The Grand Challenges in Nuclear Security

Oak Ridge National Laboratory Summer Intern Program

June 24,, 2010 -- Oak Ridge, TN

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Nuclear security covers broad areas

Nuclear Security…

The totality of activities undertaken to ensure that:

- The beneficial applications of nuclear/radiological materials and devices are not diverted to illicit or malicious purposes.
- Arms control priorities can be achieved through support and development of technologies for declaratory policy verification. Nuclear weapons and related technology are appropriately controlled and monitored, and weapons-usable materials can be accounted for and secured.
- Advances are made toward meeting other nonproliferation goals and objectives (such as for interdiction, render safe, and forensics) that mitigate threats, increase proliferation resistance, and support deterrence.
- Consequences of radiological or nuclear incidents, including attacks, are mitigated or minimized.

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The “operational” definition…

"Blind monks examining an elephant”
An 1888 ukiyo-e print by Hanabusa Itchō.

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The central questions

- How do we assure that radiological material and/or nuclear technology is where it is supposed to be, being used for its intended purpose, and properly protected?
- How do we detect things outside the bounds of appropriate use?
- How do we effectively deal with bad events?
- How do we objectively assess what we do know and what we think we know?

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How do we achieve "security?"

- Understand the threat
- Keep nuclear weapons safe, secure, and rare
- Reduce or eliminate risk of malicious use or theft
- Find and stop potential threats
- Trace the threat back to the source
- Reduce our vulnerability and limit loss of life if detonation occurs
- Clean up and restore effectively
- Ensure that the strategy is sustainable

Science and engineering must be part of a comprehensive nuclear security paradigm

Technology development

Assessments and analysis

Training and exercises

- Strategic intelligence
- Weapons design physics
- Nonproliferation/counterproliferation
- Threat assessments
- Architectures and ConOps
- Detection and identification
- Triage and reachback
- Emergency response
- Forensics and attribution
- Consequence management

Understanding the threat

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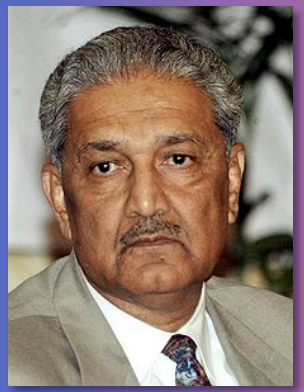
A wide spectrum of challenges



Individuals

Terrorism

Nation-States

Trans-National Networks

Nuclear criticality weapons

- Nuclear criticality in weapons relies upon carefully controlled initiation of the initial nuclear reaction
- Two types of nuclear weapons: “gun-type” and implosion
- Weapon must go supercritical quickly in order create and sustain an explosive reaction
- As the nuclear reactions occur the number of successive reactions will drop eventually resulting in the end of the reactions

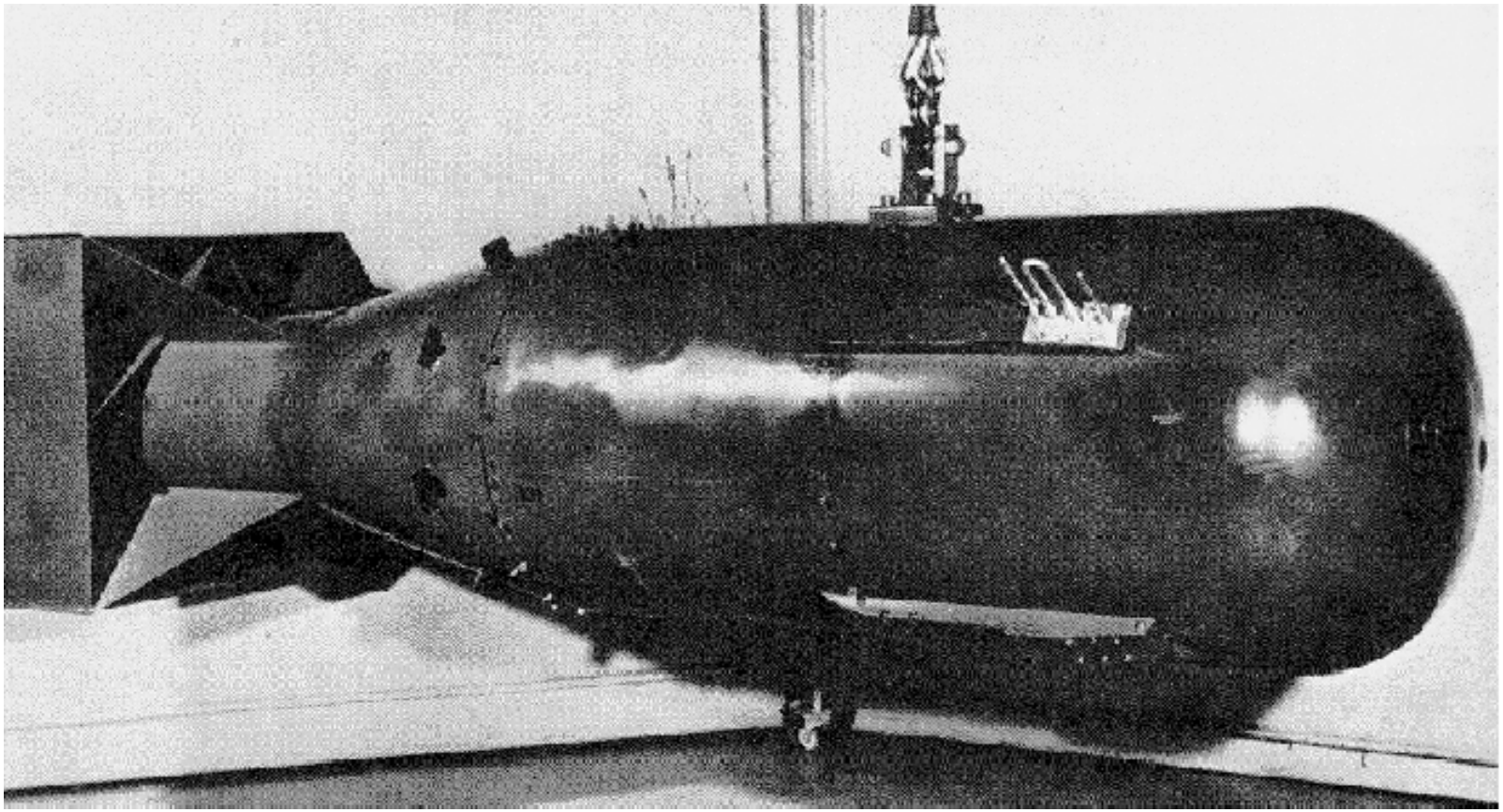
Creating a fission explosion

- Quickly assemble a supercritical configuration of fissile material and, at the instant of maximum compression (maximum density)…
- Introduce neutrons to initiate chain reactions
- Chain reactions will continue to spawn additional reactions until the increasingly hot fissile material expands sufficiently to become subcritical

Gun-type weapons

- Two sub-critical components separated in a single holding element
- One component is “fired” towards the second using a chemical propellant
- The resulting connection of these two components yields a favorable geometry and the right mass to prompt a supercritical state
- The power then increases exponentially until the reacting energy disassembles the fuel

