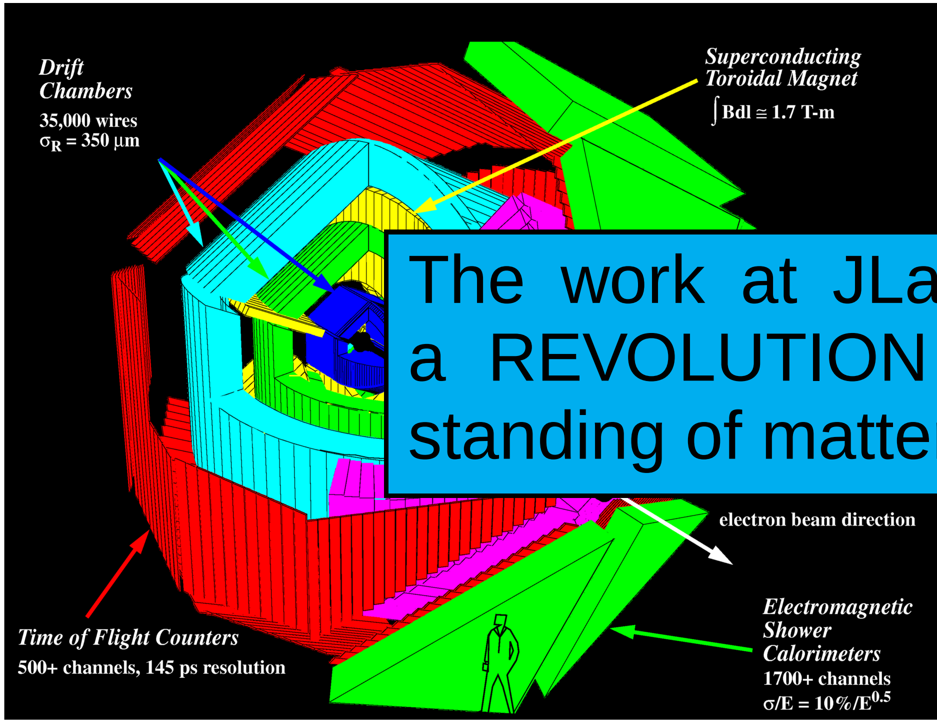

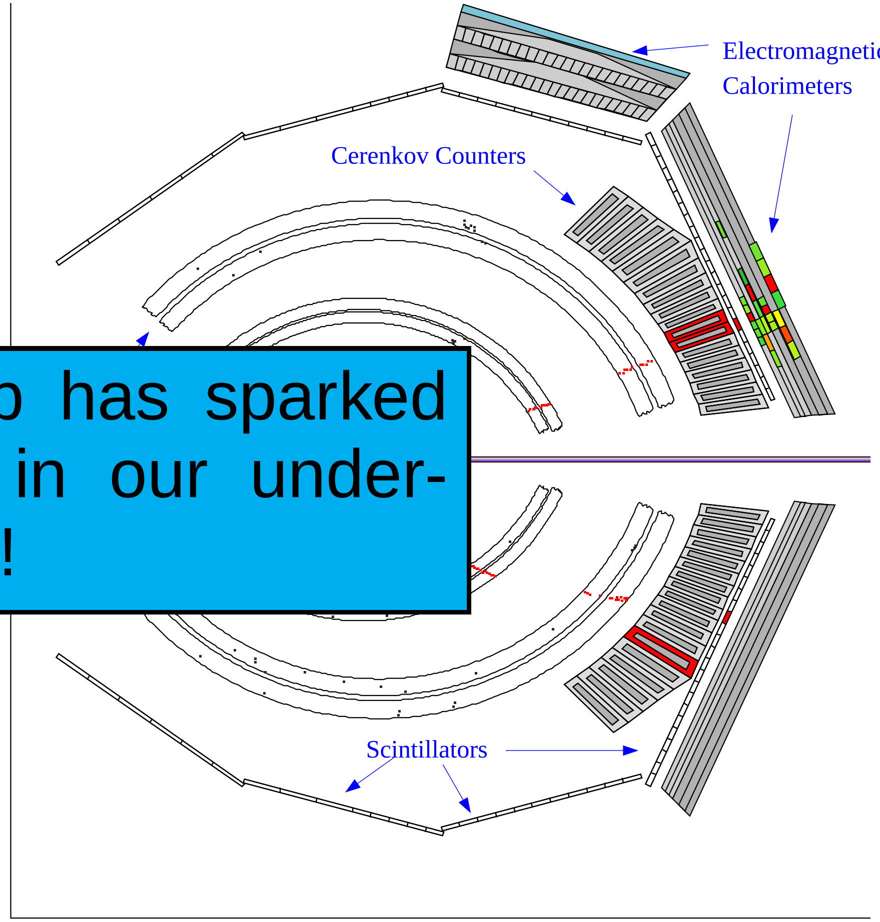

The work at JLab has sparked a REVOLUTION in our understanding of matter!

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Basic Science - Why should YOU pay for it?

1. Over the last 100 years, at least 50% of the growth in our standard of living is due to technological change.
2. Technological spinoffs: NMR$\rightarrow$MRI, WWW, transistors, computers, ...
3. Production of trained scientists, engineers, technicians. .... all from basic physics research.

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In Paris in 1783 Benjamin Franklin watched with amazement one of the first hot-air balloon flights. The following exchange was said to occur.

Questioner to Franklin: Sir, what's the use of flying in the air?

Ben Franklin's answer: Sir, what's the use of a newborn baby ?

