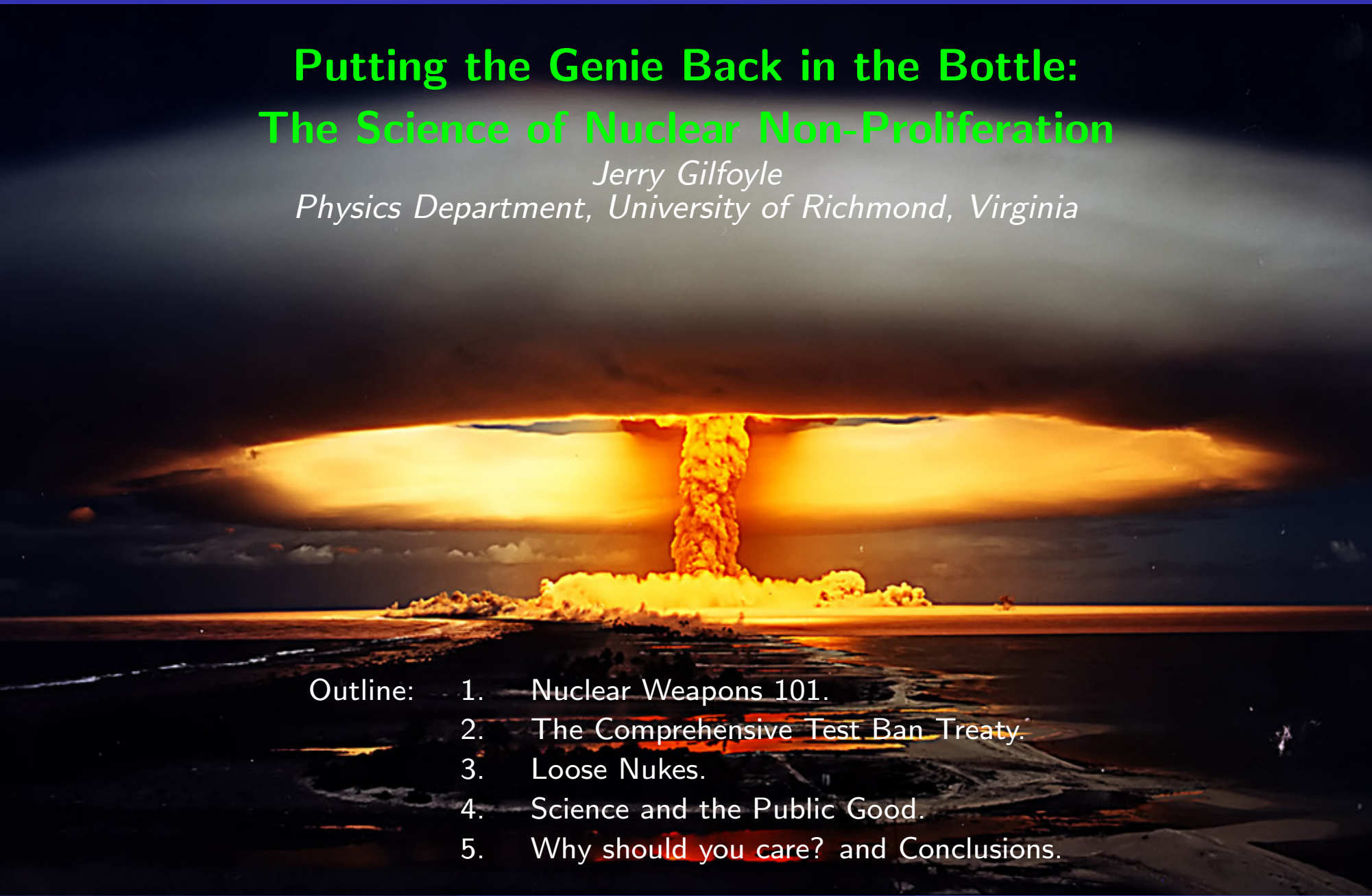
Putting the Genie Back in the Bottle: The Science of Nuclear Non-Proliferation

Jerry Gilfoyle
Physics Department, University of Richmond, Virginia



Outline:

1. Nuclear Weapons 101.
2. The Comprehensive Test Ban Treaty.
3. Loose Nukes.
4. Science and the Public Good.
5. Why should you care? and Conclusions.

Some Bits of History

- US develops and uses nuclear weapons on Japan at the end of World War II (1945). Other countries follow; current count is nine.