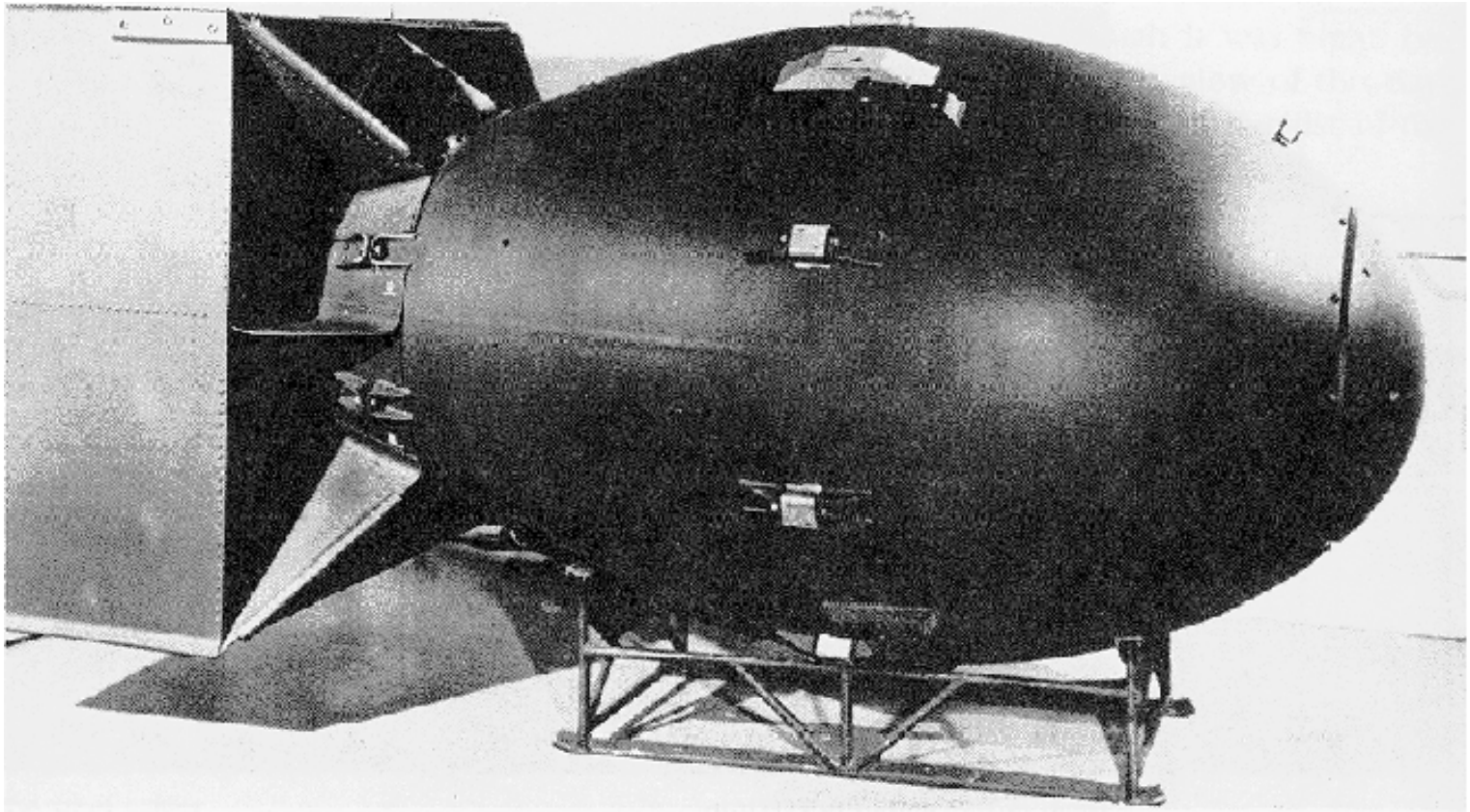
"Little Boy"



Implosion weapons

- This type of weapon is used when the military requirements demand high yield-to-weight, better fuel efficiency, and better criticality safety.
- Complexity of implosion creates a technical safety barrier to misuse
- Implosion-type weapons are the only routinely stockpiled weapons today in the US.

"Fat Man"



Implosion weapons

- As with gun-type the reaction must go supercritical quickly to achieve optimum reaction rates
- A sub-critical assembly of nuclear material (typically Pu-239) is placed into the bomb casing
- Explosives are oriented around the mass
- Explosives are detonated resulting in the increase in density of the sub-critical materials thus going supercritical

The threat of nuclear terrorism is real

"Al Qaeda has demonstrated a clear intent to acquire weapons of mass destruction. In 1993, Osama bin Laden attempted to buy uranium from a source in the Sudan. He has stated that it is Al Qaeda's duty to acquire weapons of mass destruction. And he has made repeated recruiting pitches for experts in chemistry, physics, and explosives to join his terrorist movement."

FBI Director Robert Mueller, June 11, 2007

"Soviet-era plutonium that was never accounted for after the Cold War could fuel roughly 25 nuclear weapons as powerful as the "Fat Man" atomic bomb dropped on Nagasaki…"

Former Air Force Secretary Thomas Reed, January 26, 2009

"Usama bin Laden in a 1999 interview discussed his religious duty to acquire chemical and nuclear weapons. Also, in 2003, extremist cleric Nasir bin Hamd al-Fahd issued a fatwa in which he declares that Islamic law permits the use of weapons of mass destruction for jihad."

DHS Under Secretary for Intelligence and Analysis Charles Allen, April 2, 2008

Image source: Al Qa'ida-affiliated website, reported by Israeli News Service

Understanding the threat

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What are the grand challenges?

- Controlling and reducing nuclear threats
- Deterring and dissuading proliferation
- Developing a security culture in the growing international nuclear power industry
- Finding and defeating threats
- Who did it?
- Saving lives in the event of an explosion
- Cleaning up and recovering
- Staying the course

Safe, secure, and few

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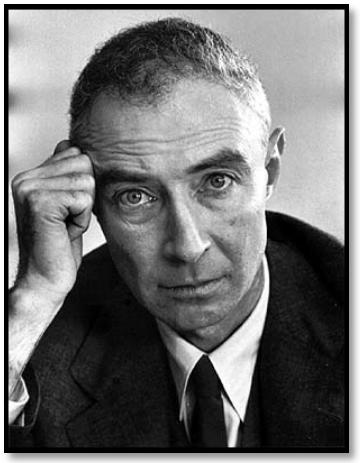
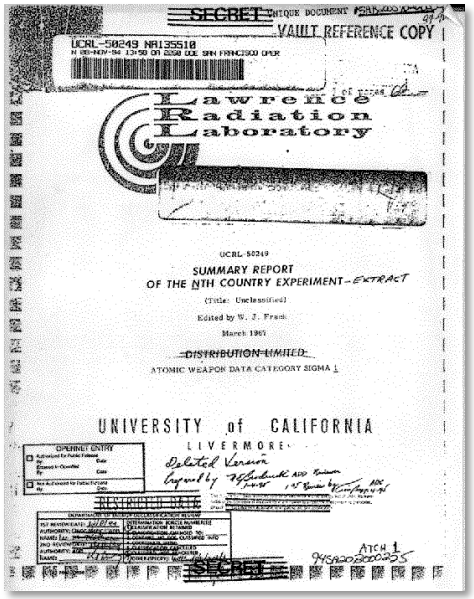
Design secrecy has limited efficacy



"The only secret is that it works."
J. Robert Oppenheimer

"The secrets of nuclear weapon design were revealed long ago. The only significant barrier remains access to fissile material: highly enriched uranium (HEU) or plutonium.."

Charles Ferguson and William Potter,
***San Jose Mercury News**, October 10, 2004*



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VAULT REFERENCE COPY
UCRL-50249 NR135510
Lawrence Radiation Laboratory
UCRL-50249
SUMMARY REPORT
OF THE NTH COUNTRY EXPERIMENT-EXTRACT
(Title: Unclassified)
Edited by W. J. Frank
March 1967
~~DISTRIBUTION LIMITED~~
ATOMIC WEAPON DATA CATEGORY SIGMA 1
UNIVERSITY of CALIFORNIA
LIVERMORE
Deleted Version
SECRET

FOIA-released cover

"An international smuggling ring that sold bomb-related parts to Libya, Iran and North Korea also managed to acquire blueprints for an advanced nuclear weapon, according to a draft report by a former top U.N. arms inspector that suggests the plans could have been shared secretly with any number of countries or rogue groups."

***Washington Post**, June 15, 2008*

Three physicists arrived at a credible design in a little over two years using only open literature – in 1967.

