Loose Nukes: Nuclear Material Security in Russia

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Outline:

1. Nuclear Weapons 101
2. What are loose nukes and why should you care?
3. What can an opponent do?
4. What is being done about it?
5. What does it all mean?

How does a physicist end up in government?

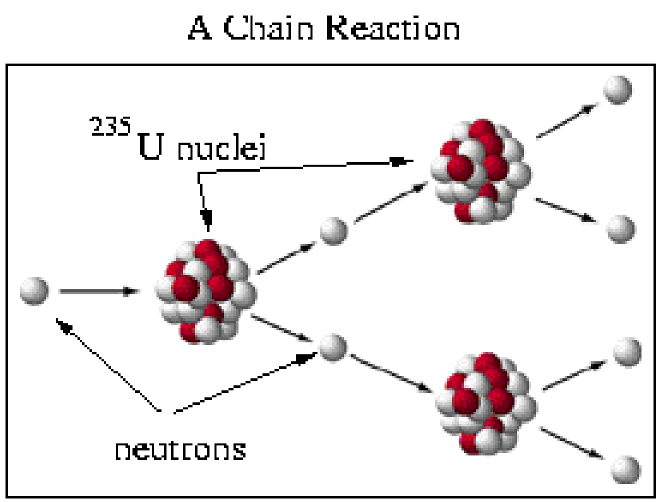
- Science and Engineering Fellowships of the American Association for the Advancement of Science (AAAS).
  - Places scientists in all areas of government from the Department of Defense to Congress to the Justice Department.
  - Brings scientific expertise into government.
  - Trains scientists to solve policy problems within government.
- Defense Policy Fellowship
  - Activities include managing research and development programs and investigating technical questions influencing defense policy.
  - Worked as a scientific consultant in the Advanced Systems and Concepts office of the Defense Threat Reduction Agency (DTRA).
  - DTRA's mission is to reduce the threat to the United States and its allies from nuclear, biological, chemical (NBC), conventional and special weapons.

Nuclear Weapons 101

- Fissile materials (^{235}U, ^{233}U, ^{239}Pu) are used to make weapons of devastating power.
- As each nucleus fissions, it emits 2 or so neutrons plus lots of energy. Usually most of the neutrons leave without striking any other nuclei.

$$^{235}\mathrm{U} + \mathrm{n} \rightarrow {}^{236}\,\mathrm{U}^{*} \rightarrow {}^{140}\,\mathrm{Xe} + {}^{94}\mathrm{Sr} + 2\mathrm{n} + \approx 200\ \mathrm{MeV}$$

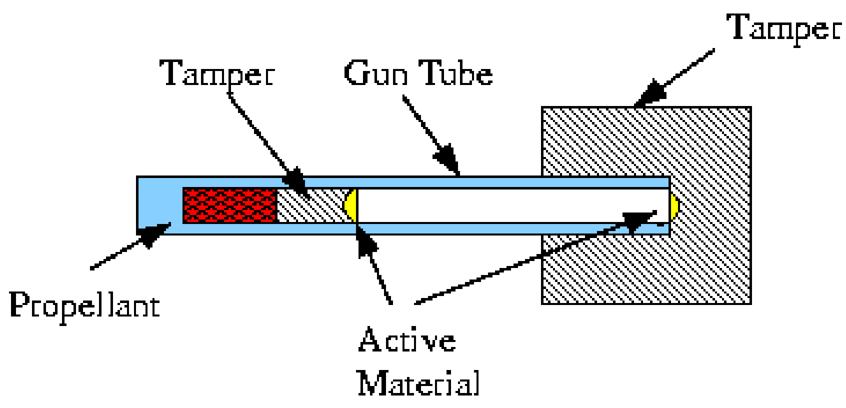
- Increasing the density creates a ‘chain reaction’ where the emitted neutrons cause other fissions in a self-propagating process.
- Only about 8 kg of plutonium or 25 kg of highly-enriched uranium (HEU) is needed is needed to produce a weapon.



Nuclear Weapons 101

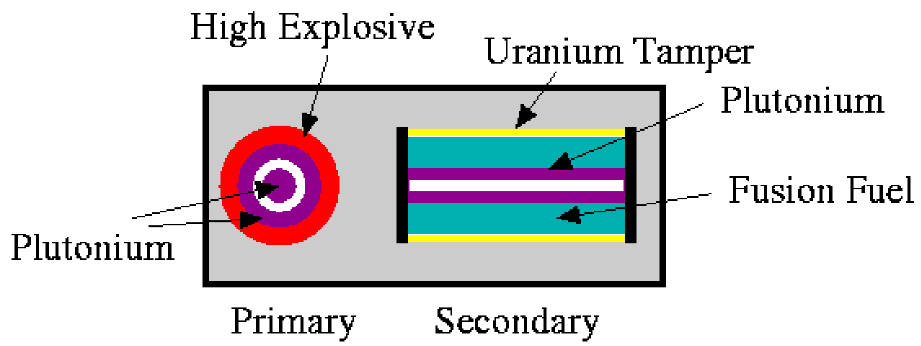
- A uranium, gun-type nuclear weapon.

