Proliferation-Resistance (and Terror-Resistance) of Nuclear Energy Systems

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What is proliferation resistance?

- Definition:

A nuclear energy system is *proliferation-resistant* if its deployment and use, on the scale and with the distribution envisioned by proponents, would not significantly increase the probability of proliferation of nuclear weapons.

  - Considering the full system life cycle (including all aspects of the fuel cycle)
  - Considering both *intrinsic* factors (e.g., difficulty of producing weapons material from material and facilities used in the system) and *extrinsic* factors (e.g., types of safeguards and security measures to be applied)

Proliferation resistance rule of thumb

- Ask yourself: Would the U.S. (and Israeli) governments be comfortable if it was this system, rather than a once-through LWR under international safeguards, that Russia was building in Iran?

If *yes*, system is clearly "proliferation-resistant."

If *no*, there may still be aspects to be debated.

(More on this case and its implications in a moment.)

Proliferation-resistance: neither side of the nuclear debate much interested

- Pro-nuclear view:
  - Existing safeguards provide sufficient protection against use of civilian nuclear energy for weapons – no country has ever used safeguarded nuclear material to make a bomb
  - Proliferation is a political issue, not a technical one – countries that are determined to get nuclear weapons will eventually do so, regardless of technology of civilian nuclear energy system
- Anti-nuclear view:
  - *All* nuclear energy systems pose proliferation risks – relying on enrichment, producing plutonium (or at least producing neutrons that could be used to produce plutonium)
  - These dangers cannot be substantially reduced without abandoning nuclear energy
- A middle view:
  - Real nuclear energy contribution to spread of nuclear weapons can be reduced substantially by technical and institutional measures

Proliferation-resistance: one key to acceptable nuclear energy expansion

- Civilian nuclear energy system has already made major contributions to spread of nuclear weapons
- To make a major contribution to meeting 21st century carbon-free energy needs, nuclear would have to grow 3-10 times over next 50-100 yrs (*Future of Nuclear Power*, MIT, 2003) – most new electricity demand is in developing world
- Governments and publics unlikely to accept such a massive nuclear expansion *unless* convinced that the expansion will *not* lead to additional spread of nuclear weapons
- How can nuclear energy be greatly expanded, deployed far more widely, without contributing to weapons programs – significant focus of current R&D (esp. GNEP)?
- Cost, safety, waste management must also be addressed for large expansion to be acceptable

Nuclear energy and proliferation

- Most nuclear weapons programs since civilian nuclear energy became widely established have had crucial contributions from the civilian sector
- Most programs: dedicated military production facilities for Pu or HEU, but civilian sector provided:
  - source for open or covert technology acquisition
  - "cover" for purchases actually intended for weapons program
  - buildup of infrastructure and expertise
- A few programs: Pu or HEU directly from ostensibly civilian facilities -- or consideration of purchase of stolen fissile material

Case I: Iraq

- Iraq purchased the "Osiraq" research reactor from France – Israel destroyed it in an airstrike, so it could not be used to produce plutonium
- Pre-1991, Iraq was an NPT member in good standing
- Nuclear experts trained in U.S. and Europe – Iraqis sent to work at IAEA to learn how to evade inspections
- Iraq had a massive secret nuclear weapons program – with a huge web of procurement agents and front companies to buy technology illegally from sources around the world (for example centrifuge technology from civil programs in Europe)
- After invading Kuwait, Iraq launched a "crash program" to build one bomb using French-supplied and Soviet-supplied HEU fuel for its safeguarded civilian research reactors

Case II: Iran

- Iran started both an open civilian nuclear power program and a secret nuclear weapons program under the Shah – both were dormant for a period after 1979 revolution
- Large numbers of nuclear experts trained in U.S. and Europe (esp. MIT) in pre-revolutionary period
- In mid-1990s, Russia agreed to complete a power reactor the Germans had begun at Bushehr – throughout 1990s, U.S.-Russian disagreements over this deal and more sensitive transfers – 100s of experts trained in Russia
- We now know that Iran was receiving centrifuge technology from the AQ Khan network – technology that originated in Urenco – with components from all over the world – in 2002, Iran's Natanz enrichment facility revealed