***N^th^ Country Experiment**, LLNL 1967*

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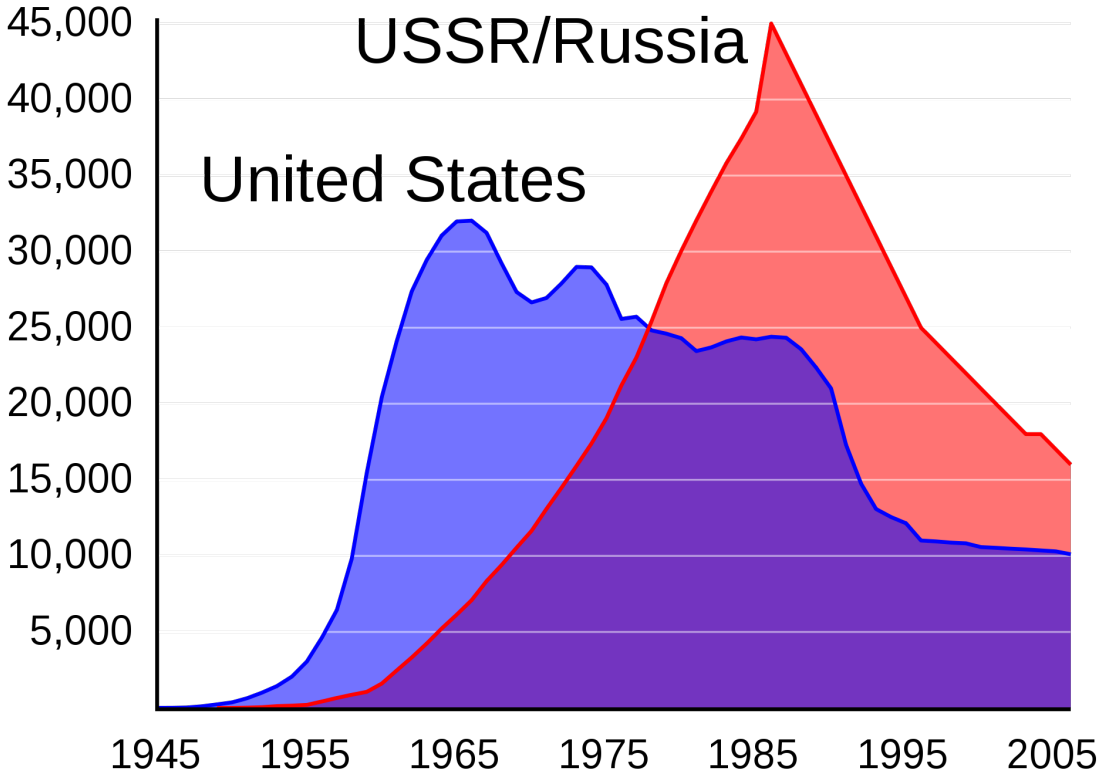
Nuclear weapons stockpiles



Robert S. Norris and Hans M. Kristensen, "Global nuclear stockpiles, 1945-2006," *Bulletin of the Atomic Scientists 62, no. 4 (July/August 2006), 64-66.*

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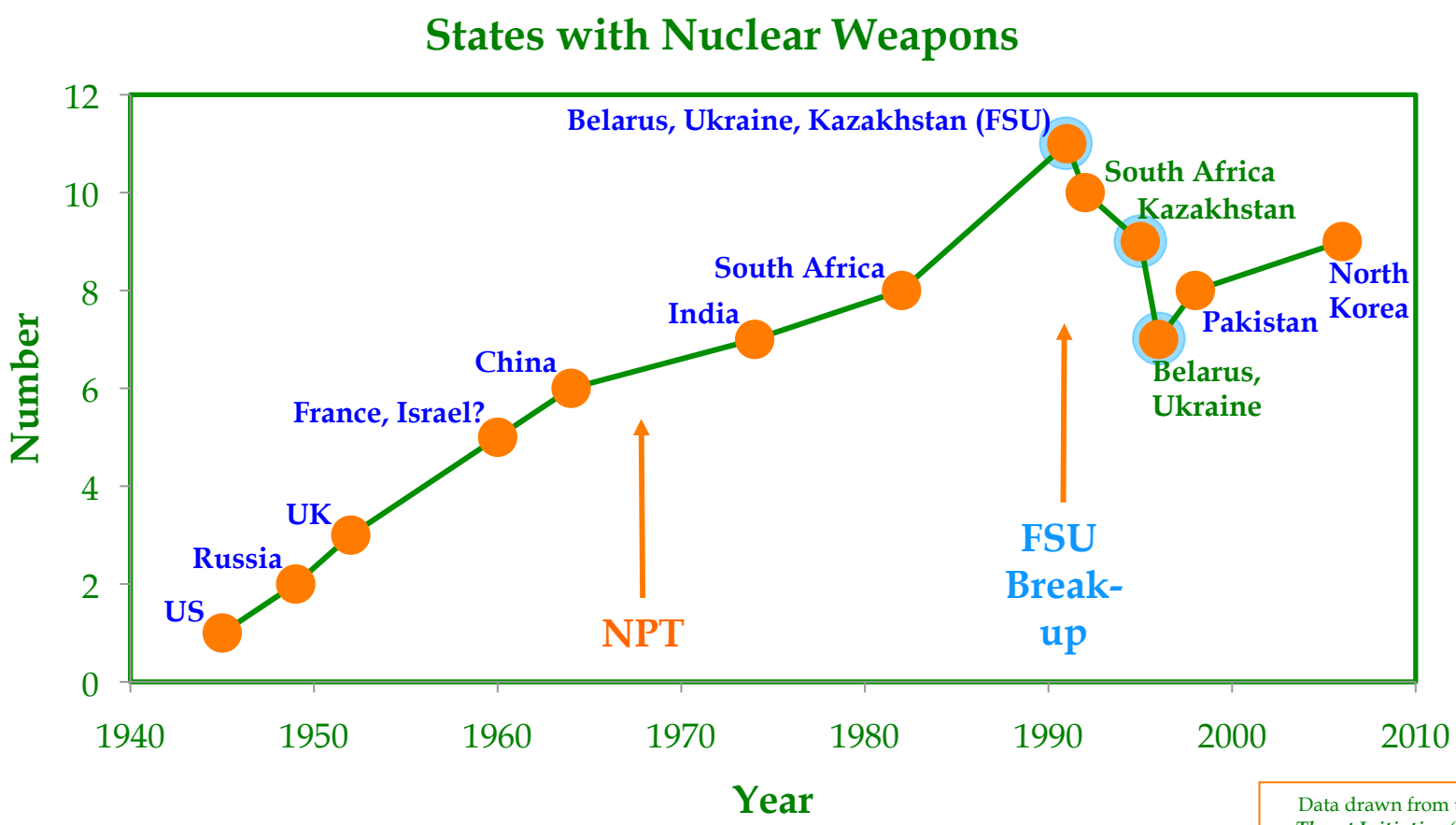
Growth of nuclear weapons states



Data drawn from the *Nuclear Threat Initiative* (*www.nti.org*)

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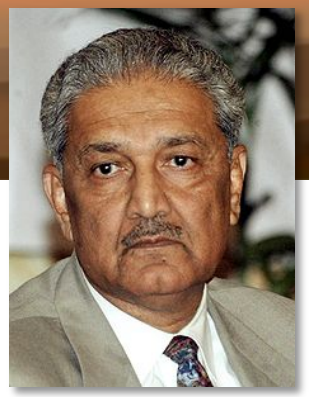
The A. Q. Khan network



- Abdul Qadeer Khan
  - Father of the Pakistani nuclear program
  - Confessed to illegally selling (with numerous international accomplices) nuclear technology
- A troubling development -- trans-national proliferation by non-state actors and corporate entities
  - Role in nuclear proliferation to Libya
  - Suspected in regards to North Korea and Iran, possibly others

Iran – the next nuclear weapons state?

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Reducing the risk

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Sources of nuclear materials are international

- **Central Asia is a major producer of uranium ore**
  - **17% of world's production**
- **Understanding aspects of the nuclear fuel cycle worldwide provides the underpinning of our interpretive framework**
- **Access to the most cogent threat materials -- weapons-usable Special Nuclear Material (SNM) from hostile foreign states such as North Korea -- is unlikely**