- High explosive detonates pushing highly-enriched uranium at high speed down the gun tube and into the other piece of active material. The density increases enough to start the chain reaction.



- A two-stage, thermonuclear weapon.

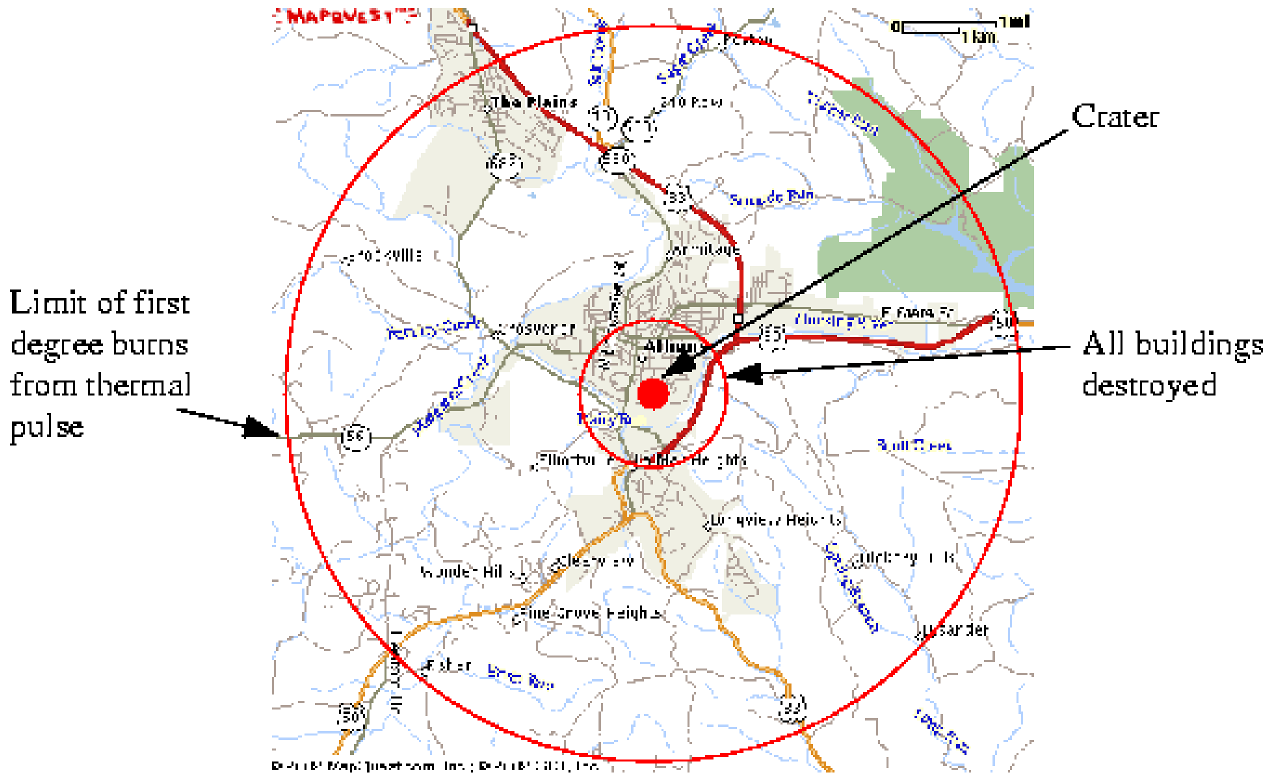
- High explosive detonates crushing the plutonium primary to a density where fission can occur.