Putting the Genie Back in the Bottle: The Science of Nuclear Non-Proliferation

Jerry Gilfoyle

Physics Department, University of Richmond, Virginia

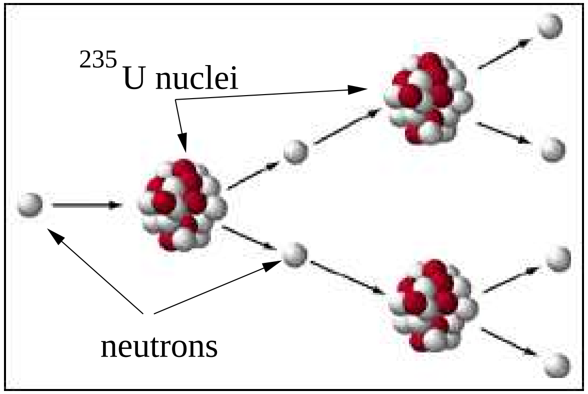
Outline:

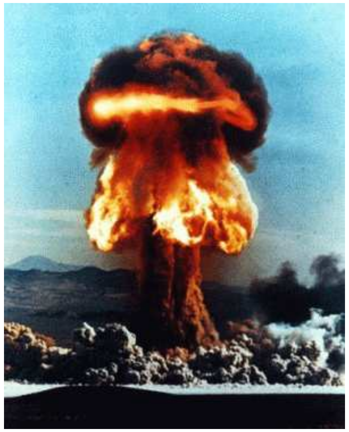
1. Nuclear Weapons 101.
2. The Comprehensive Test Ban Treaty.
3. Testing The Test Ban Treaty.
4. Why should you care? and Conclusions.

Nuclear Weapons 101 - Fission and Fusion

- Fissile materials ($^{235}\mathrm{U}$, $^{239}\mathrm{Pu}$) release enormous energies.
- As each nucleus splits, it emits 2 or so neutrons plus lots of energy $\approx 180\ \mathrm{MeV}$).
- If density is high, a ‘chain reaction’ will cause other fissions in a self-propagating process.

A Chain Reaction

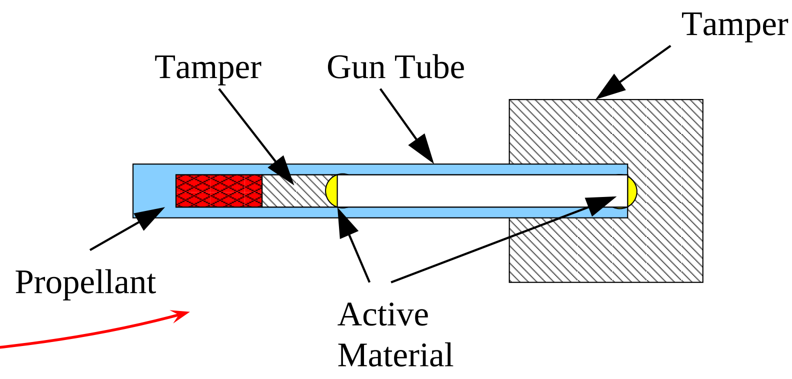


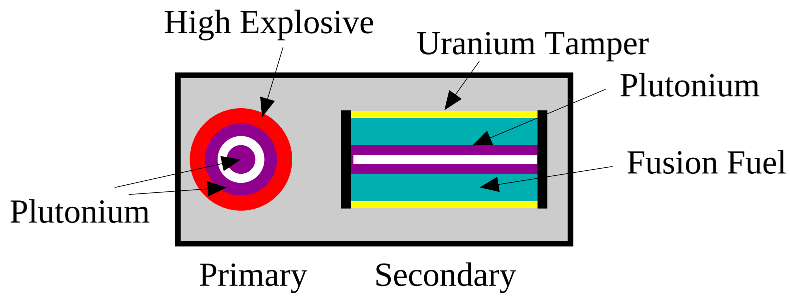


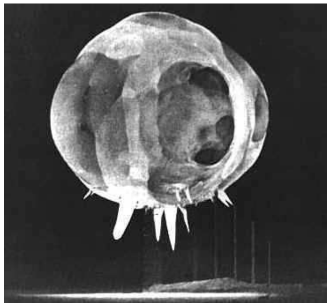
- As a fission bomb explodes deuterium and tritium can fuse releasing neutrons and even more energy; $^{2}\mathrm{H} + {}^{3}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \mathrm{n} + 17.6\ \mathrm{MeV}$.
- Only about 8 kg of plutonium or 25 kg of highly-enriched uranium (HEU) is needed is needed to produce a weapon.

Nuclear Weapons 101 - Basic Weapons Designs

- A uranium, gun-type nuclear weapon - High explosive pushes highly-enriched uranium at high speed down the gun tube and into the other piece of active material. The density increases enough to sustain the chain reaction.
- A two-stage, thermonuclear weapon. - High explosive crushes the plutonium primary to a density where fission can occur.
- The uranium and plutonium in the secondary burn and increase the temperature until fusion starts. The energy released by the fusion reaction raises the temperature even higher and burns more of the fission fuel.