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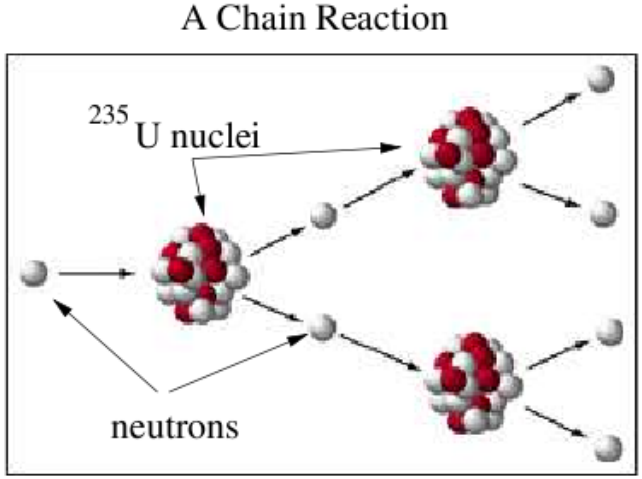
- Collapse of the Soviet Union
  - Many components of the Soviet nuclear arsenal left behind in the former Soviet Union (FSU).
  - Collapse of Russian ruble in 1998 leaves even Russian arsenal with limited funds for maintenance and security of nuclear materials.

Nuclear Weapons 101

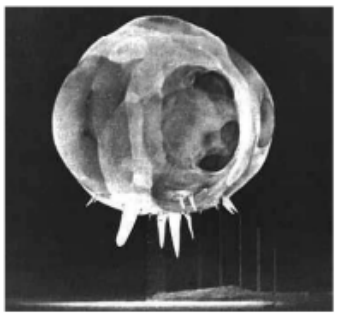
- Fissile materials ($^{235}\mathrm{U}$, $^{239}\mathrm{Pu}$) release enormous energies.
- As each nucleus splits, it emits 2 or so neutrons plus lots of energy ($\approx 180\ \mathrm{MeV}$).
- If density is high, a 'chain reaction' will cause other fissions in a self-propagating process.



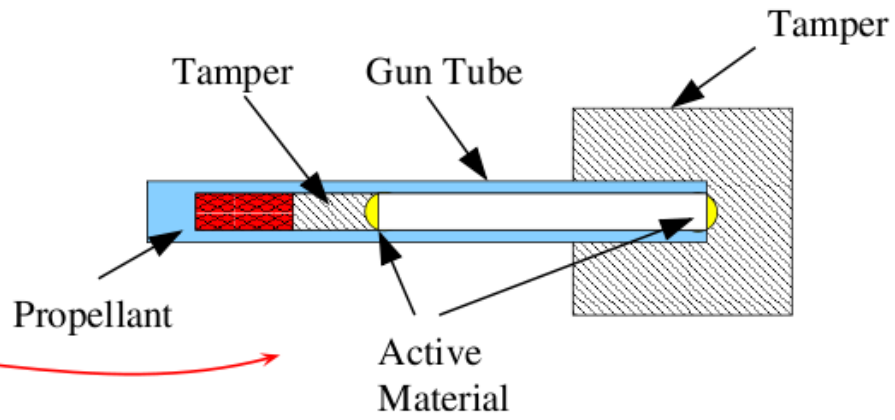
- Only about 8 kg of plutonium or 25 kg of highly-enriched uranium (HEU) is needed is needed to produce a weapon.

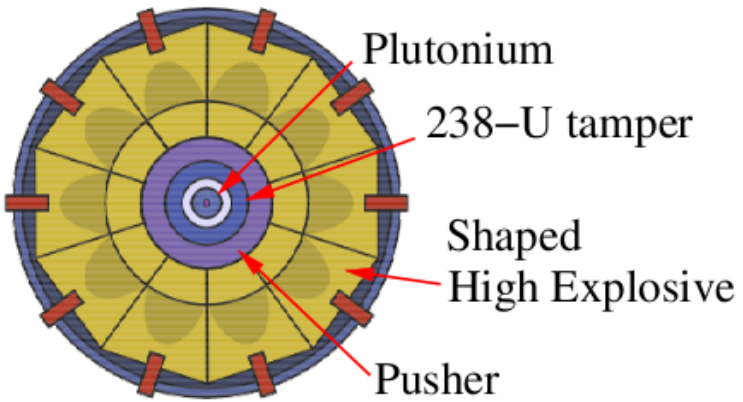
Nuclear Weapons 101

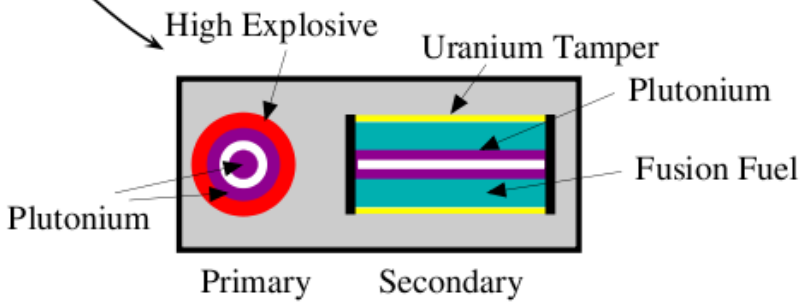
- Uranium, gun-type weapon - High explosive fires highly-enriched uranium slug down the gun tube and into the uranium target. The density increases enough to sustain the chain reaction.
- Plutonium implosion device - High explosive crushes the plutonium primary to a density where fission can occur.
- Two-stage, thermonuclear weapon - Fission weapon crushes secondary containing deuterium and tritium gas and/or a fissile 'spark plug'.