- 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 Weapons 101

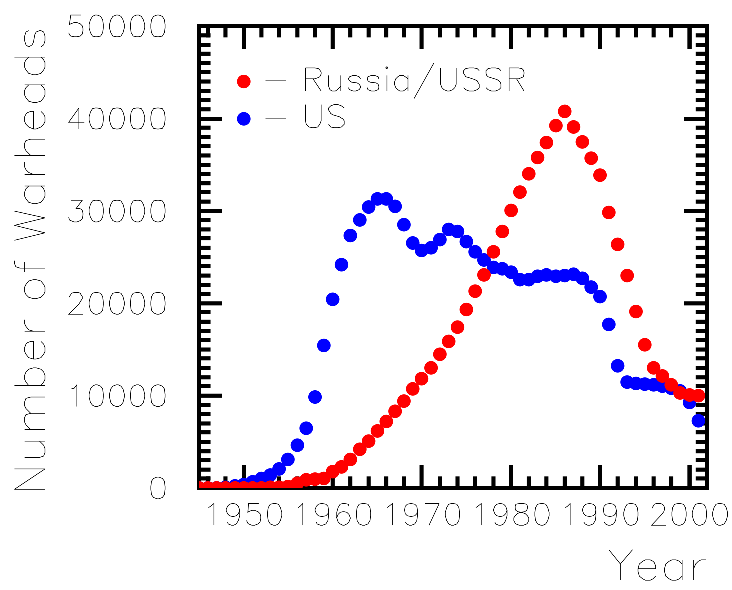
- The picture below illustrates the effect of a 20 kiloton blast (about the size of the Nagasaki bomb) dropped on the Edwards Accelerator Laboratory.



- The energy is emitted as heat, radiation, and blast. The dot in the center is the size of the crater. The first circle is the limit where essentially all buildings will be destroyed. The outer circle is the limit where the heat and radiation will cause first-degree burns.

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.

Fissile Material Security Declines in Russia (loose nukes)

- The economic situation in Russia left few funds for maintaining the security of now-unused nuclear materials.

- Weapons-grade material is dispersed in hundreds of buildings many with poor security and accounting.

Building at the Kurchatov Institute housing HEU with no motion sensors, detectors, or portal monitors.

- Since 1991 there have been numerous instances of nuclear smuggling, but there is no hard evidence that any weapons-grade material from the Russian nuclear weapons complex has been stolen.

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.

Is the threat real?

- 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 (the insider threat).
- Are there buyers?
  - Likely! There is abundant anecdotal evidence.
  - Iraq spent \$5-\$10 billion in the 1980’s to produce a few grams of plutonium. They continue this effort.
  - Aum Shinrikyo and Osama bin Laden’s group (two terrorist organizations) supposedly tried to obtain fissile material.

What Can An Opponent Do?

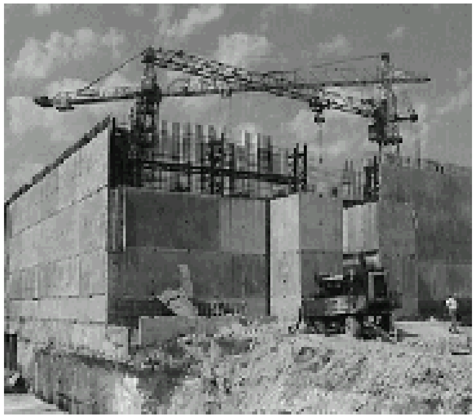
- The opponents are nation-states (*e.g.* Iraq) and terrorist organizations (*e.g.*, al Qaeda).
- Disclaimer: The statements below are my own assessment and not that of the US Government, the University of Richmond, the United Rugby Club of Richmond, Corner Cafe or anyone else.
- What can a nation-state do?
  - Acquiring the necessary technology to enrich uranium or plutonium is within the reach of many countries.
  - A gun-type, uranium weapon of low yield could probably be assembled with a reasonable chance of going off without testing. Low yield here means about the size of the Hiroshima bomb.
  - It is more difficult to produce a weapon that could be mounted on a ballistic missile.
  - A more sophisticated, higher-yield thermonuclear weapon probably cannot be built without testing.

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.