Case II: Iran (II)

- Iran has always claimed that its program is entirely for peaceful purposes – using the civilian program as a cover for technology purchases and facility construction whose weapons purpose would otherwise be obvious
- Iran has remained within the NPT, but violated its safeguards agreement by lying to the IAEA for decades
- U.S. and Europe have argued that enrichment in Iran would bring Iran too close to a nuclear weapons capability – UN Security Council has legally required Iran to suspend
- In the 1990s, U.S. sought to cut off *all* civilian nuclear cooperation with Iran, arguing that any such cooperation will contribute to a bomb program – Russia and Europe did not agree
- Controversy continues – not clear which way it will go

Case III: India

- India's civilian and military nuclear programs have been deeply integrated from their inception
- Large numbers of nuclear experts trained in U.S. and Europe
- India received a Canadian research reactor (CIRUS), with U.S. heavy water and training, provided with assurances of peaceful use – but no safeguards to verify assurances
- India built a reprocessing plant with a U.S.-provided design
- India used that reactor and plant to produce material for its "peaceful" nuclear explosion in 1974
- India has been under nuclear sanctions ever since, which prevent fuel sales, reactor sales, technology coop. – though new U.S.-India deal would lift these, if it goes through

Nuclear energy and proliferation: lessons from the cases

- In some cases, countries DO decide to make nuclear material in ostensibly civilian facilities (e.g., India), even facilities under safeguards (e.g., Iraq).
- In some cases, countries DO decide to use safeguarded weapons-usable material from their civilian program to make a bomb (e.g., Iraq).
- However, proliferation-resistance is NOT just about avoiding having separated plutonium or HEU in the cycle. Civilian programs also provide:
  - Source for acquisition of technology (e.g., Iraq, Iran, India)
  - Cover for building facilities whose military intent would otherwise be obvious (e.g., Iranian centrifuge plant)
  - Facilities that can later be turned to weapons production (same)
  - Buildup of core of nuclear experts that can later be turned to bomb program (e.g., Iranians being trained in Russia)

Proliferation-resistance: the wrong way to think about it

- Simple metrics based on characteristics of material in the fuel cycle, e.g.:
  - "I'll be OK if I have no pure separated plutonium"
  - "I'll be OK if the radiation field of the recycle material is more than *x* rem/hr at 1 m"
  - "I'll be OK if the Pu-239 content of the recycle material is less than *y* percent of total plutonium"
  - "I'll be OK if I make sure there's not step in the fuel cycle where the material could be used in a bomb without processing"
- Such simplistic approaches miss most of the real proliferation problem – but are amazingly common in current discussions of R&D for proliferation resistance

Proliferation-resistance: some better ways to think about it

- How might U.S. adoption of the technology *influence* other countries' adoption of sensitive technologies?
- By what percentage would access to the *material* in the proposed fuel cycle reduce the time and cost to produce weapons-usable material?
- By what percentage would access to the *facilities* and *technologies* used in the proposed fuel cycle reduce the time and cost to produce weapons-usable material? By what percentage might the difficulty of ensuring against *leakage of technology* increase or decrease if the proposed fuel cycle were implemented?
- By what percentage would access to the *experience* involved in operating the proposed fuel cycle reduce the time and cost to produce weapons-usable material?

Proliferation-resistance: some better ways to think about it (II)

- How many *people* with advanced nuclear training – who might also contribute to a weapons program – would be required in a country generating electricity using the proposed approach, to manage it safely and securely?
- By what percentage would the number of *inspection-days* per kW-hr generated increase or decrease in the proposed fuel cycle, compared to once-through LWRs? By what percentage would the *uncertainty* in meeting safeguards goals increase or decrease?
- Useful standard for comparison: better or worse than LWR once-through?