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

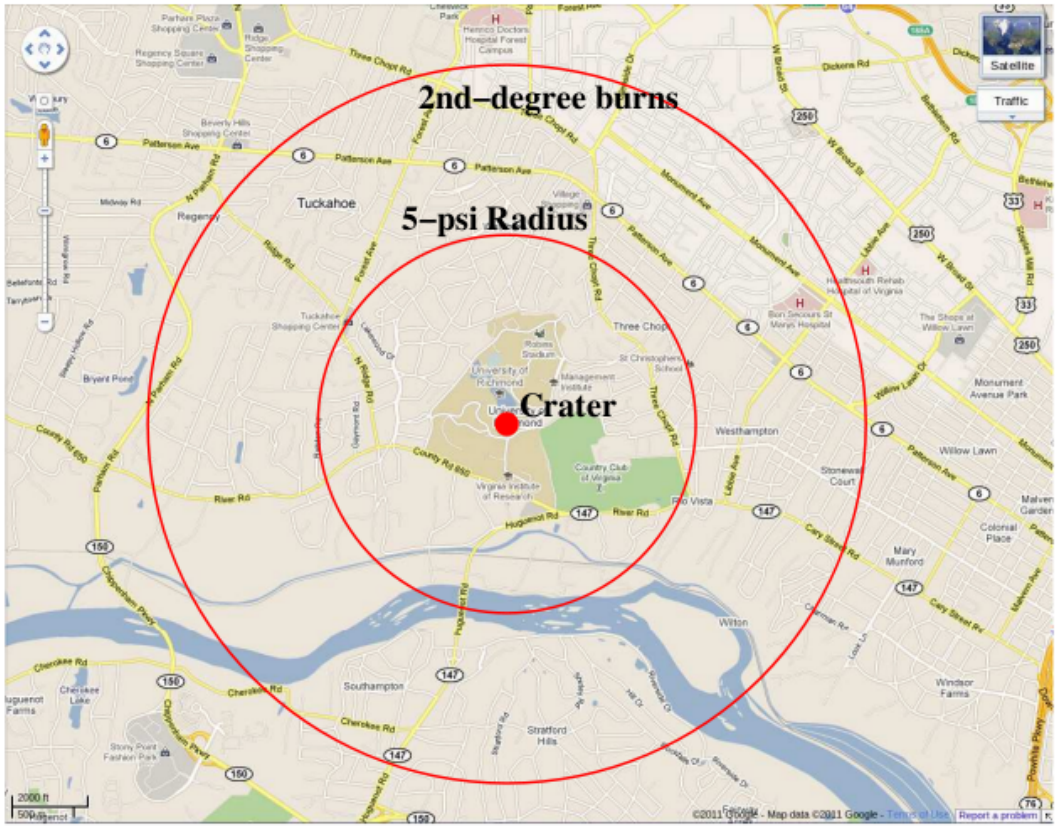






Nuclear Weapons 101

- 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 a 15 kiloton bomb (about the size of the Hiroshima bomb) exploded over the Gottwald Science Center.



▸ Play

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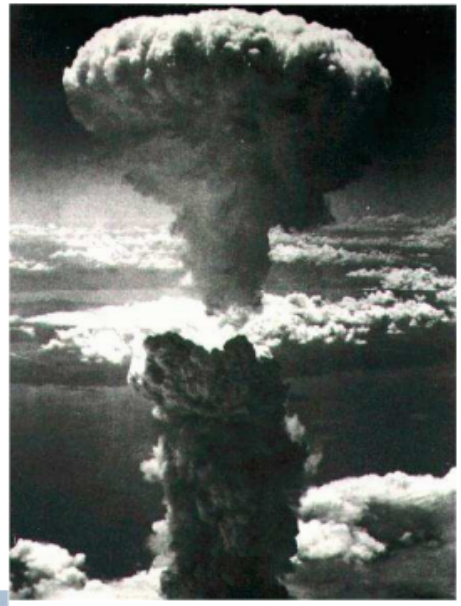
The Comprehensive Test Ban Treaty (CTBT)

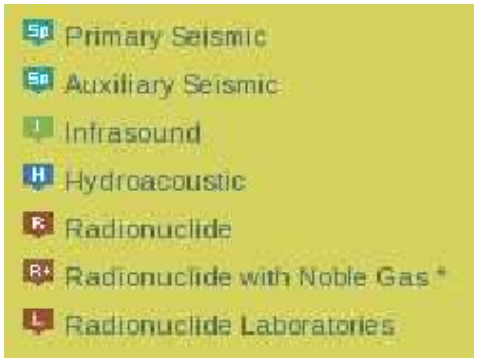
- The CTBT bans all nuclear explosions to limit the proliferation of nuclear weapons.
- A network of seismological, hydroacoustic, infrasound, and radionuclide sensors will monitor compliance.
- On-site inspection will be provided to check compliance.
- The US has signed the CTBT, but not ratified it.