Layers of Defense

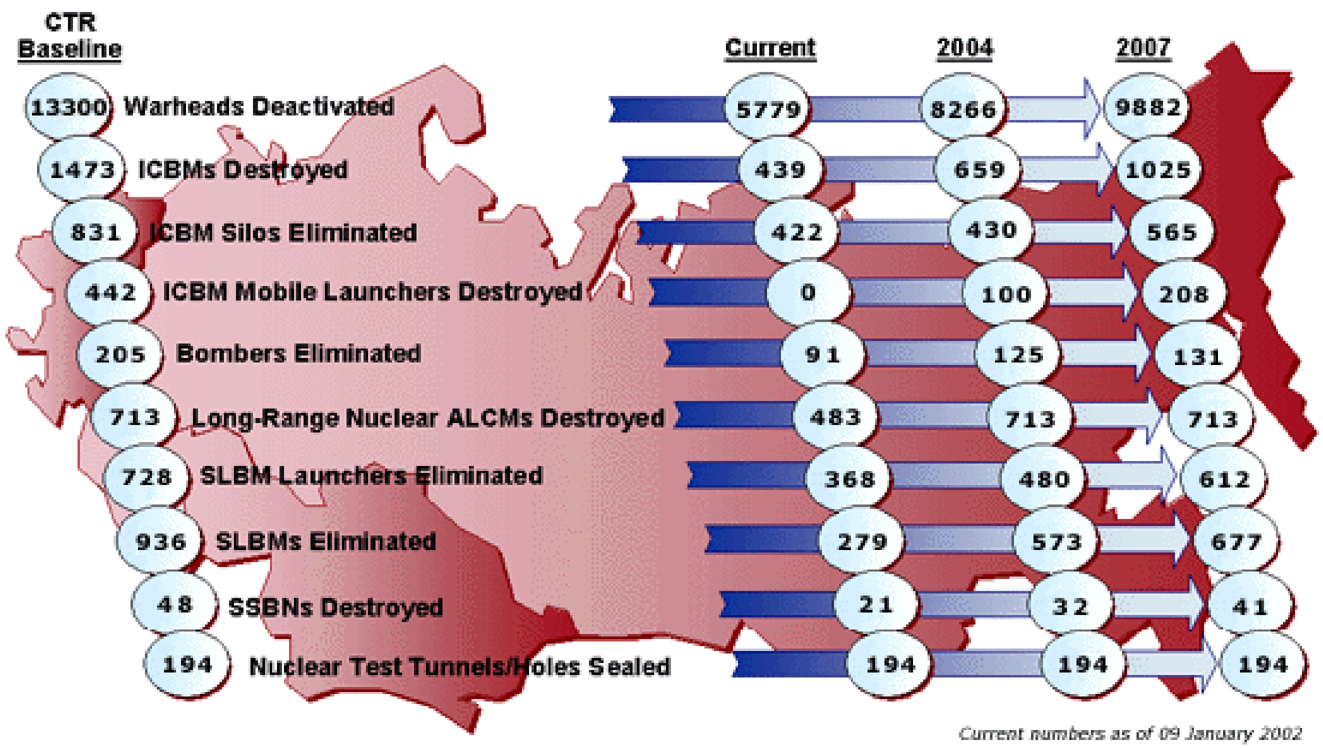
- The first line of defense.
  - Consolidate, eliminate, and secure Russian nuclear materials and delivery systems.

- The second line of defense.
  - Provide equipment and training for export controls in Russia and the central Asian states like Uzbekistan, Turkmenistan, *etc*.
- The third line of defense problem.
  - The US has extensive, porous borders. In 2000, 645 metric tons of cocaine were shipped into the US.[1]

1. National Drug Intelligence Center, *National Drug Threat Assessment 2002*, 2002-Q0317-001, December, 2001.

Is It Working?

The Defense Threat Reduction Agency (DTRA) Scorecard



Is it Working?

- Considerable progress has been made.
- The US Department of Energy has installed complete or partial security systems to protect about 32% of 603 metric tons of insecure, weapons-grade material.[2]
- Opps! The previous statement means there are about 410 metric tons vulnerable to theft.
- Much remains to be done.

Example of enhanced security systems at Russian Minstry of Defense nuclear storage sites that are provided by the US.