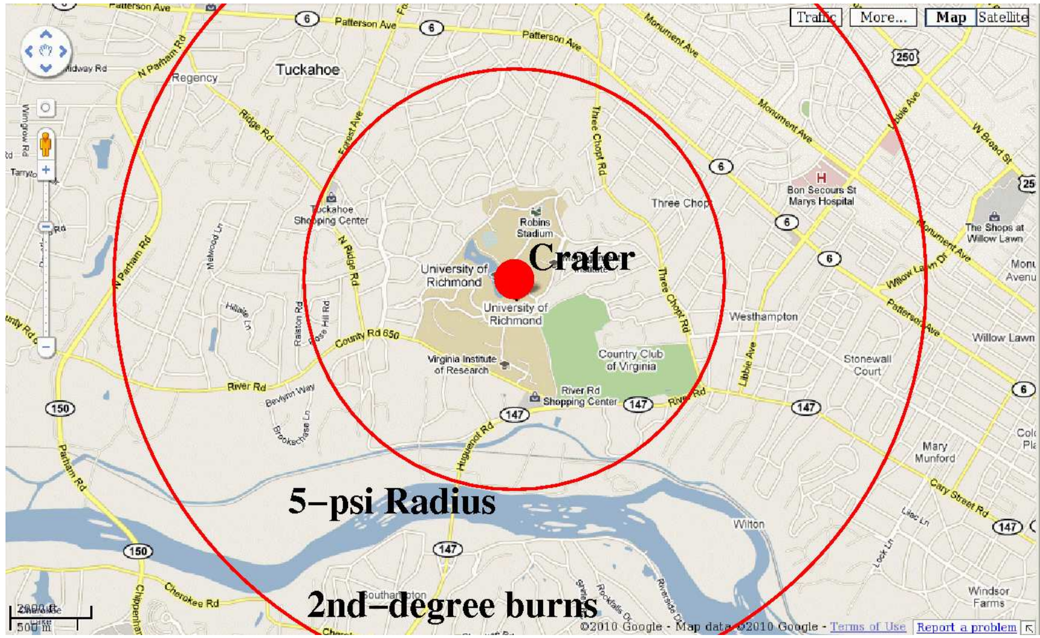




Nuclear fireball $1 \ ms$ after detonation (Tumbler Snapper). The fireball is about 20 m across.

Nuclear Weapons 101 - Effects

- Energy released in the form of light, heat and blast.
- Blast ≈40-50% of total energy.
- Thermal radiation ≈30-50% of total energy.
- Ionizing radiation ≈5% of total energy.
- Residual radiation ≈5-10% of total energy.
- Figure shows effect of 15 kiloton bomb (about the size of the Hiroshima bomb) exploded over the Gottwald Science Center.



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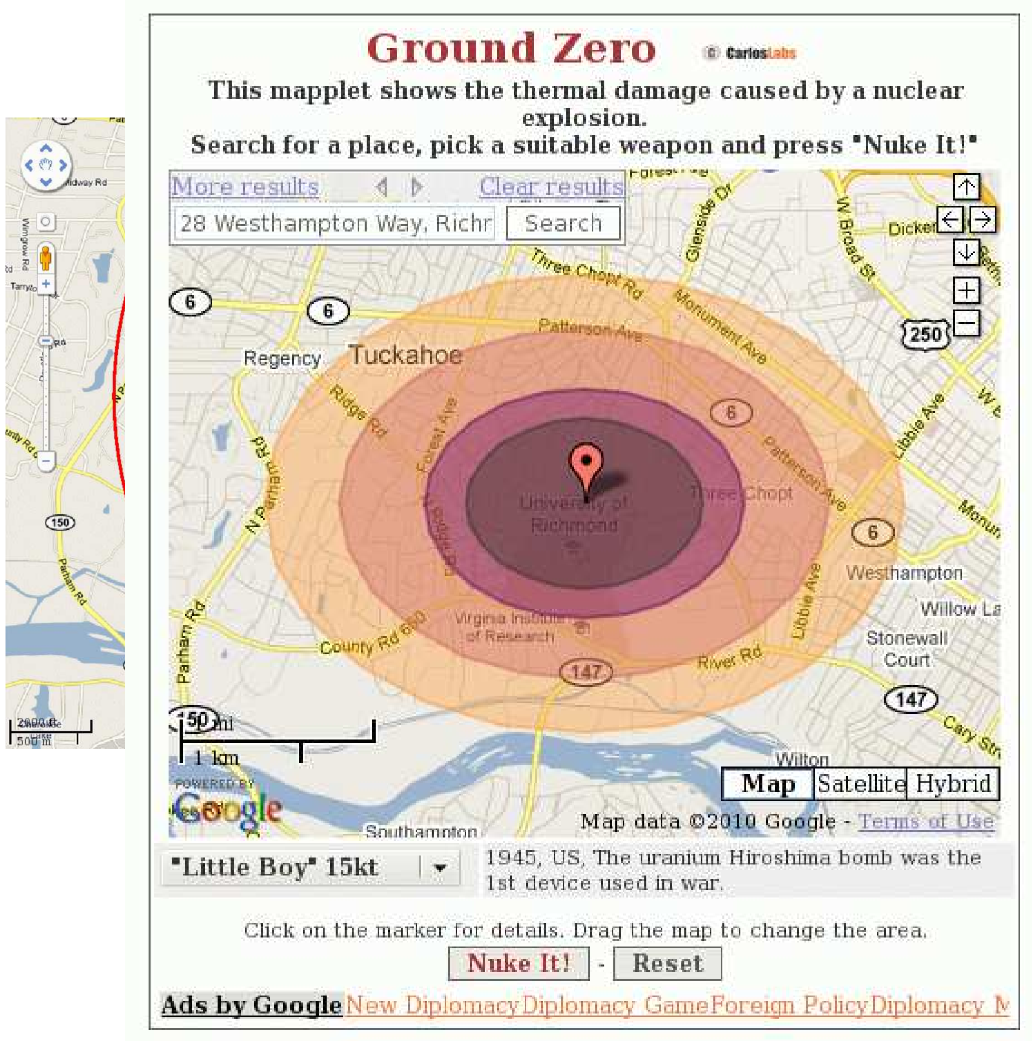
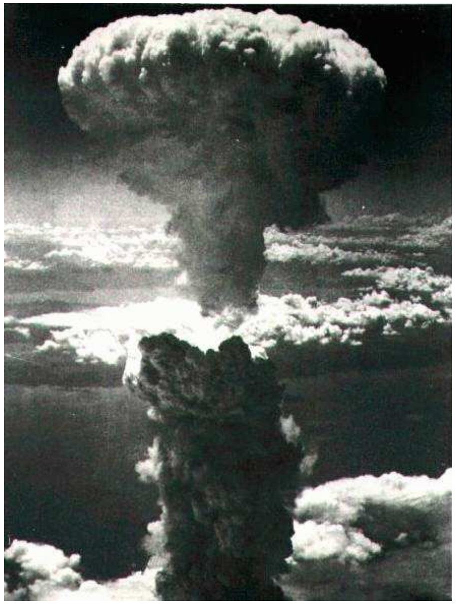
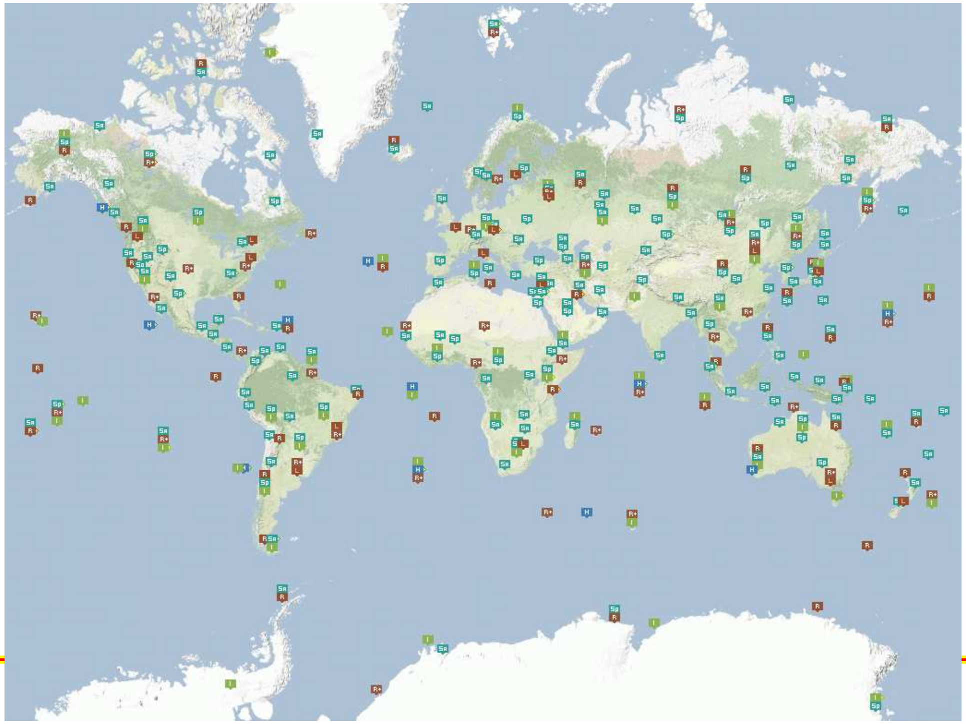