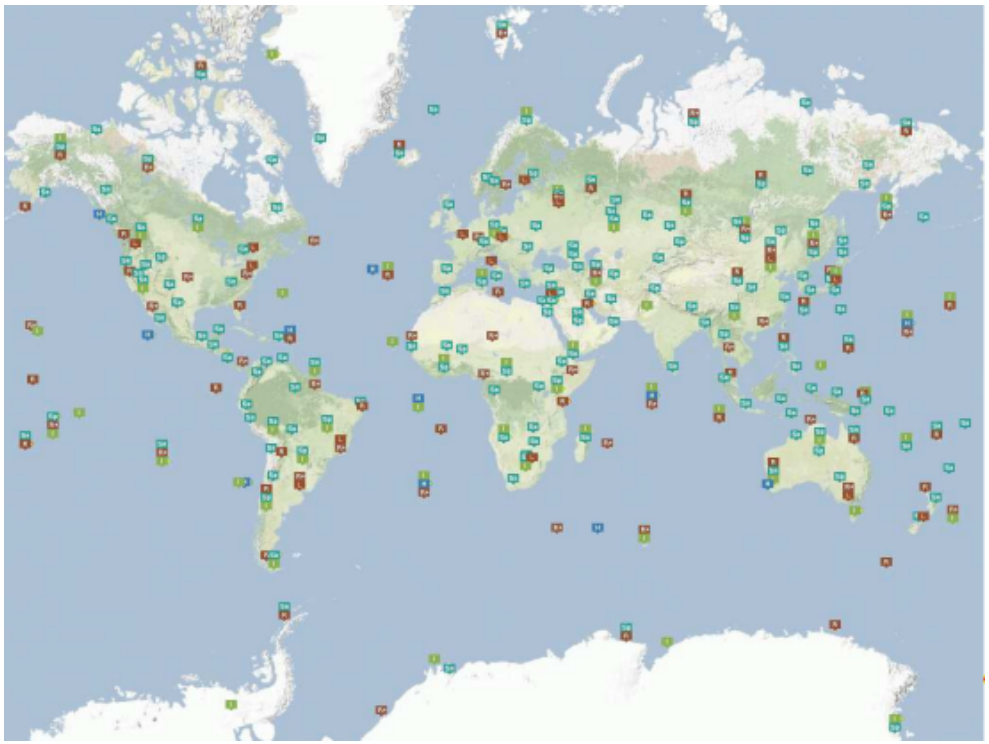


Green - ratified
Blue - signed
Red - outside treaty

The CTBT Verification Regime

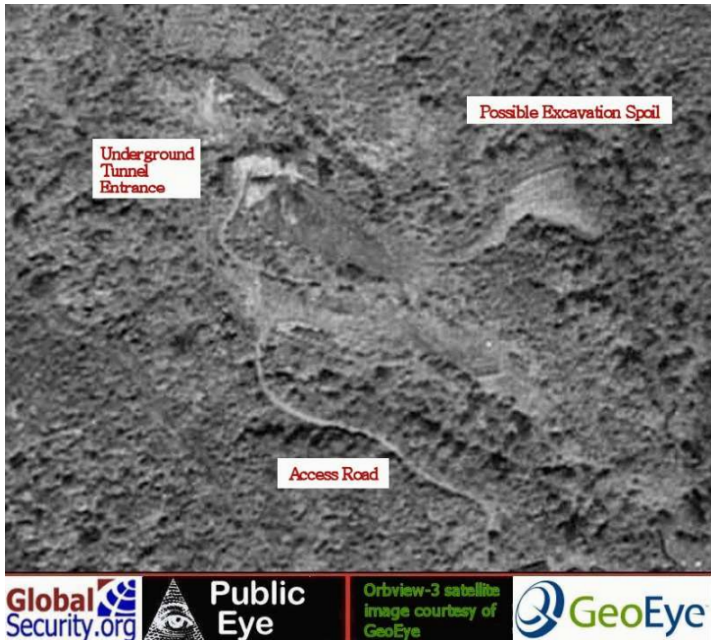
- The International Monitoring System (IMS), consists of 337 facilities that constantly monitor for signs of nuclear explosions. Over 70% are already collecting data.
- Detection technologies:
  - Seismic: 50 primary and 120 auxiliary seismic stations monitor shock waves.
  - Hydroacoustic: 11 hydrophone stations 'listen' for sound waves in the oceans.
  - Infrasound: 60 stations on the surface can detect ultra-low frequency sound waves (inaudible to the human ear) that are emitted by large explosions.
  - Radionuclide: 80 stations measure radioactive particles in the atmosphere, 40 also pick up noble gases.
- On-site-Inspection: If IMS data from the IMS show a nuclear test has ocurred, a Member State can request an on-site-inspection subject to a vote .