2. Government Accounting Office, *Security of Russia's Nuclear Material*, GAO-01-312, February 2001.

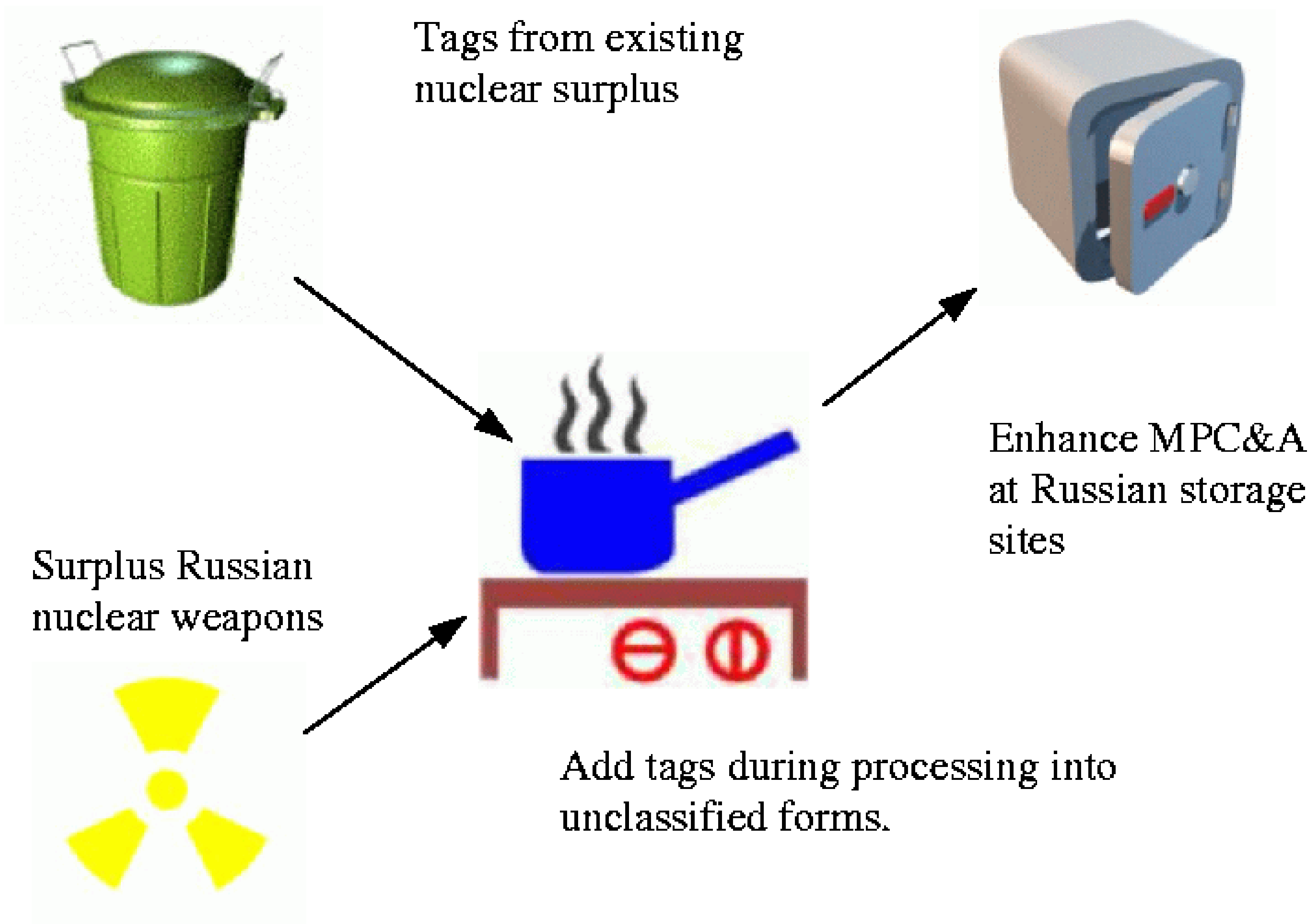
Can We Enhance Fissile Material Security?

- Highly-enriched uranium (HEU) is not very radioactive (*i.e.*, it's easy to hide and smuggle).
  - *Add a detection tag (* ^{232}U*) to brighten the radioactive signature of HEU.*[3]
  - *Detection tag will set off alarms at portal monitors, at storage sites, and at exit and entry points (layers of defense).*

- If stolen material is recovered, it is difficult to identify the source.
  - *Deter smuggling of HEU and plutonium by creating a nuclear fingerprint to enable forensic analysis on recovered material.*[3]
  - *Use* ^{233}U *for HEU and* ^{244}Pu *for plutonium to tag storage sites.*
  - *Enable police to find the source (remember the insider threat).*

3. G.P.Gilfoyle and J.A.Parmentola, *Using Nuclear Materials to Prevent Nuclear Proliferation*, Science and Global Security, **9**, 81 (2001).

The Nuclear Tagging Scheme



Seize New Opportunities to Prevent Nuclear Use and Proliferation

- The US has surplus radio-isotopes; redirect some of them to produce tags.
  - US has only recently developed plans for long-term disposal.
- The US and Russia will process large amounts of weapons-grade material anyway so insert the tags during this phase.
  - Weapons dismantled for storage at US-built facility in Mayak (FMSF).
  - US buying Russian HEU (Purchase Agreement).
- US and Russia are installing equipment to detect nuclear smuggling; tags enhance those capabilities.
  - US now provides equipment and expertise for First and Second Lines of Defense.

Do the Tools Exist?

Do the tags exist? Yes, use ^{232}U/^{233}U for HEU and ^{244}Pu for plutonium.

Can we get enough of it? Yes, already in US surplus.

Can it be added to the weapons-grade material? Yes, during dismantlement.

Will it disrupt future use as fuel? No, taggant quantities are small.

Can it be detected? Yes, enhances existing detection systems in Russia.

How will attribution be performed? Use tag proportion as identifier.

Is it vulnerable to countermeasures? Difficult to defeat.

Are tags safe and affordable? Yes, small marginal cost.

Do HEU detection and attribution tags exist?

- Mixture of ^{232}U and ^{233}U added during HEU processing.
- Use ^{232}U as detection tag for HEU.
  - Emits a high-energy (2.6 MeV), penetrating gamma ray.
  - The ^{232}U gamma rays persist for centuries.
- Use ^{233}U as the attribution tag for HEU.
  - Rarely produced and only under extreme conditions.
  - Can be detected at low levels (20 ppb) with mass spectrometry.
  - Amount of ^{233}U varied to fingerprint different HEU processing and/or storage sites.
  - Contamination by background ^{233}U is very low (0.1 ppb) compared with the amount added (10 ppm).