Finding well-hidden threats is hard

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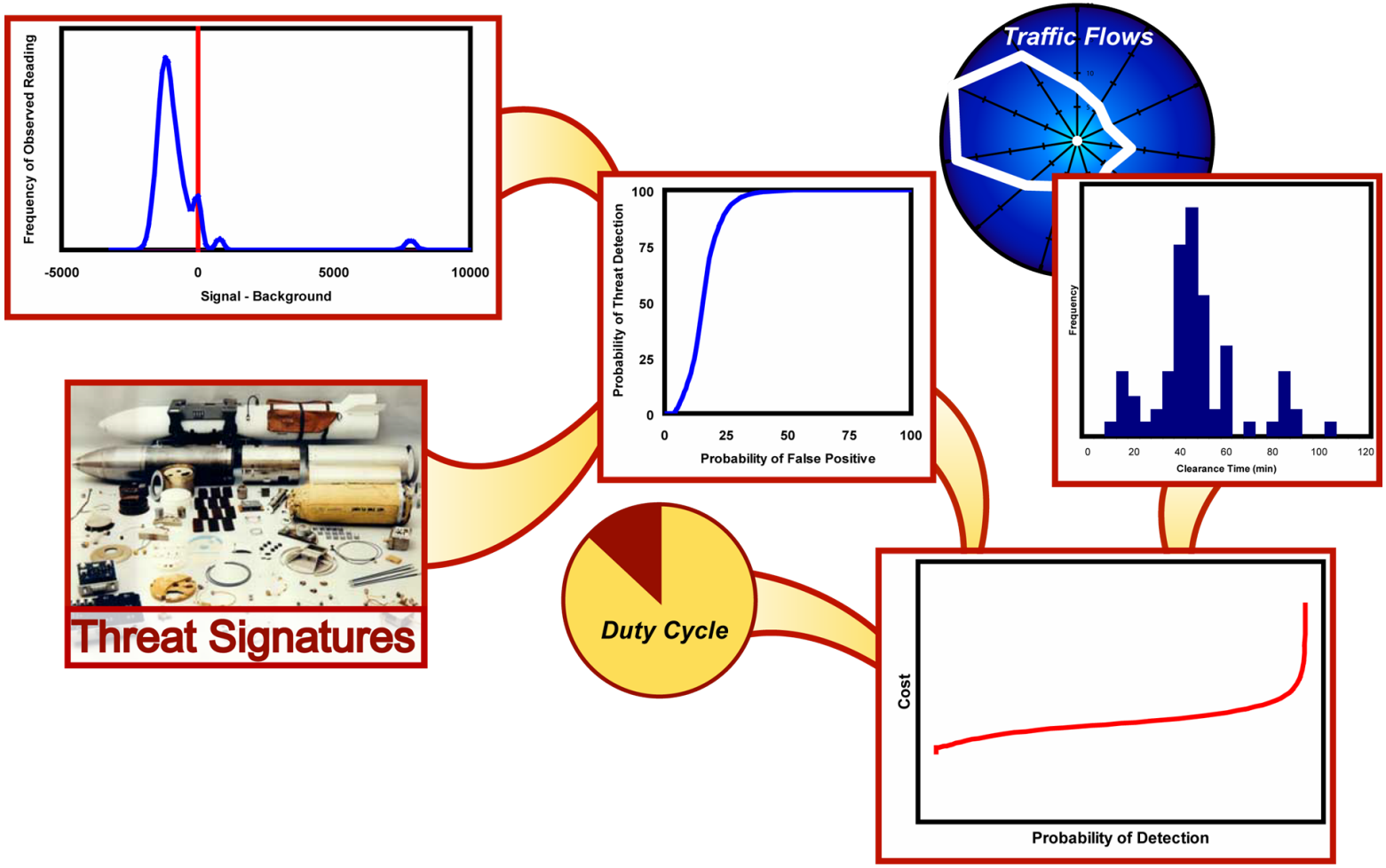
Risky materials need to be secured

Stopping threats

How do you detect the threat effectively?



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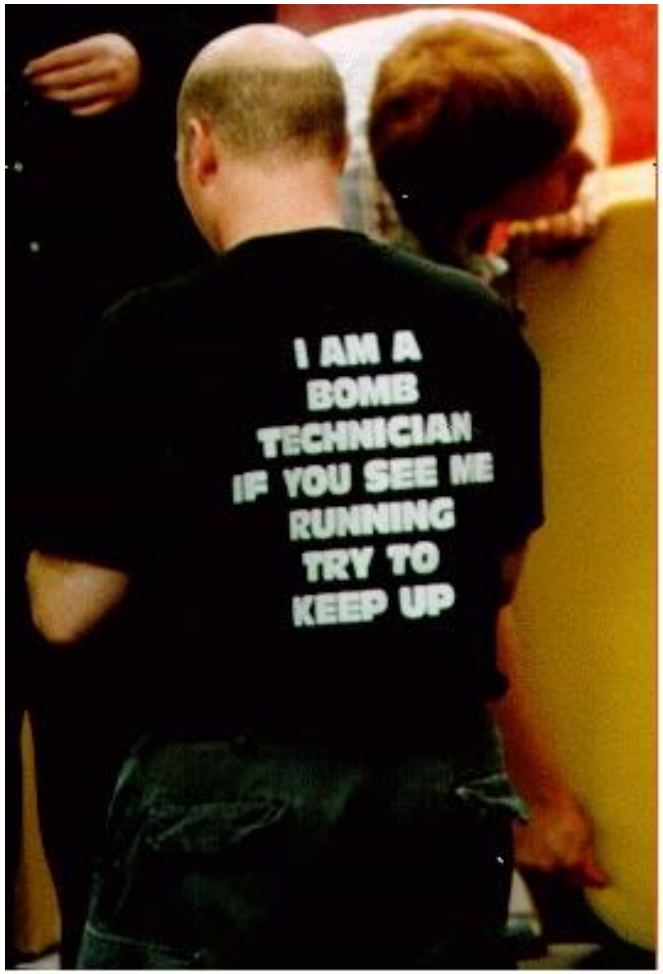
What if we find a bomb?



Emergency response systems have a tough job…

Answering "who did it?"

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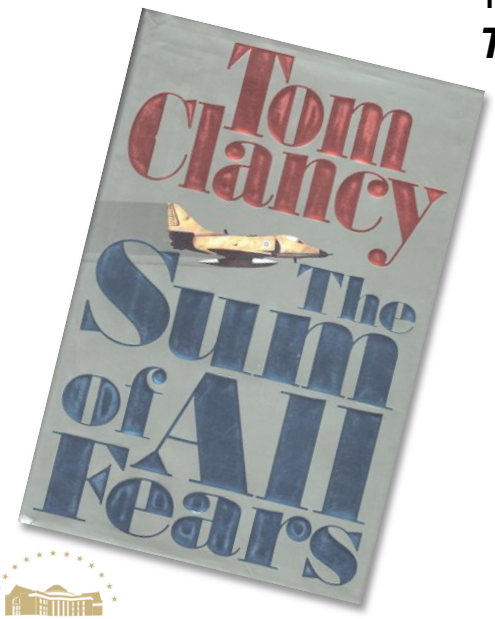
Popular media fosters misperceptions

"Get the book!"

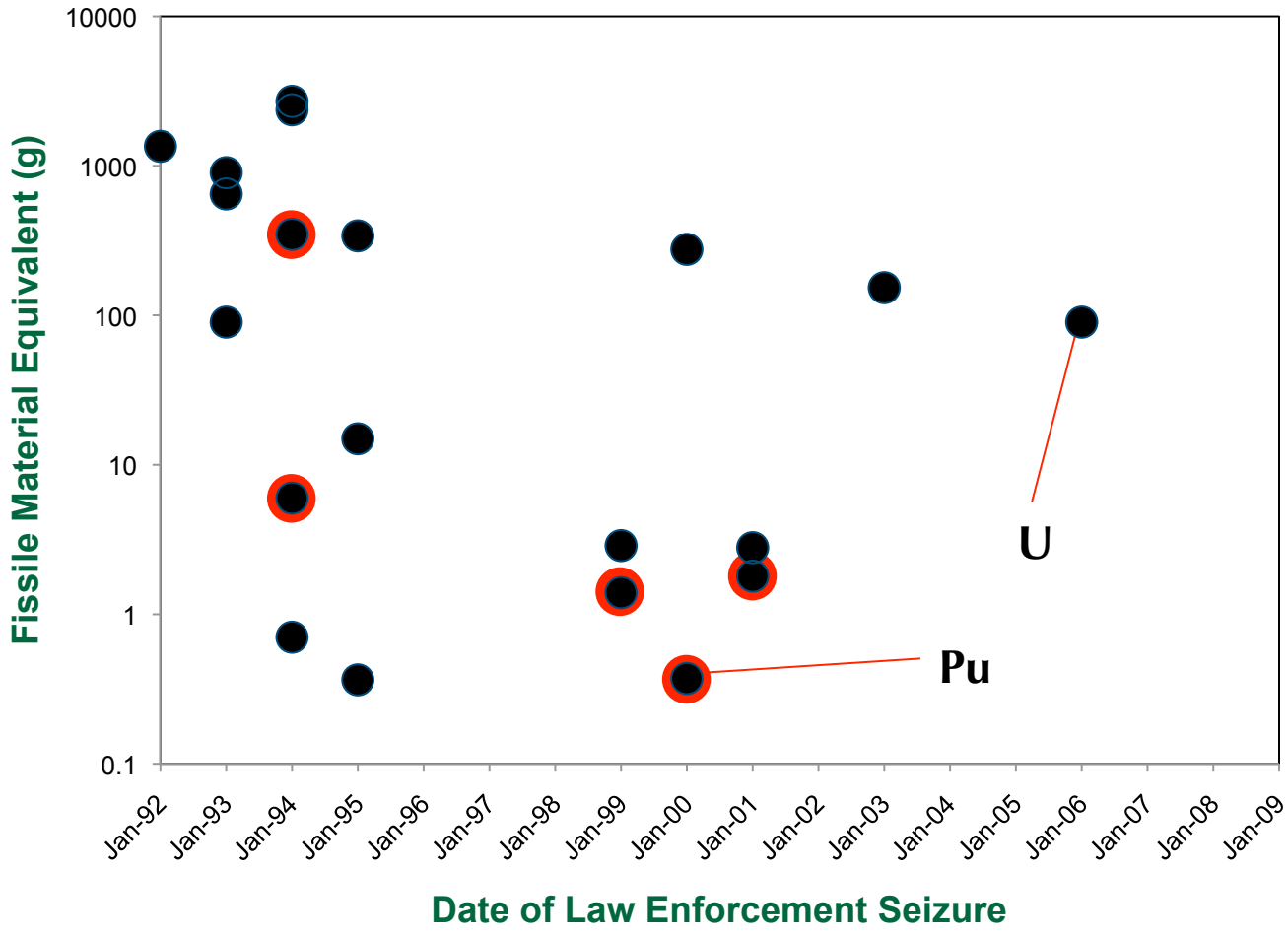
Sitting on the shelf opposite the spectrometer was a three-inch binder of red vinyl.