Testing the Testers

- North Korean tests a nuclear bomb on October 9, 2006.
  - More than 20 CTBTO seismic stations capture the blast.
  - Radionuclides detected two weeks and 4700 miles away (!) in the Yukon.
- They do it again on May 25, 2009
  - Sixty-one CTBTO seismic stations capture the blast.
  - No radionuclides are found!!?? $\rightarrow$ Epic fail?



- The fun never ends; another test on February 12, 2013
  - CTBTO seismic stations capture the blast.
  - Radionuclides found again! ▸ Link

What is Happening?

- Geologists detect the shaking induced by the blast and pinpoint the site of the explosion within 100 meters - first sign of a test. And then estimate the yield (**geology**).
- A few special nuclei made in the blast (xenon) are chemically inert and find their way through a kilometer of rock to reach the atmosphere.
- Calculations of the weather enables meteorologists to predict the spread of the plume from the blast (**meteorology, physics, computer science**).
- Air monitoring stations process huge amounts of air to capture the xenon atoms (**chemistry**).
- Nuclear physics detectors make the final identification of the decay of the xenon nuclei (**nuclear physics**).
- Now comes the response (**political science**).

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International response is driven by the scientific results - scientists have to get it right!

Why Should You Care?

- The President is committed to bringing the CTBT to a vote for ratification in the Senate.
- ... clandestine nuclear tests could not be verified (by the IMS). ... even when Pyongyang declared that it would conduct a nuclear-weapons test and announced where and when it would occur, this monitoring system failed to collect necessary radioactive gases and particulates to prove that a test had occurred.

  Senator Jon Kyl - R, Arizona: *Why We Need to Test Nuclear Weapons*, Wall Street Journal, October 20, 2009.

- 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.

Why Should You Care?

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The New York Times

Late Edition
New York: **Today**, cloudy with some light snow, high 35. **Tonight**, early snow, low 27. **Tomorrow**, becoming partly sunny, high 35. **Yesterday**, high 34, low 25. Weather map, Page D8.

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REPORT TO CLINTON ASKS U.S. TO RATIFY TEST-BAN TREATY

A LAST-DITCH CAMPAIGN

Retired Head of Joint Chiefs Seeks to Assuage Critics of Pact Assailed by Bush

By MICHAEL R. GORDON

A former chairman of the Joint Chiefs of Staff who conducted a comprehensive study of the nuclear test ban treaty at the request of President Clinton has concluded that the United States must ratify it in order to mount an effective campaign against the spread of nuclear weapons.

The assessment by Gen. John M. Shalikashvili, who was chairman of the Joint Chiefs from 1993 to 1997, is part of a last-ditch attempt by Mr. Clinton to build support for the treaty, which Senate Republicans rejected in 1999 and on which President-elect George W. Bush's own top aides have sharply disagreed.

General Shalikashvili's report outlines measures intended to assuage critics of the treaty, including increased spending on verification, greater efforts to maintain the United States nuclear arsenal and a joint review by the Senate and administration every 10 years to determine whether the treaty is still in American interests.

President-elect Bush assailed the treaty as unverifiable and unenforce-

Road Ban Set For One-Third Of U.S. Forests

Clinton Order Will Put Logging Off Limits

By DOUGLAS JEHL

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The move, covering more than 58 million acres in 39 states, is to be cast by the White House as a capstone in the president's efforts to protect public lands from development. It would effectively prohibit not only commercial logging but also oil and gas development across an area larger than the nation's current national parks. And while not specifically banned, off-road vehicle activity would probably be severely limited in the roadless areas because of their inaccessibility.

The president's order, a strengthened version of an October 1999 administration proposal, is likely to set off furious challenges from Western states and Republican lawmakers who have called the plan hasty and irresponsible.

Among those who plan to head almost immediately to federal court to try to block the sweeping effort is the governor of Idaho, who with other Westerners has denounced the action as an unwise intrusion into land-use decisions better made at a local level.

In the presidential campaign,

Three Who Are Losing Their Old Chairmanships . . .

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Former chairman of the Transportation and Infrastructure Committee announced yesterday that he was resigning.