http://www.carloslabs.com/projects/200712B/GroundZero.html

The Comprehensive Test Ban Treaty (CTBT)



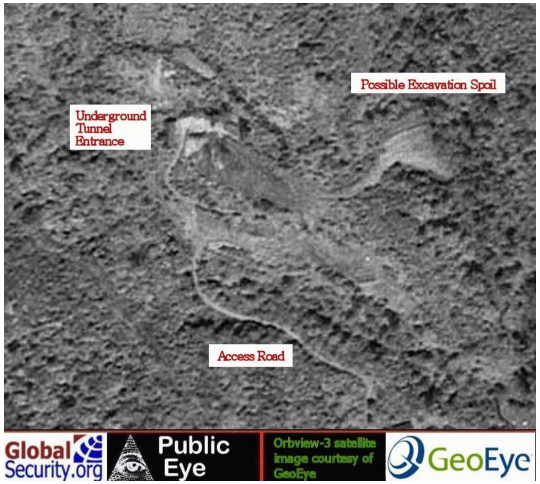
- The CTBT bans all nuclear explosions to limit the proliferation of nuclear weapons.
- A network of seismological, hydroacoustic, infrasound, and radionuclide sensors will monitor compliance (International Monitoring System or IMS).
- On-site inspection will be provided to check compliance.
- The US has signed the CTBT, but not ratified it.



337 monitoring stations planned, 70% in place now.

Testing the Test Ban Treaty

- On October 9, 2006 the Democratic People's Republic of Korea detonated a nuclear bomb underground in the vicinity of P'unggye in the northeast part of North Korea.



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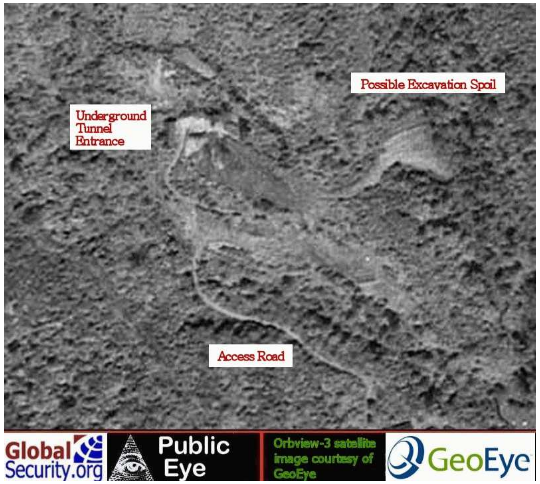