Example: pyroprocessing

- Idea: retain minor actinides, some lanthanides with Pu in recycling system
- Somewhat better than PUREX -- reduces the risk of terrorist theft and use in a weapon
- *But*, if widely deployed, would mean large number of states building up expertise, facilities, operational experience with chemical processing of intensely radioactive spent fuel, and with plutonium metallurgy -- could significantly reduce time and cost to go from there to nuclear weapons program
- Material much easier to get Pu from than LWR spent fuel
- Paying attention to expertise and infrastructure -- what history suggests is nuclear energy's biggest contribution to weapons programs -- can lead to different answers than focusing only on material characteristics

Example 2: Simple, lifetime core systems

- Various concepts for nearly "plug and play" reactors – possibly factory-built, with high inherent safety, shipped to a site, operated for 10-20 years without refueling, returned to factory
- Need for nuclear expertise in each state using such reactors might be greatly reduced
- High burnup (and difficult reprocessing) could make spent fuel unattractive (though not impossible) for weapons use
- Conceivable could have large-scale, widely distributed deployment with modest contribution to proliferation risk (mainly from availability of enrichment technology used to support reactors)
- Been pursued largely for economics and possibility of wide deployment, but proliferation-resistance interesting also

Proliferation hazards of spent fuel repositories

- Sometimes argued disposal of spent fuel of current types in repositories would create large long-term proliferation hazard – fuel will cool, higher Pu isotopes will decay, safeguards may someday not be maintained
- *But:*
  - Low-cost safeguards on repositories likely to be maintained as long as nuclear energy is in use anywhere – can set aside endowment now adequate to fund them forever
  - World will look very different, proliferation issues it faces will be very different, centuries from now
  - Should not increase large near-term risks (e.g., by separating plutonium into weapons-usable form) to decrease small and highly uncertain long-term risks
- Bottom line: if we could get to the point where Pu in spent fuel in repositories was biggest proliferation hazard remaining, would be a great victory

Proliferation hazards of the research infrastructure

- Proliferation impact of the civilian energy system does not come *only* from the power sector – research sector must be considered as well
- India made Pu for its bomb in research reactor; Iraq sought to use HEU from its research reactors for a bomb
- ~140 operating research reactors in >30 countries still use HEU as their fuel (MIT reactor uses ~12 kg of 93% enriched material in its core)
- Some have no more security than night watchman and chain-link fence
- 41 heavily armed terrorists who seized a theater and hundreds of hostages in Moscow in October 2002 reportedly considered seizing Kurchatov Institute – site with enough HEU for dozens of bombs

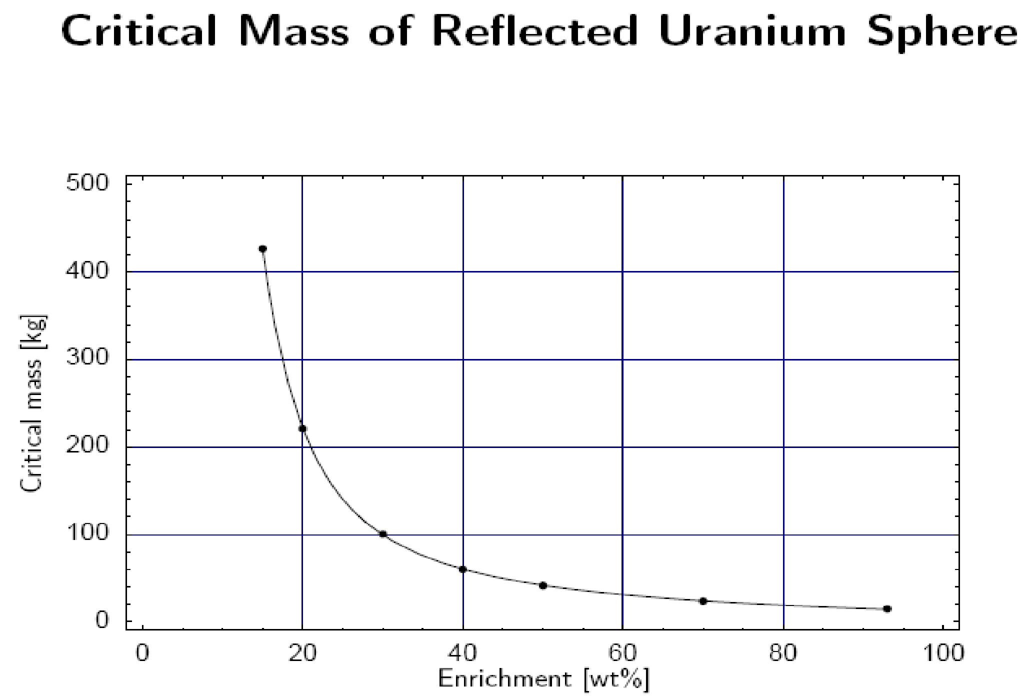
Reactor-grade plutonium is weapons-usable