The HEU tags exist!

Does a plutonium attribution tag exist?

- Brightening the radioactive signature of plutonium is unnecessary. Plutonium is already very radioactive.
- Use ^{244}Pu as an attribution tag.
- ^{244}Pu is a unique signature for attribution.
  - Rarely produced and only under extreme conditions.
  - Can be detected at low levels (20 ppb) with mass spectrometry.
  - Amount of ^{244}Pu varied to identify different plutonium storage sites.
  - Contamination by background ^{244}Pu is very low (less than 0.1 ppb) compared with the amount added (about 200 ppb).

The plutonium tags exist!

Can we get enough of it?

- Abundant amounts of ^{233}U and ^{232}U already exist at Oak Ridge National Lab (ORNL).
  - There are $^{233}\mathrm{U}/^{232}\mathrm{U}$ mixtures and ^{233}U alone.
- Adequate amounts of ^{244}Pu exist at the Savannah River Site.
- DOE is developing and implementing plans to process the above material into more stable forms for long-term disposition.

There is plenty of material for the tags in EXISTING US stockpiles!

An opportunity to use US radio-isotope surplus.

- DOE is planning final disposition of ^{233}U.
  - Allocated $100 million for processing and packaging only.
  - Additional funds necessary for final disposition.
  - Program to create uranium tags will cost about $20-25 million.
- DOE is planning final disposition of ^{244}Pu.
  - Program to create plutonium tags will cost about $15-20 million.
  - Roughly the same processing cost regardless of end product.

Redirect some of the radio-isotope surplus to tags to enhance fissile material security in Russia and take advantage of existing or planned programs.

Calculating the Tag Demand.

	Tag Supply (kg)	Tag Proportion	Amount to be tagged (metric tons)	Tag Demand (kg)[d]
^{232}U	0.30[a]	1 ppb	600 (HEU)	0.0006
^{233}U	351[a,b]	50 ppm	600 (HEU)	30
^{244}Pu	0.020[c]	200 ppb	75 (Pu)	0.015

a. Oak Ridge National Laboratory.

b. Another 704 kg mixed into 14 $tons$ of thorium at the Idaho National Engineering and Environmental Laboratory.

c. Savannah River Site.

d. Tag demand is the product of the tag proportion (column 3) and the amount to be tagged (column 4).

Can It Be Added to the Weapons-Grade Material?

- HEU is flourinated in the early stages of processing for the HEU Purchase Agreement.
  - Add a pellet of the combined detection/attribution tags ($^{232}\mathrm{U}/^{233}\mathrm{U}$) to the flourination process and mix (the tags are the same element).
- Plutonium and uranium will be recast for storage in the Fissile Material Storage Facility at Mayak.
  - Make pellets containing the tags ($^{232}\mathrm{U}/^{233}\mathrm{U}$ for HEU and $^{244}\mathrm{Pu}$ for plutonium) and drop them into the melt and stir. Again, they are the same element so mixing should be easy.

The tags can be added to a large fraction of the insecure material during already-planned processing.

Can We Build the Lines of Defense?

The US and Russia have begun placing equipment to detect nuclear smuggling at Russian nuclear sites (first line of defense) and exit points (second line of defense).

The HEU detection tag will increase the chances of detecting illicit material passing through one of the portal monitors.

Reduces the imposing 3rd line of defense problem.

A bonus that enhances accounting

- Nuclear materials will be stored at Mayak and at Russian HEU processing sites.
- Containers will be periodically removed and tested.
  - HEU tested using attributes (*e.g.*, mass) and by activation.
  - Plutonium monitored with intrinsic gamma ray emissions.
- The ^{232}U tag verifies the site of the processing.
  - The amount of ^{232}U is far above background.
- To account for plutonium in the same way add some of the ^{232}U brightener during processing.

The ^{232}U detection tag can also act as an accounting tool to monitor stored material and enhance the 1st line of defense.

Vulnerability to Countermeasures

Can it be shielded? Yes, but you need lots of lead.

Can it be chopped up? Yes, but attribution still works.