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FIGHT FOR COVETED POSTS

In the Evenly Divided Senate, Democrats Move Toward a Deal to Share Power

By LIZETTE ALVAREZ

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The newly created selection process created fierce competition among members who sought the positions, intensified party fund-raising by the members seeking to demonstrate loyalty and led to the creation of a new committee.

Representative Bill Thomas, a Californian known for his sharp intellect and temper, was named as the chairman of the Ways and Means Committee, which oversees tax policy, Medicare and Social Security, defeating a more senior and more conservative competitor. And Representative Henry J. Hyde of Illinois, who as chairman of the Judiciary Committee handled President Clinton's impeachment, will now head the International Relations Committee.

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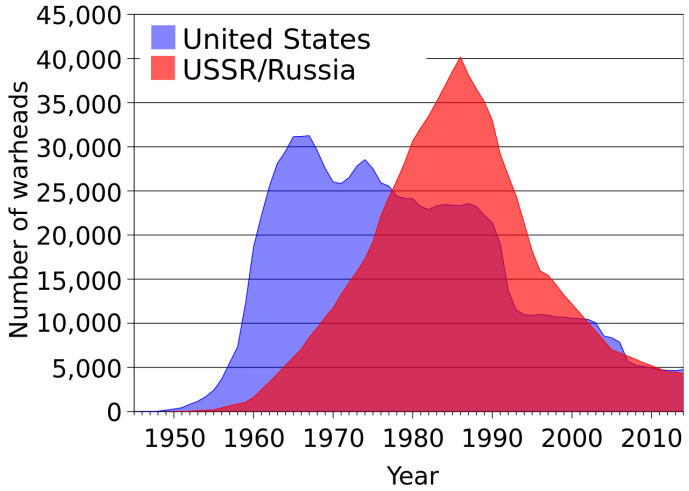
Loose Nukes

The Soviet and US Nuclear Arsenals

- By the end of the Cold War the US and USSR had nuclear arsenals containing about 64,000 warheads on various delivery vehicles.
- US and Soviet military stockpiles contained about 1600 tons of highly-enriched uranium (HEU) and about 200 tons of plutonium.



- An unforeseen consequence of the end of the Cold War was the disposition of nuclear weapons materials.

Loose Nukes?

Fissile Material Security in Russia Declines

- The economic situation in Russia left few funds for maintaining the security of now-unused nuclear materials.
- Reports by the National Research Council in 1994, 1997 and 1999 have revealed the extent of the decline of security.

Building at the Kurchatov Institute housing enough HEU for a nuclear bomb. It had no motion sensors, detectors, or portal monitors.

- In the 1990's there have been numerous instances of smugglers apprehended with nuclear materials.
- In late 1998 the Russian FSB (successor to the KGB) reports stopping an attempt to steal 18.5 kg of weapons-usable material.

Why Should You Care?

- The US and most other nations have a long-standing policy of nuclear nonproliferation.
- A nuclear blast would have horrific consequences; loss of life, property, and security.
- Even acquisition of a nuclear weapon by an adversary could have a devastating influence on US security and non-proliferation.
- **One of the highest hurdles to obtaining a nuclear weapon is acquiring enough weapons-grade fissile material to produce a bomb**. Iraq spent $5-$10 billion in the 1980's to produce a few grams of plutonium.
- Smuggling fissile material is a 'short-cut' to acquiring nuclear weapons; it lowers the acquisition hurdle.
- Prevention (*i.e.*, security) is critical especially against an 'insider' threat.

What Can an Opponent Do?

- What can a terrorist organization do?
  - Acquiring the necessary technology to enrich uranium or plutonium is beyond the capabilities of most terrorists.
  - Stealing the necessary fissile material is NOT!
  - A gun-type, uranium weapon of low yield is still a difficult endeavor, but could be done.
  - There are other alternatives for terrorists like a 'dirty bomb'.
  - The likeliest terrorist weapons are still guns and conventional explosives.
- All of the above can be negated if one of the current nuclear powers gives one away. This is unlikely.