- Higher neutron emission rate:
  - For Nagasaki-type design, even if neutron starts reaction at worst possible moment, "fizzle yield" is ~ 1kt – roughly 1/3 destruct radius of Hiroshima bomb – more neutrons won't reduce this
  - Some advanced designs are "pre-initiation proof"
- Higher heat emission:
  - Various ways to deal with – for example, plutonium component can be inserted into weapon just before use (as in early U.S. designs)
- Higher radiation:
  - Can be addressed with greater shielding for fabrication facility
  - Last-minute insertion of plutonium component again
- *Reactor-grade plutonium is <u>not</u> the <u>preferred</u> material for weapons, but any state or group that can make a bomb from weapon-grade plutonium can make one from reactor-grade*

Reactor-grade plutonium is weapons-usable (II)

- "Virtually any combination of plutonium isotopes -- the different forms of an element having different numbers of neutrons in their nuclei -- can be used to make a nuclear weapon... At the lowest level of sophistication, a potential proliferating state or subnational group using designs and technologies no more sophisticated than those used in first-generation nuclear weapons could build a nuclear weapon from reactor-grade plutonium that would have an assured, reliable yield of one or a few kilotons (and a probable yield significantly higher than that). At the other end of the spectrum, advanced nuclear weapon states such as the United States and Russia, using modern designs, could produce weapons from reactor-grade plutonium having reliable explosive yields, weight, and other characteristics generally comparable to those of weapons made from weapons-grade plutonium.... Proliferating states using designs of intermediate sophistication could produce weapons with assured yields substantially higher than the kiloton-range possible with a simple, first-generation nuclear device."
  - *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives* (Washington, DC: DOE, January 1997)

HEU at far below "weapon-grade" is weapons-usable



Critical mass of a beryllium-reflected uranium sphere as a function of the uranium-235 enrichment in weight percent (wt%). MCNP 4B simulations at 300 K. Reflector thickness is 10 cm.

Source: Alexander Glaser, Science & Global Security, 2002

Properties of key nuclear explosive isotopes

Isotope	Critical Mass (kg)	Half Life (years)	Decay Heat (watts/kg)	Neutron Generation (neutrons/g-sec)
U-233	15	160,000	0.3	0.0009
U-235	50	700,000,000	0.0001	0.00001
Pu-239	10	24,000	1.9	0.02
Pu-240	40	6,600	6.8	900
Pa-231	162	32,800	1.3	0
Np-237	59	$2.1x10^6$	0.021	0.00014
Am-241	57	430	110	1.2
Am-242m	9-18 kg	141	n.a.	$5.8x10^7$
Am-243	155	7,380	6.4	.9
Cm-245	13	8,500	5.7	147
Cm-246	84	4,700	10	$9\ x10^6$
Bk-247	10	1,400	36	0
Cf-251	9	898	56	0