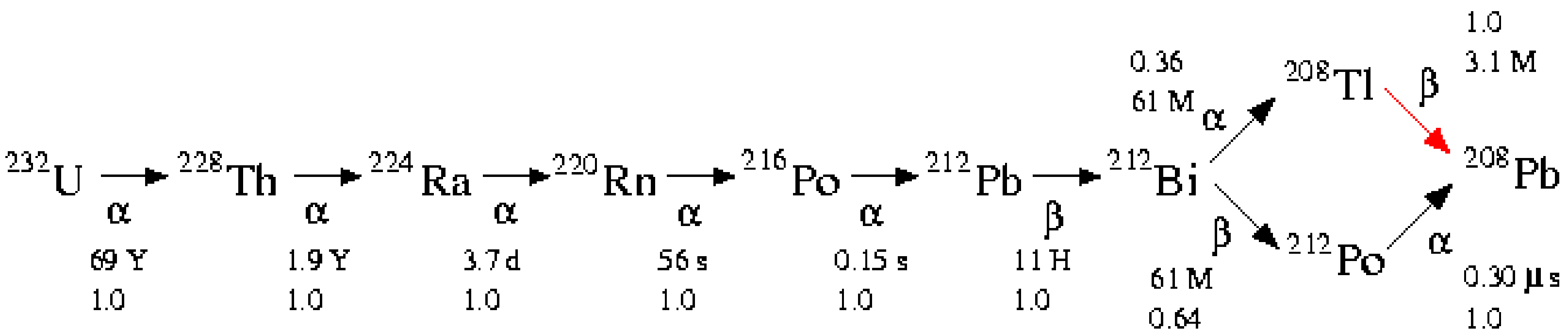
Can the tags be removed? Only with methods beyond the capabilities of smugglers.

Can the ^{208}Tl **be removed?** Yes, but it grows back in about a month.

Can the attribution tags be masked? No, the attribution tags are rare.

Can the HEU detection tag be removed?

^{232}U Decay Scheme



1. The red arrow marks the nuclear decay that produces the high-energy (2.6 MeV) gamma ray.

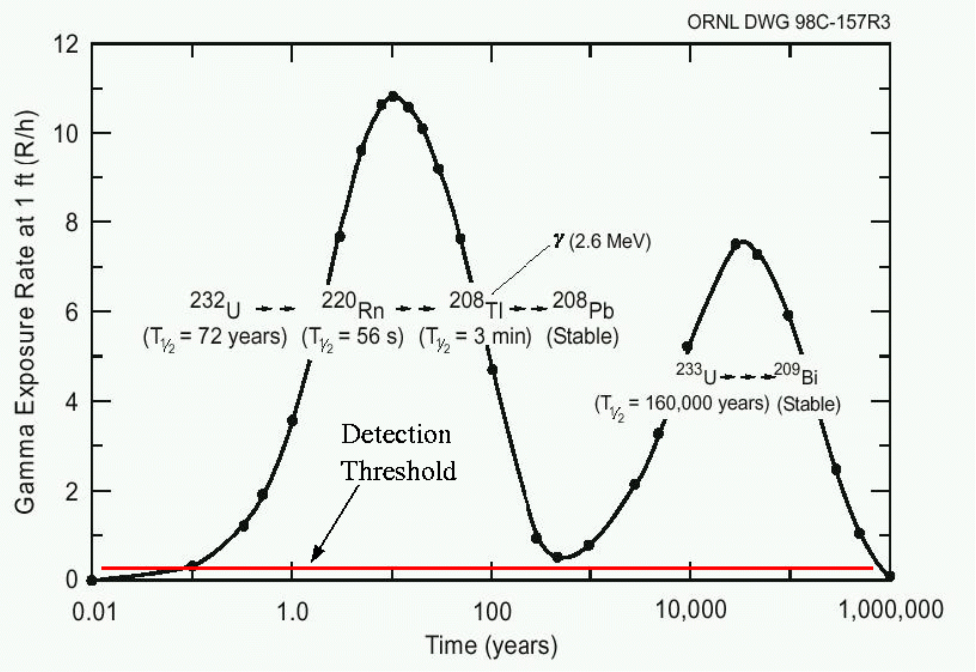
2. Chemical removal of the ^{208}Tl temporarily eliminates emission of this gamma ray.

3. The 2.6-MeV gamma ray returns in detectable amounts in about 1 month due to ingrowth of the ^{208}Tl.

Can the HEU detection tag be removed?

Gamma rays are bright enough to be detected after about one month.

Gamma ray intensity is above the detection threshold from one month to about one million years.



Gamma-ray exposure for 1 kg of ^{233}U with 100 ppm ^{232}U starting from an initial mixture of ^{233}U and ^{232}U only. Plot from Oak Ridge National Laboratory Report, ORNL-6952, C.W.Forsberg and L.C.Lewis, 1999.