"Savannah River," the technician said. "They've always had that gadolinium problem…

- Tom Clancy,
  The Sum of All Fears



SNM has been found on the black market



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And yet again…

Global Security Newswire by National Journal Group

Daily news on nuclear, biological and chemical weapons, terrorism and related issues.

Georgia Prevented Illicit HEU Sale, President Says

Wednesday, April 14, 2010

Georgian President Mikheil Saakashvili said yesterday authorities in his nation last month seized weapon-grade uranium intended to be traded through the black market, the London *Guardian* reported (see ***GSN***, Feb. 27, 2009).

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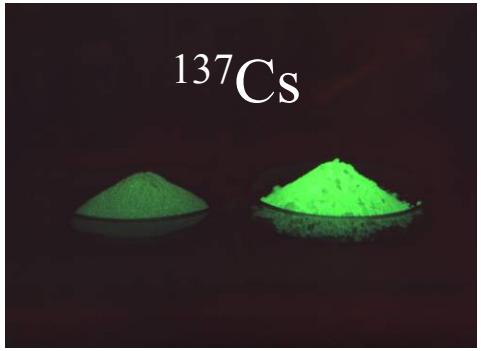
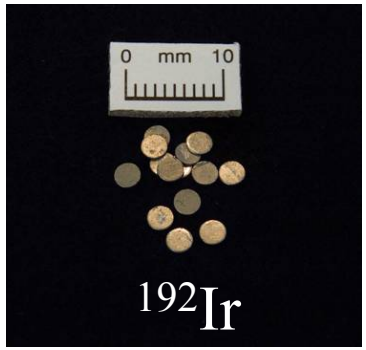
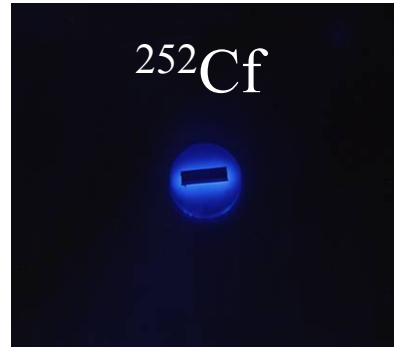
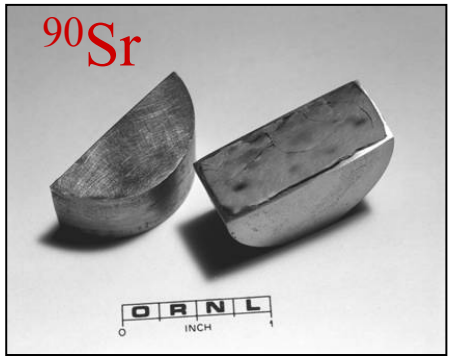
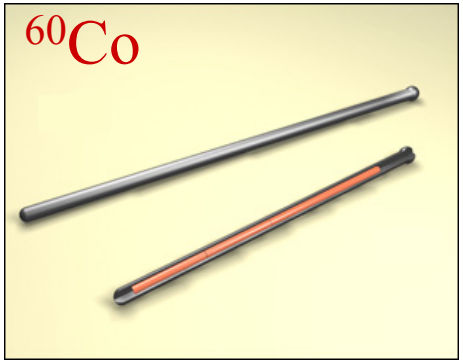
Isotopes of greatest concern

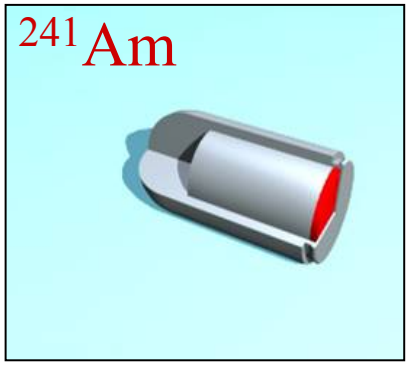


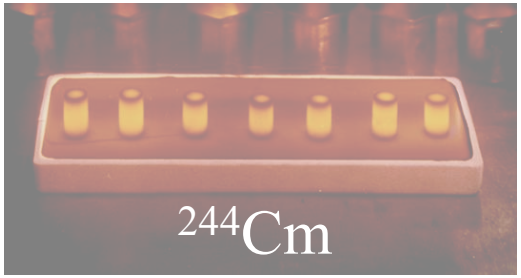


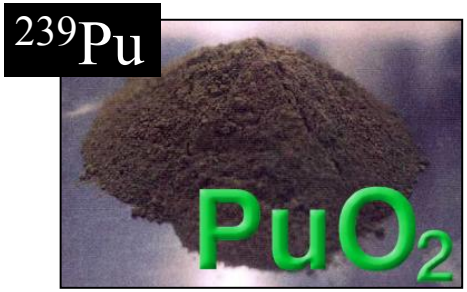


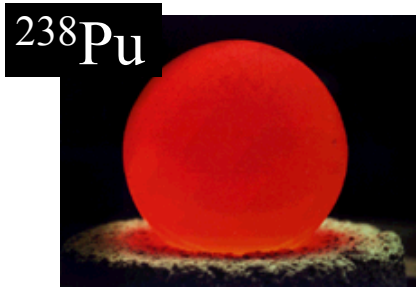






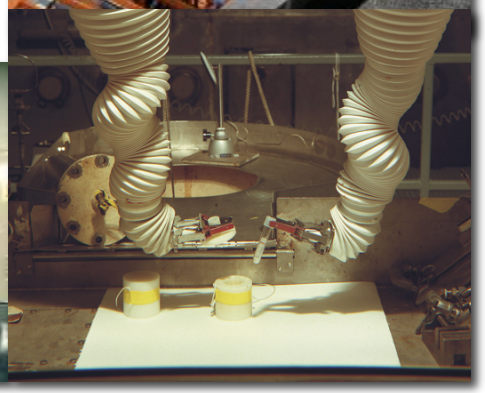






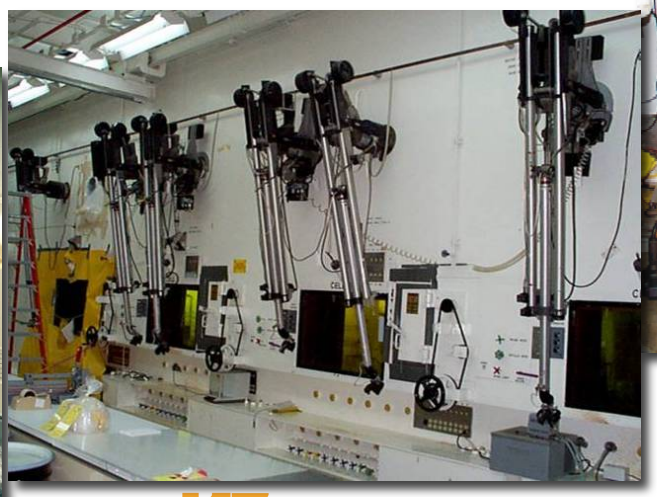
Complex analyses *and* radioactive too

- Package imaging
- Bulk analysis (mass, specific activity, etc.)
- Verify major radioisotope and minor (gamma spectroscopy)
- Subsampling for laboratory analysis
- Transfer to laboratories for detailed analysis