Source:“Annex: Attributes of Proliferation Resistance for Civilian Nuclear Power Systems” in Technological Opportunities to Increase the Proliferation Resistance of Global Nuclear Power Systems (TOPS) *(Washington, D.C.: U.S. Department of Energy, Nuclear Energy Research Advisory Committee, 2000, available at http://www.nuclear.gov/nerac/FinalTOPSRptAnnex.pdf as of 9 January 2007), p. 4, with corrections and additions from “Chart of Nuclides” (Upton, N.Y.: Brookhaven National Laboratory), and David Albright and Lauren Barbour, “Troubles Tomorrow? Separated Neptunium-237 and Americium,” in David Albright and Kevin O’Neill, eds.* The Challenges of Fissile Material Control, *(Washington, DC: Institute for Science and International Security, 1999)*

International control

- International control and ownership (as opposed to just verification) of all sensitive operations – e.g., enrichment, reprocessing, fabrication and use of Pu fuels – could increase the political barrier to withdrawing from the regime, using the material or facility for weapons program
- Host state *could*, in principle, still seize material or facility
- Would not prevent covert facilities – though international staff might notice if experts disappearing for days
- Would have only modest impact on problem of build-up of expertise, infrastructure for weapons program
- High political barriers to implementing this approach; dates back to Acheson-Lillienthal (concluded "unanimously" that security could not rest on verification of nationally-controlled nuclear activities alone)

Giving states incentives not to build enrichment and reprocessing

- Article IV of the NPT guarantees all parties access to civilian nuclear technologies
- Each party allowed to build enrichment and reprocessing facilities, even produce HEU and Pu, as long as under safeguards – come right up to the edge of a weapons capability while staying within the regime
- Iran case demonstrates the dangers
- Government-backed commercial consortium could offer a "new deal":
  - Guaranteed lifetime fuel supply and spent fuel management to any state that agrees no enrichment, no reprocessing of their own – and Additional Protocol to confirm that commitment
  - Some states would say "yes" – those that said "no" would immediately be the focus of international concern
  - Similar idea proposed in Bush speech 2/04, being worked

The dominance of economics

- In countries around the world, electricity is being wholly or partly deregulated, becoming more competitive, decisions on what plants to build increasingly in private hands
- Historical record indicates that except (possibly) for requiring more guards or safeguards inspectors, governments will *not* force private industry to adopt more expensive approaches to improve proliferation resistance
- Hence, a proliferation-resistant system is *only* likely to be broadly adopted if it is *also* the most economic – "how much more are we willing to pay for proliferation resistance?" is the *wrong question*
- New system must be *very* widely adopted to reduce global proliferation risk (building such systems in United States but not elsewhere would not help much)

Steps to reduce proliferation impact of the civilian nuclear energy system

- Reduce demand
  - More successful than often realized: e.g., Sweden, Italy, Argentina, Brazil, S. Africa, S. Korea, Taiwan…
- Secure all nuclear materials and facilities
- Minimize spread of sensitive facilities/activities
  - Including by providing assured fuel cycle supply
- Beef up controls on technology transfers
- Strengthen verification (safeguards)
- Establish international ownership, control of key facilities
- Improve technical proliferation-resistance

Terrorism-resistance

- 1st priority in terrorism-resistance is ensuring potential nuclear bomb material cannot fall into terrorist hands – minimize use of separated Pu and HEU, provide stringent security for stocks that continue to exist
- 2nd priority is protection from catastrophic sabotage:
  - Terrorist attack will clearly be a factor utilities, publics, governments consider in choosing energy options
  - Strengthens case for “inherently safe” systems
  - Designs must ensure against catastrophic release BOTH in the event of external attacks AND internal sabotage (harder problem)
  - External attack could include:
    - Groups of armed terrorists attacking by land, boat, or helicopter
    - Truck bombs, boat bombs
    - Large aircraft crashes
    - Small aircraft packed with explosives

Terrorism-resistance (II)