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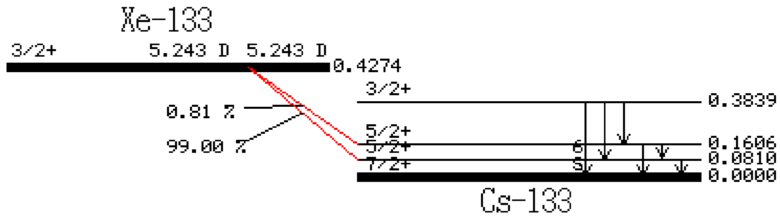
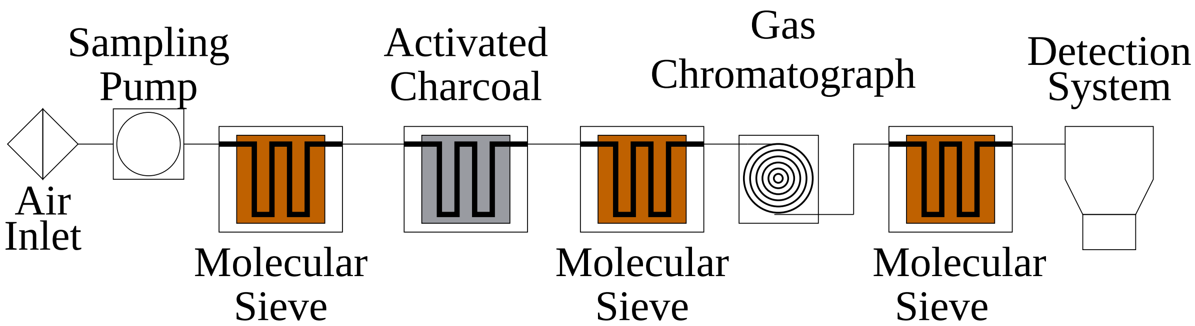
Detecting Radioxenons from Nuclear Tests

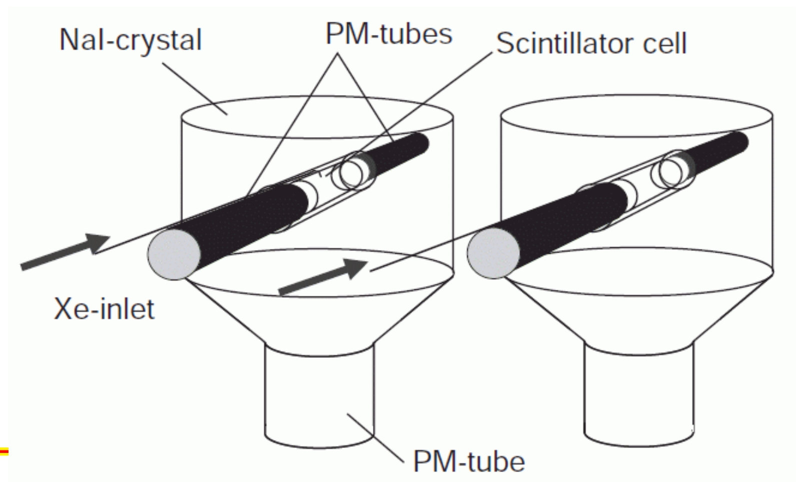
- Radioactive isotopes of xenon are produced in the explosion and none exist in nature.
- One form $^{133}\mathrm{Xe}$ decays in about 5 days emitting a β (an electron) and a γ (a quantum of light).



- Atmospheric gas is collected for many (6) hours and xenon extracted through a series of filters, absorbers, gas chromatograph, *etc* - 1-2 events every 15 minutes per m^3 of air!