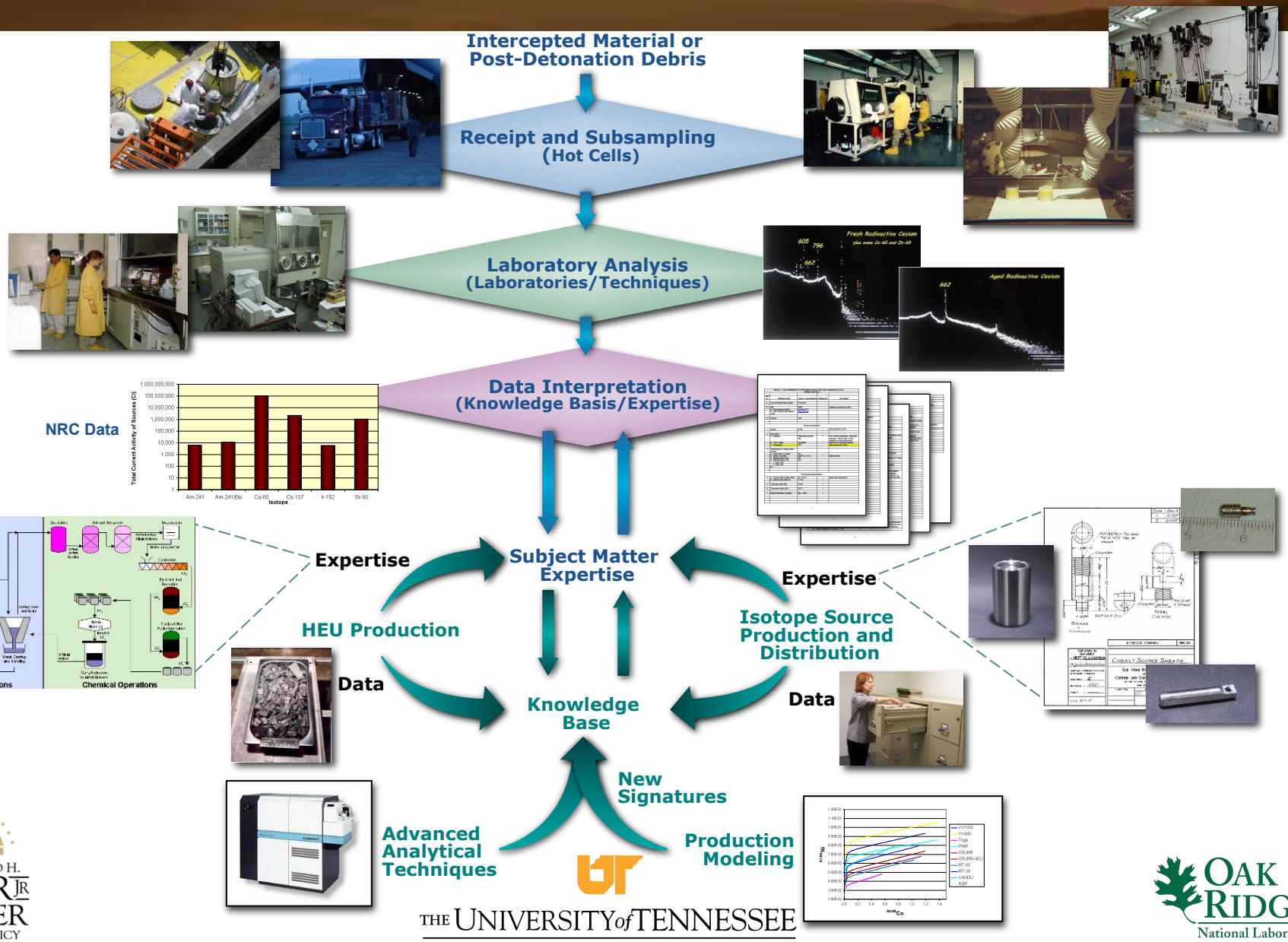


ORNL hot cells and glovebox facilities

- Analytical Chemistry Lab - to receive and prepare beta-gamma emitting radioisotopes (^{60}Co, ^{137}Cs, ^{192}Ir, ^{90}Sr, etc.) and to conduct a full spectrum of analyses
- REDC – to receive and prepare actinide (alpha and neutron emitters) radioisotopes (^{241}Am, ^{252}Cf, ^{244}Cm, ^{210}Po, ^{238}Pu, ^{239}Pu, ^{235}U, etc.)
- Fuels Examination Lab – metallurgical analysis of spent fuel and large sources



ORNL Nuclear/Radiological Forensics Science Programs



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Improving our resiliency

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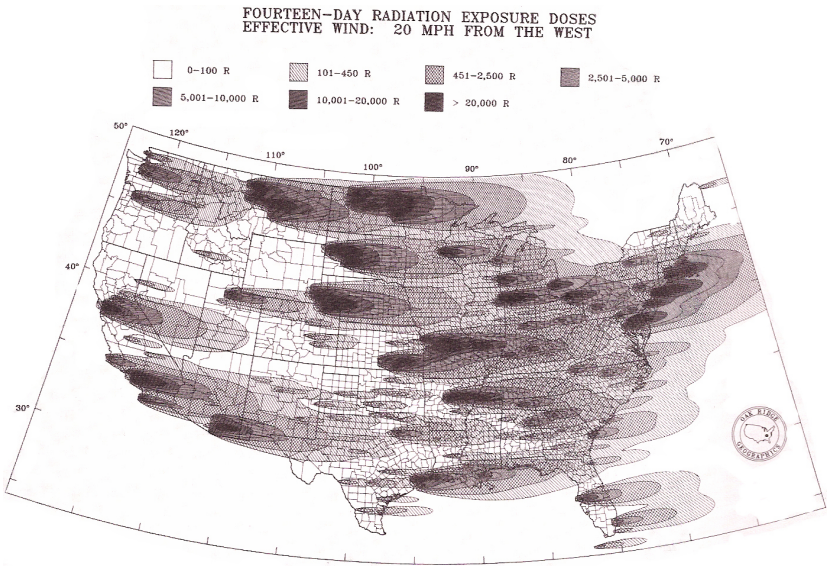
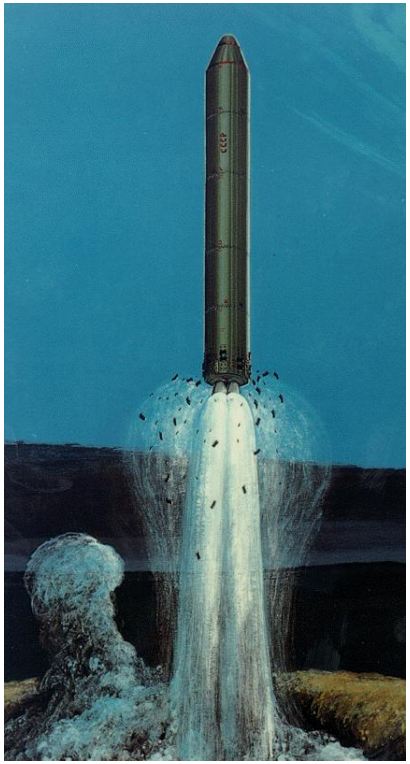
Respond to reduce loss of life

- Cold War perceptions shape nuclear explosion responses
- Nuclear terrorism scenarios are a different beast



National Council on Radiation Protection and Measurements, 1982



Soviet/Russian SS-18 "SATAN" missile with 20 MT warhead

FAS; and Norris and Kristensen, Bull. Atomic Sci. (2009)