- Most civilian nuclear facilities worldwide (and even some military facilities) are not secured against demonstrated terrorist and criminal threats:
  - 9/11: 4 teams of 4-5 well-trained, suicidal terrorists each, striking without warning, from group with access to heavy infantry weapons and sophisticated explosives
  - 10/02, Moscow: 41 well-trained, suicidal terrorists, with automatic weapons and explosives, striking without warning
  - Crimes all over the world: multiple insiders conspiring together
- Nuclear material theft leading to a terrorist bomb anywhere in the world would be a disaster for the nuclear industry going far beyond Chernobyl – successful nuclear sabotage with Chernobyl-scale effects would also be a disaster
- Nuclear industry, in its own self-interest, should work to make sure all facilities are secure – as they have with safety

Nuclear facility and material security

- Designed to detect, deter, and prevent *theft* of material, or *sabotage* of facilities by unauthorized insiders or outsiders (not *diversion* by the host state – that's what international safeguards do)
- Physical protection:
  - Designed to detect, slow, and interdict any theft or sabotage attempt
  - Fences, alarms, access control, locked vaults, response forces
- Material control:
  - Designed to monitor and control material in real time
  - Cameras, seals, tags, alarms, two-person rule
- Material accountancy:
  - Designed to reveal thefts after they occur, or confirm that they have not occurred (and to support international safeguards)
- Nuclear safety systems make sabotage more difficult

A systems engineering approach similar to that used for nuclear safety…

- Step 1: Define actions to be prevented (theft, sabotage), vital targets to be protected
- Step 2: Define *design basis threat* (DBT) to be protected against (comparable to design basis accidents)
- Step 3: Assess vulnerability of existing security arrangements to DBT – identify adversary tactics most likely to succeed (worst vulnerabilities)
- Step 4: Design and implement upgraded security system having high probability of defeating DBT
- Step 5: Operate and maintain upgraded system
- Step 6: Regularly re-assess (and test) vulnerability, implement improvements as needed

The threat of nuclear theft

- Well-organized terrorist group could plausibly make at least crude nuclear explosive if they had enough HEU or plutonium – most states could do so
- Hundreds of tons of weapons-usable nuclear material in dozens of states, with widely varying levels of security
- Particularly urgent problem in the former Soviet Union—but insecure material in dozens of other countries as well
- IAEA has 15 documented cases of seizure of stolen HEU or plutonium in last fifteen years
- Potential bomb material could fall into the hands of a terrorist group or hostile state at any time

The threat of nuclear sabotage

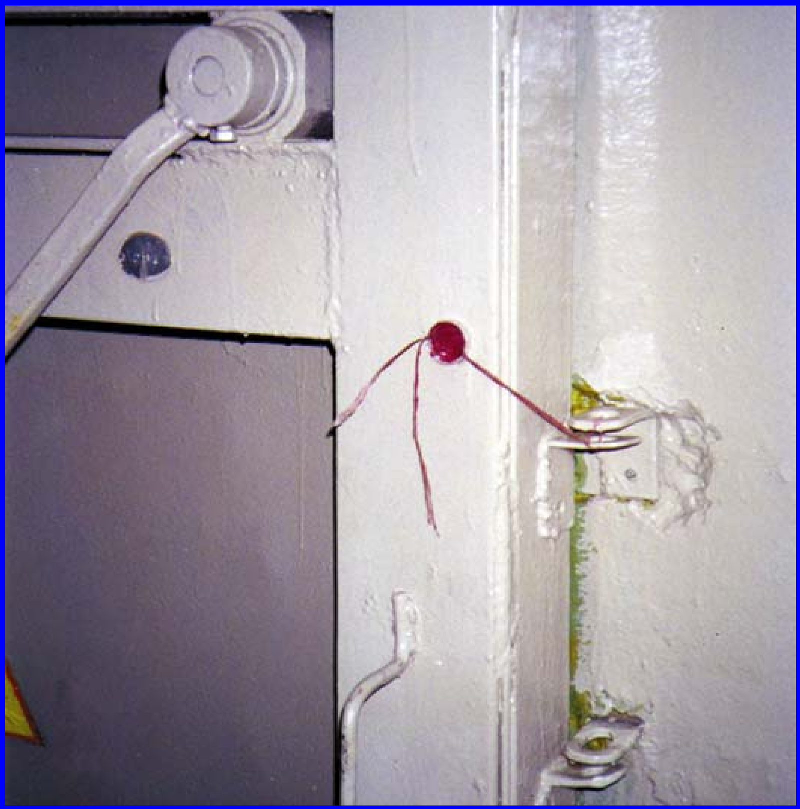
- While most nuclear power plants reasonably well-protected, sabotage remains a key issue – probably higher probability of catastrophic release from sabotage than from pure accident
- "Security Chernobyl" would cause immense damage – and put an end to any prospect for large-scale nuclear growth to cope with climate change
- Sabotage danger *does* increase substantially with larger numbers of plants
- Strengthens case for design emphasis on "inherent safety"
- Industry, in its own self-interest, needs to launch major effort to bring the worst security performers up to the level of the best performers – as they have with safety