$\boxed{\textbf{Is it safe?}}$

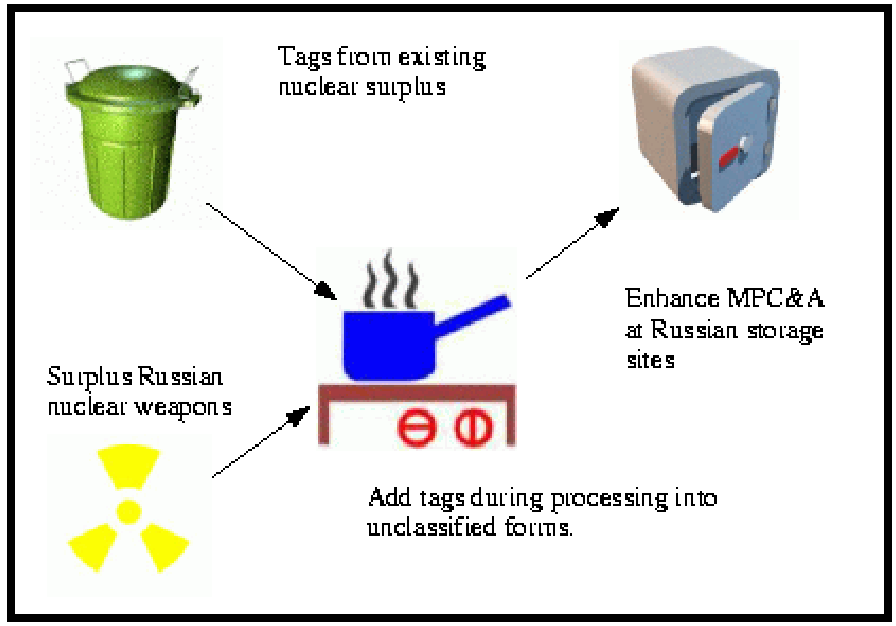
- For plutonium, will addition of the tag increase any radiation hazard?
  - No. The ^{244}Pu is at a low concentration and has a long half-life so it emits little radiation.
- For HEU will addition of the tag increase any radiation hazard?
  - No. Dilute the $^{232}\mathrm{U}/^{233}\mathrm{U}$ tag so the added radiation hazard is reduced to $0.1\ mrem/hr$ after tagging the HEU.

Is it affordable?

- Yes. The marginal cost is small.
- HEU tags.
  - DOE has allocated \$100 million to convert surplus ^{233}U to a safe storage form. Additional funds are needed for disposition.
  - Additional processing to create tags will cost about \$20-25 million.
- Plutonium tags.
  - DOE must dispose of excess ^{244}Pu, but funds not allocated.
  - Processing to create tags will be about \$15-20 million.
- Incorporating tags in Russian fissile material.
  - DoD has allocated \$1.3 billion for fissile material control including the FMSF at Mayak.
  - HEU Purchase agreement will spend \$20 billion by 2013.
  - Addition of tags is a ‘no-brainer’ at a variety of processing steps.

Conclusions of Tagging Study

- Seize upon a rare confluence of opportunities!
  - Nuclear weapon dismantlement in Russia.
  - US radio-isotope surplus disposition.
  - Nunn-Lugar programs in Russia.



- Adding ^{232}U tag to HEU enhances detection.
- HEU fingerprinted with ^{233}U.
- Plutonium fingerprinted with ^{244}Pu.
- Tags are safe, affordable, robust, and don't affect future fuel use.
- Tags can also be a safe, secure accounting tool.

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.
  - Be a AAAS Fellow! Government (the US and others) is in desperate need of technical expertise.

What are all those abbreviations?

Abbreviation	Full title	Status before 9/11	Status after 9/11
CTBT	Comprehensive Test Ban Treaty	Not supported by administration.	No change.
NPT	Non-Proliferation Treaty	See CTBT.	No change.
ABM	Anti-Ballistic Missile Treaty	US is scheduled to withdraw.	No change.
BWC	Biological Weapons Convention	US withdraws.	No change.
CTR	Cooperative Threat Reduction	Faced significant budget cuts.	Budget restored.

Other Projects and Lessons Learned

- Other things I did.
  - Net Assessment of the Comprehensive Test Ban Treaty.[4]
  - Investigating the future of cooperative threat reduction.
  - Assessing preventive threat reduction.
  - Science and technology review of R&D in the Defense Threat Reduction Agency (DTRA).

- Lessons learned.
  - Government is in dire need of technical and scientific expertise.
  - The research tends to be broader than traditional physics research, but is not as ‘deep’ (don’t take this to mean it’s lower quality, easier, less important, *etc*).
  - The issues you confront are national and international ones.
  - Uses your physics training to contribute to improving society.

4. M.Gordon, ‘Clinton Gets Nuke Test Ban Report’, *The New York Times*, January 5, 2001, p. 1.

Opportunities in Public Policy for People With Bachelors Degrees in the Sciences

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.

Opportunities in Public Policy for People With Bachelors Degrees in the Sciences

If you can live without getting paid (internships):

- Try all of the above.
- Call a Congressional or White House office.
- Call a local Congressional office.