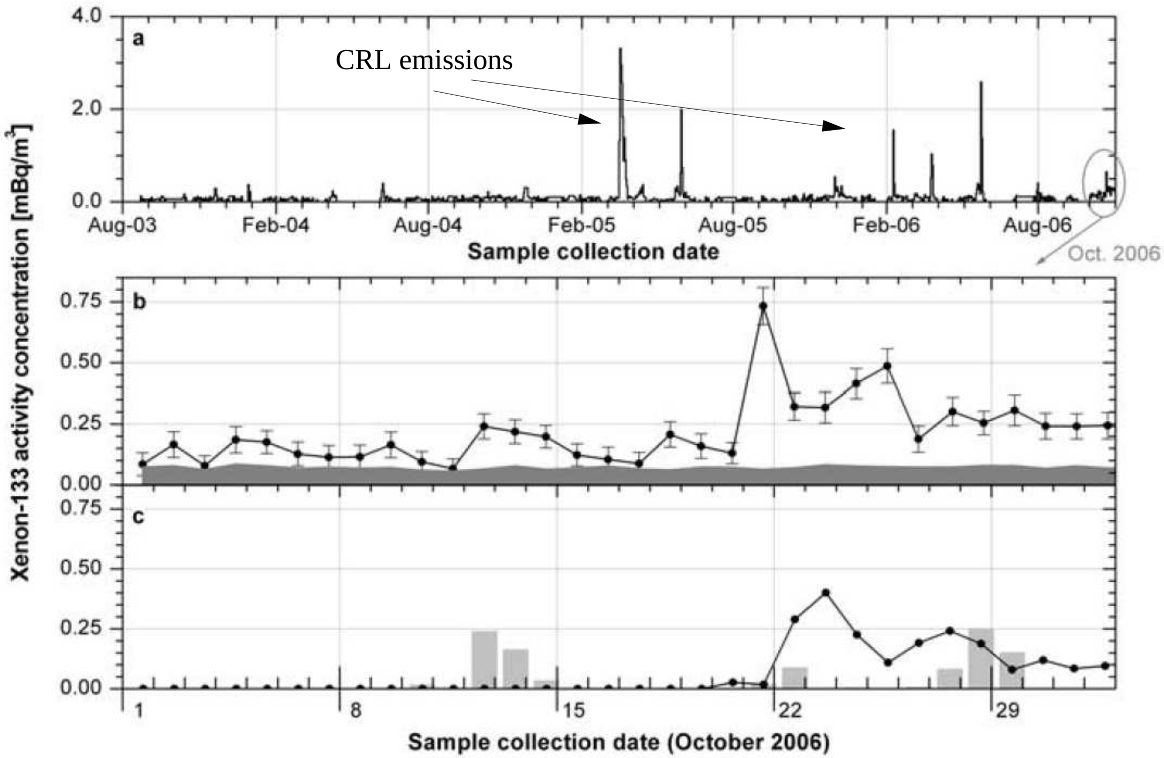


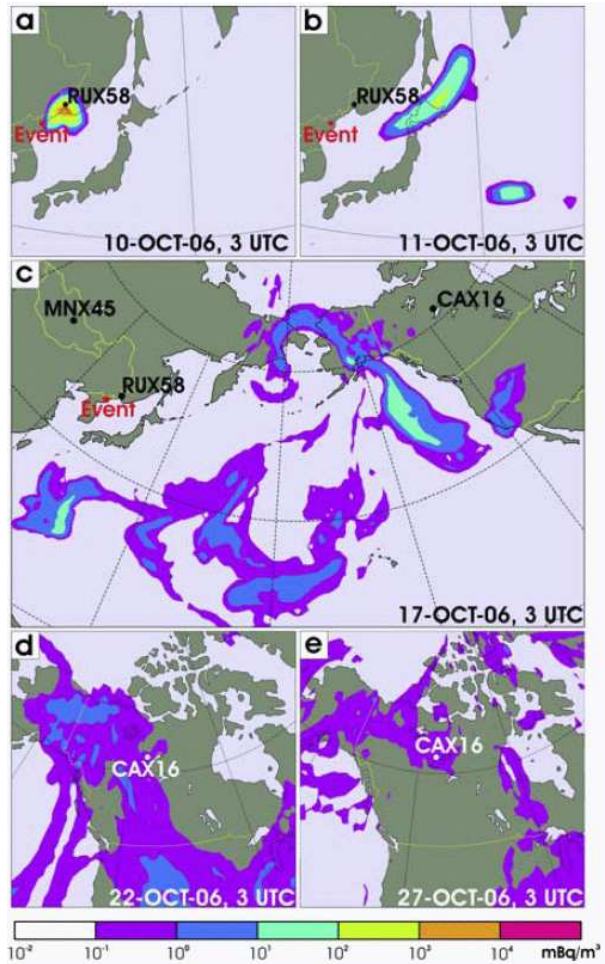
- Xenon is passed into the chamber of a hollow cylinder made of plastic scintillator inserted in a cylindrical hole inside a NaI crystal. Light produced by β and γ particles is detected with photomultiplier tubes and counted.



Getting the Right Gun

- Background studies of known sources are required to eliminate false positives.
- Atmospheric transport modeling (ATM) is done to determine the effect of known backgrounds and hypothesized nuclear explosions.
- Comparison of ATM with background and signal.





- Consistent with venting about 10% of the $^{133}\mathrm{Xe}$.

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The American Geophysical Union and the Seismological Society of America have stated the IMS will detect all explosions down to 1 kiloton (and much less in some areas) and within a radius of 35 km (October, 2009).

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- The worst-case scenario under a no-CTBT regime poses far bigger threats to U.S. security - sophisticated nuclear weapons in the hands of many more adversaries - than the worst-case scenario of clandestine testing in a CTBT regime, within the constraints posed by the monitoring system.

  National Academy of Sciences (NAS), *Technical Issues Related to the Comprehensive Nuclear-Test-Ban Treaty*, Washington, D.C., National Academy Press, 2002, pp. 10.

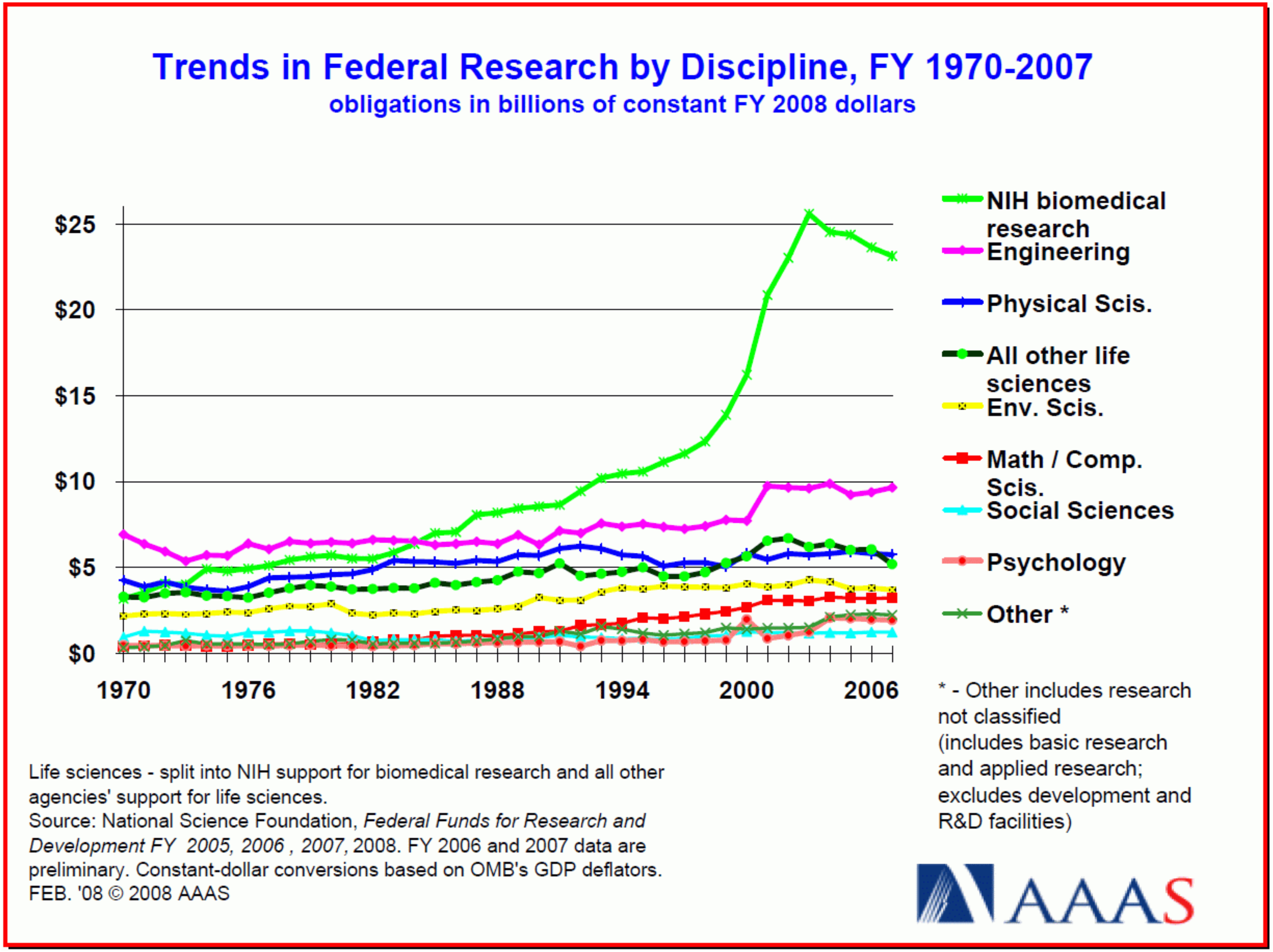
Research Opportunities in Nuclear Non-proliferation