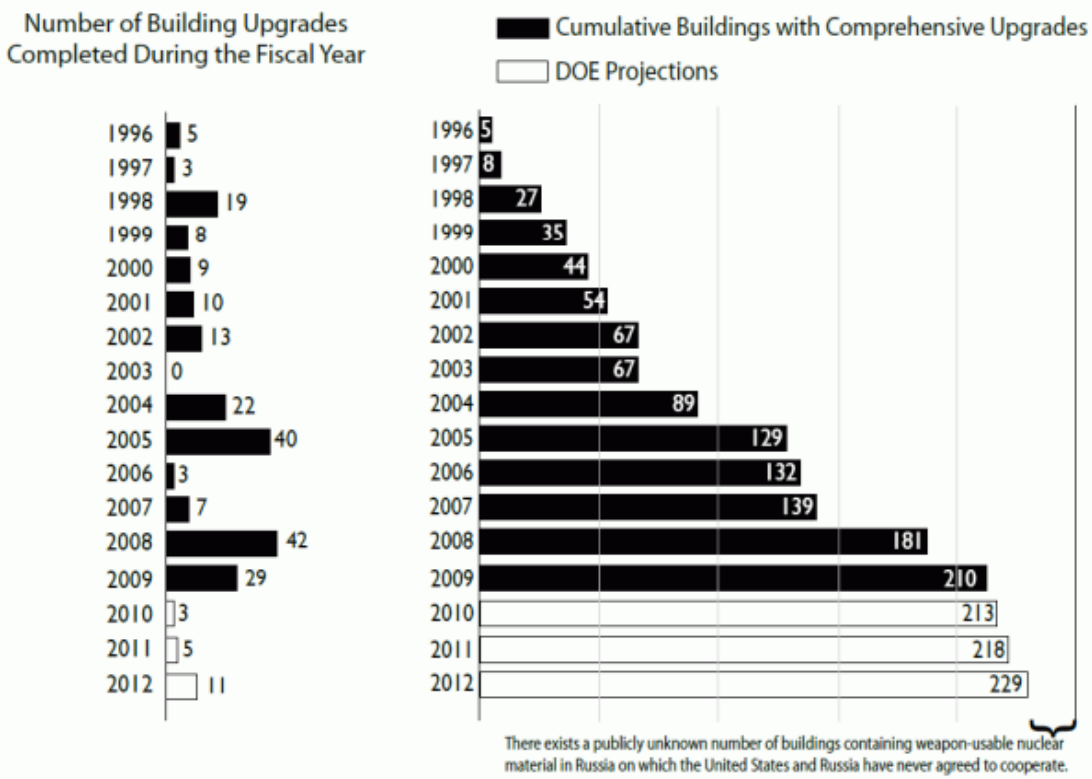
The US Response?

- In 1991 the US Congress passes the Nunn-Lugar Act. The US pays to improve security of fissile materials and to dismantle the Russian nuclear complex (cooperative threat reduction).

Fissile Material Storage Facility under construction at Mayak, financed by the US Cooperative Threat Reduction program.

- The US spends about $700 million a year to reduce this threat.
- The Fissile Material Storage Facility (FMSF) will securely store plutonium and uranium from dismantled weapons.
- The HEU Purchase Agreement requires 500 metric tons of HEU to be downblended to reactor fuel (a form not usable in a nuclear weapon) by 2013 at a cost of $20 billion.

How Loose are the Nukes?



Country	Year
Iraq	1992
Colombia	1996
Spain	1997
Denmark	1998
Georgia	1998
Philippines	1999
Thailand	1999
Slovenia	1999
Brazil	1999
Sweden	2002
Greece	2005
South Korea	2007
Latvia	2008
Bulgaria	2008
Portugal	2008
Romania	2009
Libya	2009
Taiwan	2009
Turkey	2010

Countries that have eliminated all weapons-usable fissile material.

Reproduced from M. Bunn, *Securing the Bomb 2010*, Harvard University and the Nuclear Threat

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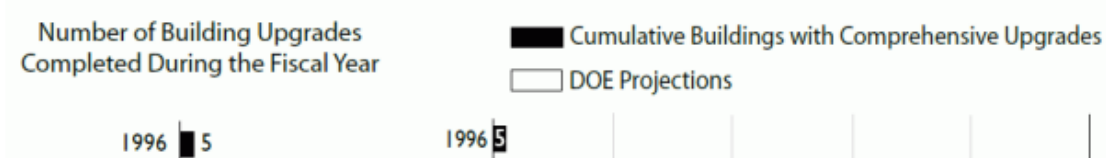

Country	Year
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Action Taken	Completed	% of 2017 Goal	Action Taken	Completed	% of 2017 Goal
Warheads Deactivated	7616	82.2%	SLBM Launchers Eliminated	492	80.4%
ICBMs Destroyed	914	87.8%	Nuclear Air-to-Surface Missiles Destroyed	906	100%
ICBM Silos Eliminated	498	76.4%	Bombers Eliminated	155	100%
ICBM Mobile Launchers Destroyed	197	54.9%	Nuclear Test Tunnels/Holes Sealed	194	100%
Nuclear Weapons-Carrying Submarines Destroyed	33	84.6%	Nuclear Weapons Transport Train Shipments	611	73.7%
Submarine-Launched Ballistic Missiles (SLBMs) Destroyed	695	95.3%	Nuclear Weapons Storage Facility Upgrades	24	100%
Cooperative Biological Engagement Laboratories Secured	47	57.3%	Declared CW Agent Destroyed (Metric Tons)	4018.6	73.4%