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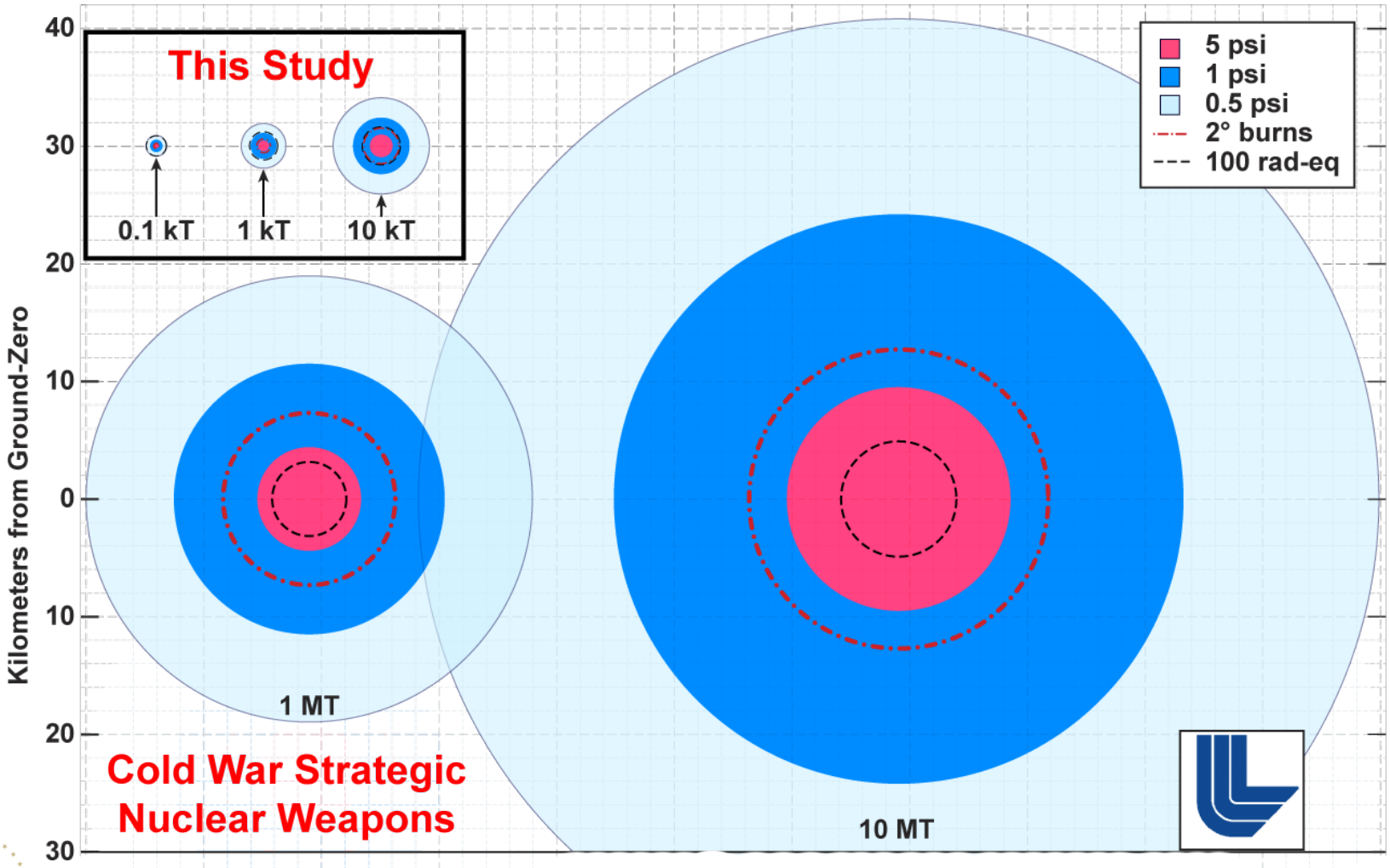
The terrorist nuclear device is expected to be low yield



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Avoiding fallout saves thousands or more

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Clean up and recovery…

Before, during, and after

Staying the course -- sustainability

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Tomorrow, how do we…

…measure, track, secure, and monitor strategic materials and weapons?

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Global efforts in nuclear security: *All depend on people*

- Education is the critical underpinning to ***sustain*** our abilities and meet the needs of the future
- An effective security framework requires:
  - Scientific and technical disciplines
  - Medical and health sciences, social sciences, humanities, and law
  - Policy and law, diplomacy
  - Civilian, military, intelligence, and NGO commitment

East Tennessee has a long history in things nuclear

Photo by Ed Westcott

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Significant events in nuclear history in Tennessee

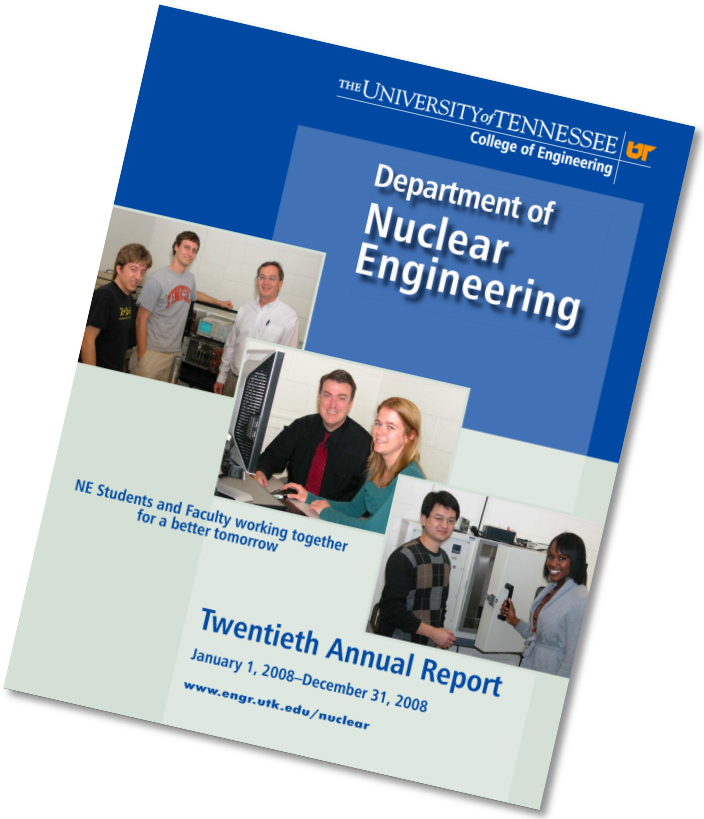
- February 18, 1942 – Ground broken for first calutron building in Oak Ridge
- December, 1942 – Ground broken for the ORNL Graphite Reactor
- 5 AM, November 4, 1943 – the Graphite Reactor goes critical
- January, 1944 – First reactor-produced plutonium isolated
- March, 1944 – First enriched uranium shipped to Los Alamos

Selected events in the birth of U.S. nuclear engineering

- 1946 – the Clinton Training School
  - A collaboration of ORNL, UT, and MIT
  - "Clinch College of Nuclear Knowledge"
  - Transitioned to ORSORT
- Oak Ridge Institute of Nuclear Studies
  - Biological applications, tracers
- Oak Ridge School of Reactor Technology (ORSORT)
  - Classified applications of nuclear science for military uses
  - AEC focused
  - "Doctor of Pile Engineering," or D.O.P.E.'s
- "Atoms for Peace" created opportunities for academic programs

Nuclear Engineering at UT

- Department (undergraduate and graduate degrees) established 1957
- Over 1000 graduates to date
- Top-ranked department in the College of Engineering at UT
  - Most R&D productivity
  - Student scholarships and awards average $5,165 (2008)
- Top 10 program