- Congress recently passed the Nuclear Forensics and Attribution Act (Feb, 2010).
  - Creates the National Technical Nuclear Forensics Center within the Domestic Nuclear Detection Office (DNDO) of the Department of Homeland Security (DHS).
  - Establishes fellowships for undergraduates (summer research) and graduate students and awards for their advisors.
- Examples of DNDO research.
  - Hope College - Cathodoluminescent Signatures of Neutron Irradiation.
  - CUNY - Infrared Studies of CdMgTe as the Material of Choice for Room Temperature Gamma-Ray Detectors
  - Stanford - Improved Transparent Ceramic Fabrication Techniques for Radiological and Nuclear Detectors
- US National Labs
  - PNNL - Triple Coincidence Radioxenon Detector
  - Office of Defense Nuclear Nonproliferation (part of NNSA).

So You Want To Do Science?

- Read! You are likely not trained enough yet to read the scientific literature, but there are abundant sources of books, stories, movies, *etc* that describe science.
  - *A Short History of Nearly Everything* by Bill Bryson.
  - Anything by Richard Preston - *Hot Zone*, *First Light*, *Demon in the Freezer*, *The Wild Trees*
  - *Scientific American*
- Do research - here or elsewhere.
  - Summer research fellowships.
  - Summer research/technical jobs in industry, hospitals,...
- Volunteer in government (state of federal) for specific committees/elected officials that have a scientific component.
- Non-governmental organizations (NGOs) like Union of Concerned Scientists, Federation of American Scientists, ...
- Read some more.
- Go to talks at museums, universities, high schools, wherever.
- Ask questions!!! And then ask some more!!

So You Want To Do Science?



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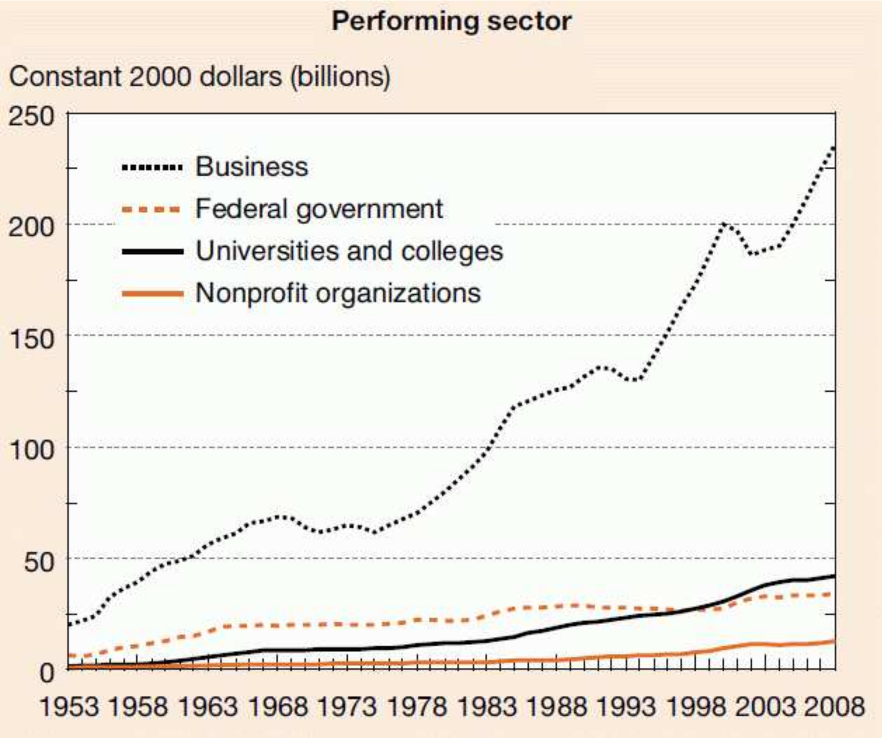