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Conclusions

- Do we live in a safer world than during the Cold War? Yes, sort of.
  - The threat of nuclear Armageddon has receded with the lowering of tensions between Russia and the US.
- Has the threat of a nuclear conflict increased? Yes, sort of.
  - While the threat of a large-scale nuclear war between Russia and the US is smaller, the proliferation of nuclear weapons technology has increased the risk of nuclear weapons being used.
- What can be done? Lots, but it will take time, money (Opps! There goes my tax cut!) and leadership from the US (CTBT, NPT, ABM, BWC, CTR).
- What can I do?
  - Learn! Cut through the hype.
  - Vote! Write to Congress.
  - The US and other countries are in desperate need of technical expertise.

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4. Production of trained scientists, engineers, technicians. .... all from basic science research.
   About 200 doctoral theses have come out of JLab.

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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?

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Why Should You Pay For It (basic science, that is)?

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?

JLab, where I do my research, cost about $500 million in 1994 (about 1/4 – 1/2 a Space S

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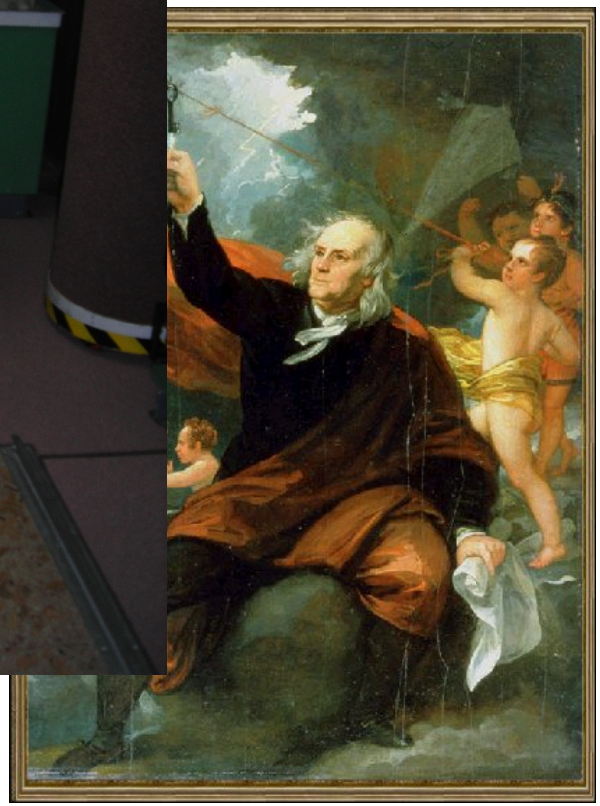

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Additional Slides

What is the Threat?

- Vulnerability of fissile material to insider theft.
  - The USSR relied on 'guards, guns, and gulag' for security. Morale in the defense complex was high and there was less concern about smuggling by the staff.
  - Financial and economic problems in the Russian nuclear cities during the 1990's made the staff susceptible to the temptation of nuclear smuggling.
- Are there buyers?
  - Maybe!
  - Iraq spent $5-$10 billion in the 1980's to produce a few grams of plutonium. They continue this effort.
  - Iran has been acquiring nuclear technology (some from the Russians) for many years.
  - Aum Shinrikyo and Osama bin Laden's group (two terrorist organizations) supposedly tried to obtain fissile material.

Public Policy Opportunities

If you want to get paid (jobs):

- The National Academies (NAS, NAE, NRC, IOM) hire Senior Project Assistants and Research Assistants.
- The scientific societies (AIP, APS, AGU, AGI, ACS, AAAS or AAS) hire science policy researchers.
- Other organizations like the Center for Science, Policy, and Outcomes, the Federation of American Scientists, and the Union of Concerned Scientists sometimes hire researchers.
- The General Accounting Office hires researchers.
- The Congressional Research Service (CRS) produces an annual guide of policy jobs in Washington, DC.

Science Policy and Education

- Policy-makers are in dire need of technical expertise in writing laws to evaluate national security threats, handle privacy, and regulate medical diagnostic testing.
- People are hungry for information.
- An educated electorate is essential.
- Training the populace could save lives in the event of an attack.
  - Panic will amplify the effect of an attack.
  - Panic is greatly diminished when people receive training.

Assessing Risk

What should you stay awake worrying about at night?

Deaths in 2002*	Cause
2,443,387	All causes
918,628	Heart Disease
46,380	Vehicle Accidents
65,681	Influenza/Pneumonia
31,655	Suicide

Deaths in 2000	Cause
17,638	Homicide
17,550	Poisoning
16,257	Falling
3,447	Drowning
3,159	Fire

* National Vital Statistics Reports, **53**, no. 5, October 12, 2004.