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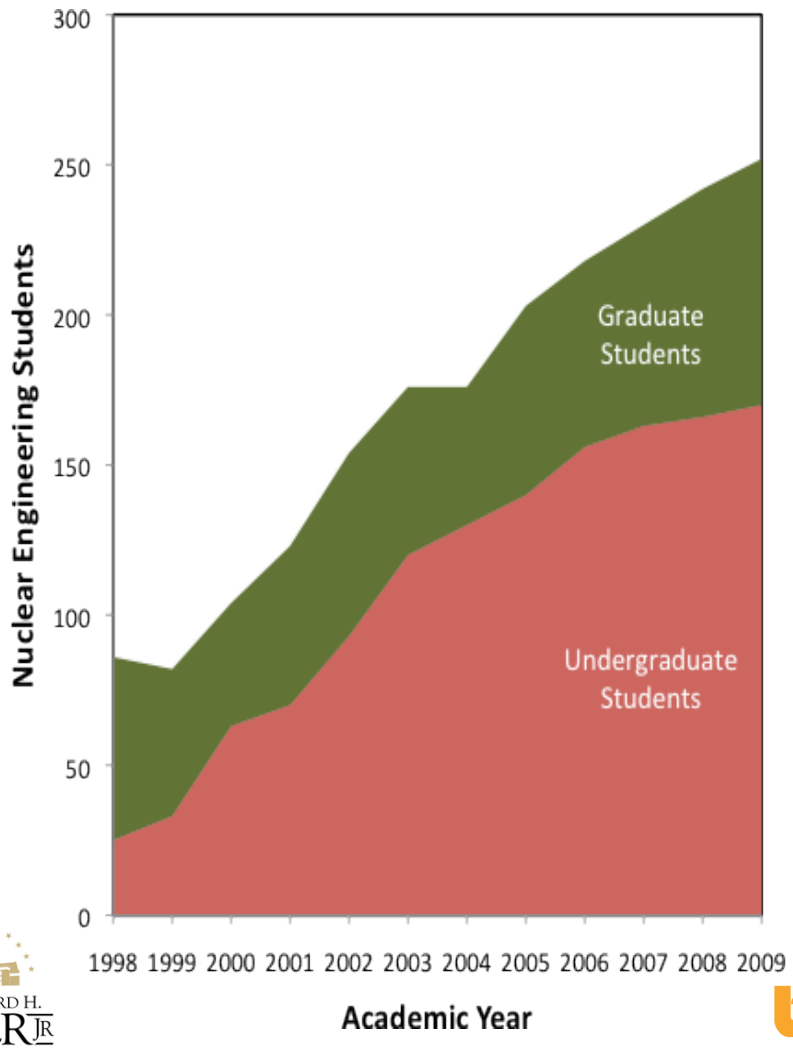
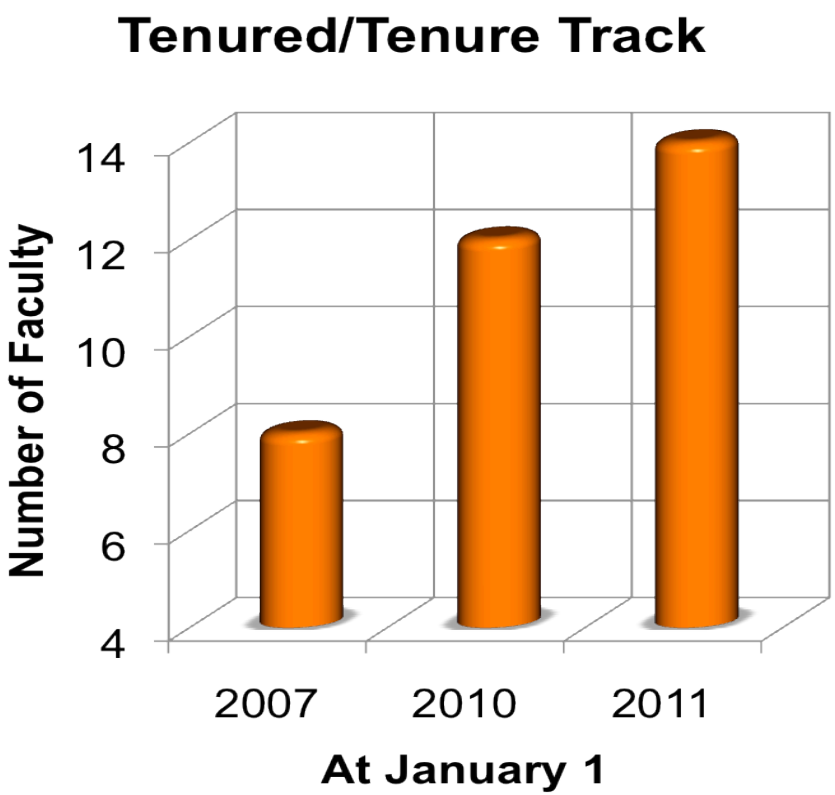
Growth in UT nuclear engineering





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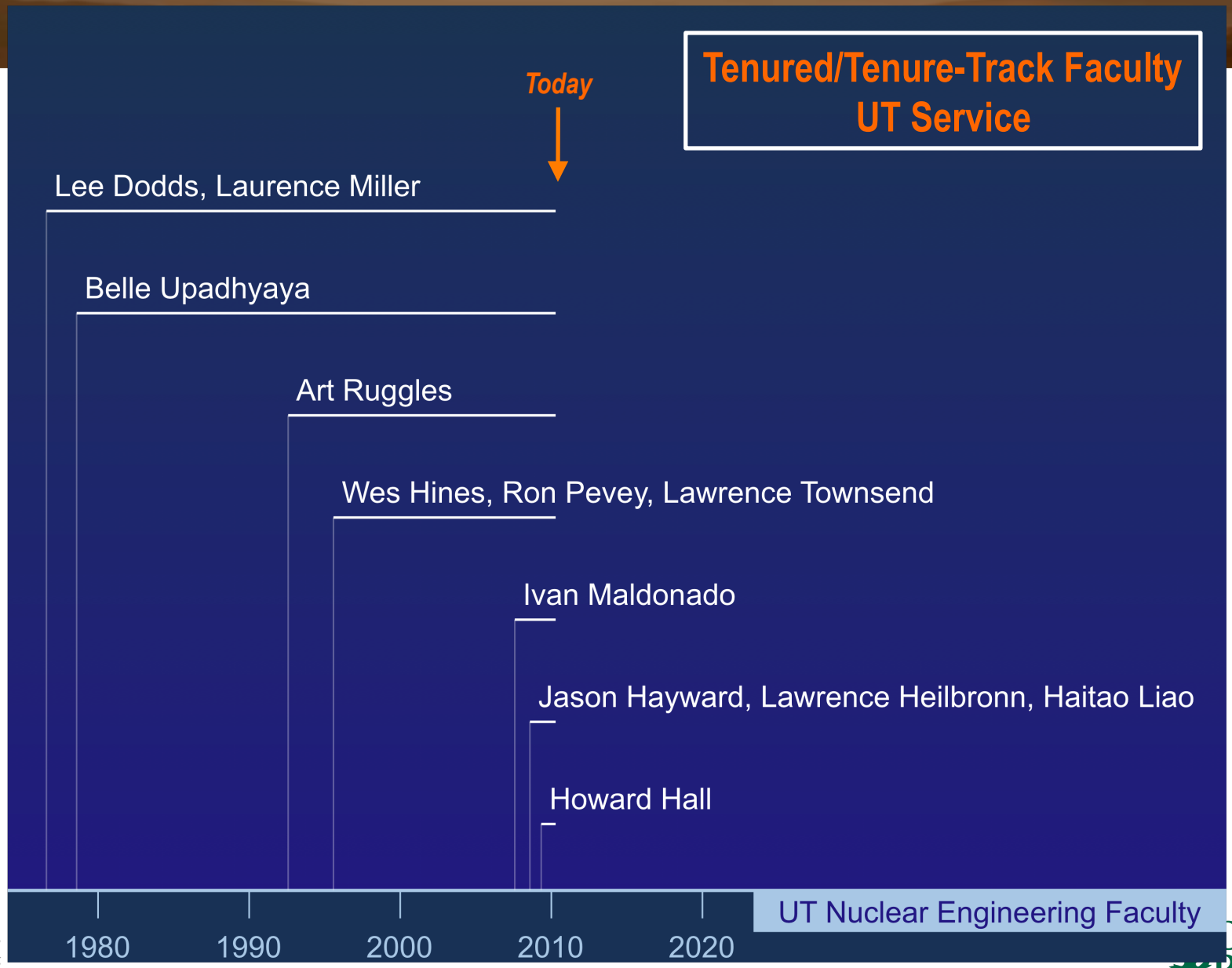
Tenured/Tenure-Track Faculty
UT Service
Today
Lee Dodds, Laurence Miller
Belle Upadhyaya
Art Ruggles
Wes Hines, Ron Pevey, Lawrence Townsend
Ivan Maldonado
Jason Hayward, Lawrence Heilbronn, Haitao Liao
Howard Hall
UT Nuclear Engineering Faculty
1980
1990
2000
2010
2020

The UTNE Nuclear Security Certificate

- Currently part of our Master's degree track
- "Hits the catalog" this fall
- Earned by taking 4 out of the following 6 courses:
  - NE 530 (Nuclear Security Science and Analysis)
  - NE 404 (Nuclear Fuel Cycle)
  - NE 433 (Health physics) *or* NE 470 (Nuclear Reactor Theory I)
  - NE 550 (Radiation Measurements Laboratory)
  - NE 532 (Advanced Topics in Nuclear Security Science and Analysis)
  - Political Science 688 (Seminar on Arms, Arms Control, and Nuclear Non-proliferation)

Hands-on learning at ORNL and Y-12

- Undergraduate and graduate radiation measurements classes typically spend several weeks in the ORNL Safeguards Lab
- NE530 Red/Blue exercise is table-topped at Y-12 National Security Complex
- Collaborative education and graduate research training with ORNL and Y-12 continues to grow

The UT Political Science Department Nuclear Security Certificate

- Nuclear Engineering, Political Science, and the Baker Center are collaborating on this new certificate program
- Expected to be available Fall 2011

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