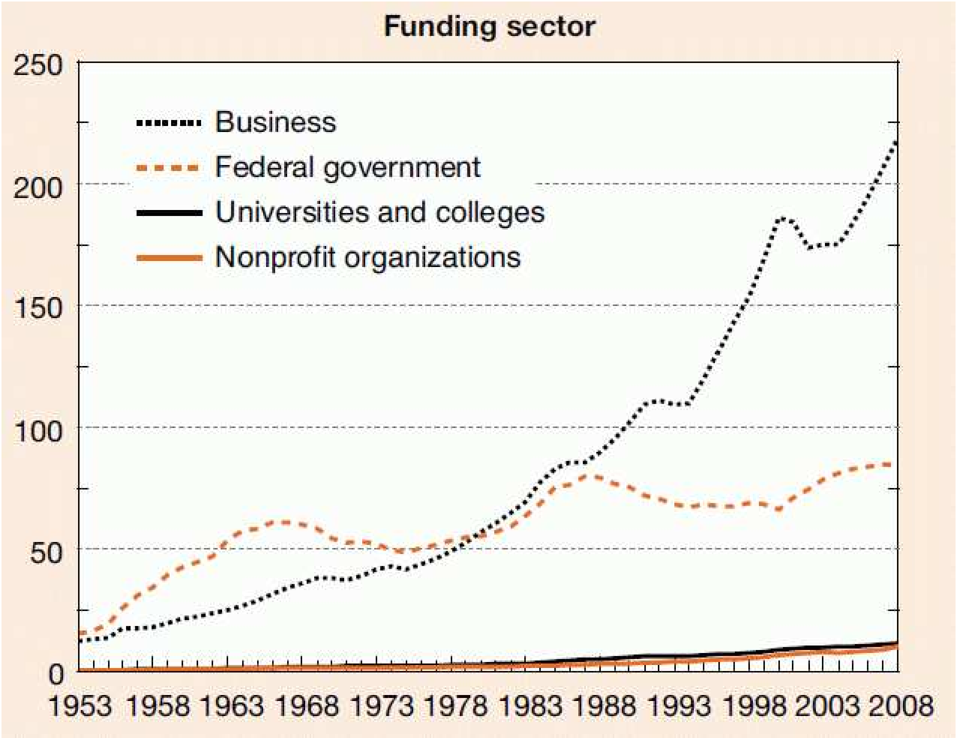

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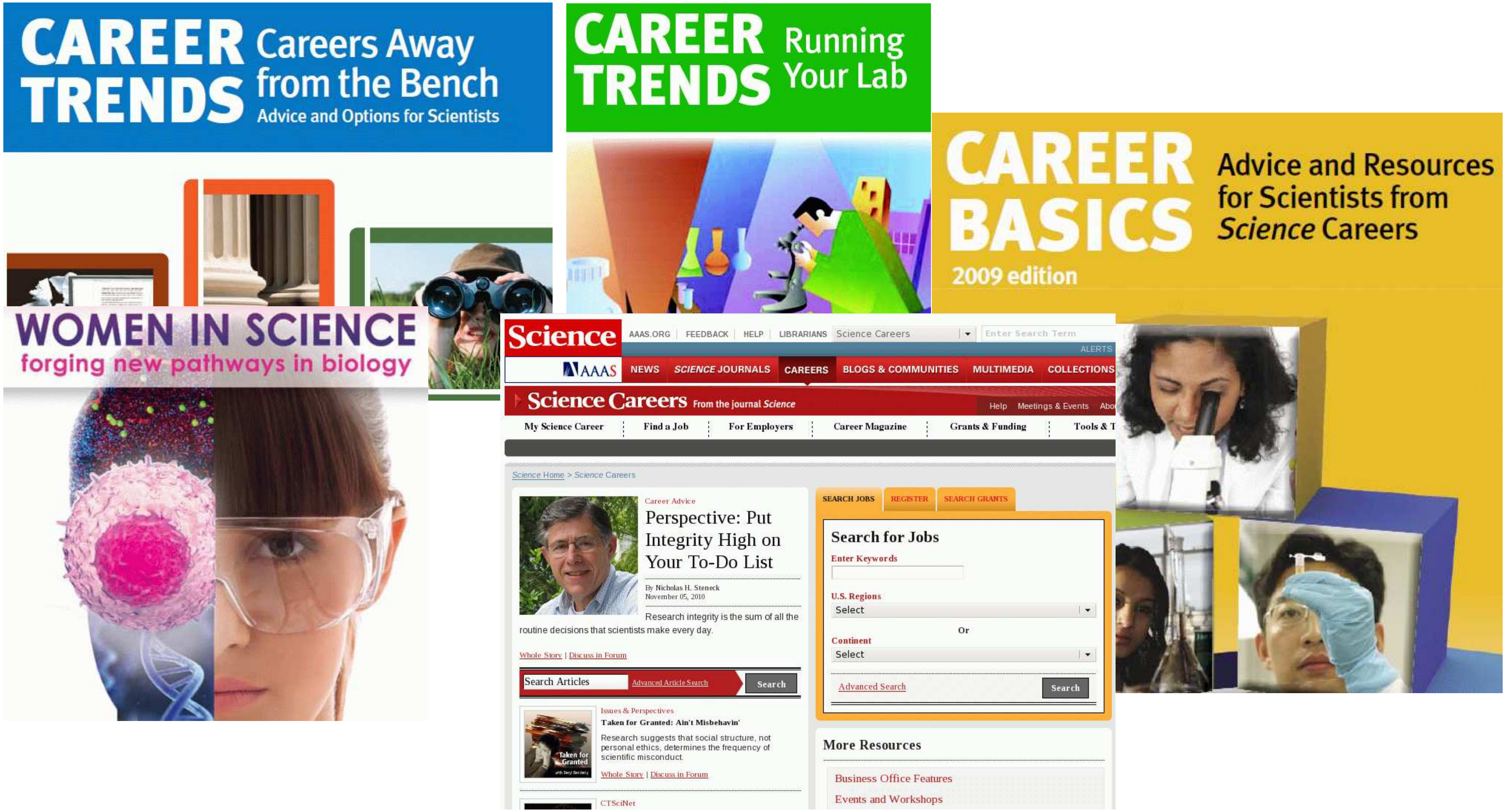

Some great places to start looking:

`http://sciencecareers.sciencemag.org/`

`http://sciencecareers.sciencemag.org/tools_tips/outreach/booklets_signup`