Securing nuclear stockpiles -- a global problem

- Thousands of tons of weapons-usable nuclear material exist in hundreds of buildings in more than 40 countries worldwide
- Security ranges from excellent to appalling -- no binding global standards in place
- ~140 operational research reactors fueled with HEU in >30 countries – most with modest security
- Pakistan: small nuclear stockpile, heavily guarded – but huge threats, outsider and insider
- Russia has world’s largest stocks, still in transition from Soviet security system not designed for open society with open borders – other Eurasian states have little experience, few resources, for guarding nuclear materials

Moscow building with enough HEU for a bomb -- 1994

Ineffective padlocks and seals for nuclear material in Russia

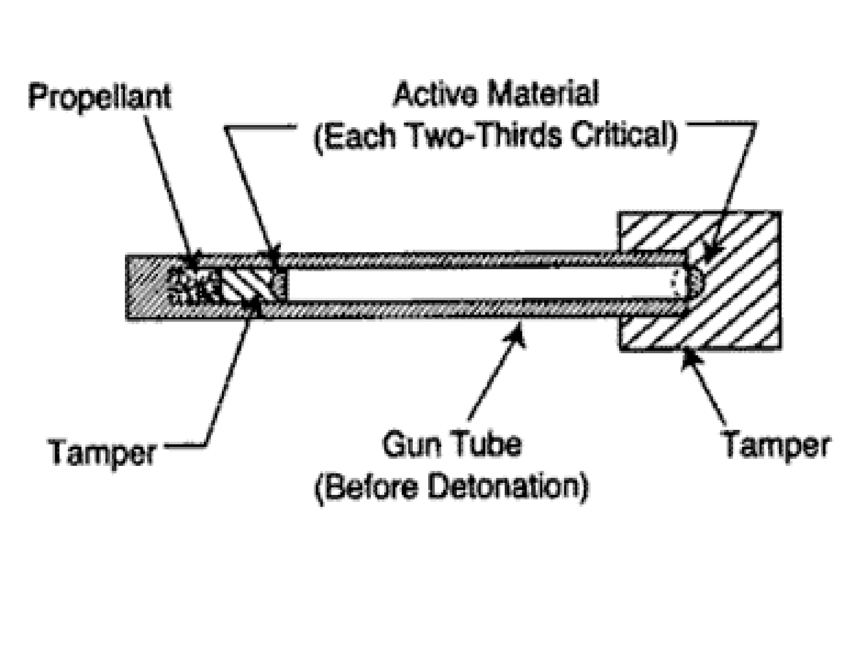


The threat in Russia today

- Russia is a different place today than 10 years ago – economy has stabilized; government in firmer control; nuclear workers paid a living wage, on time
- Nuclear security at most facilities *dramatically* improved – 1990s incidents of 1 insider or outsider stealing without detection would generally not be possible now
- *But:*
  - Resources devoted to nuclear security remain *far* below what is needed (Moscow MVD chief: only 7 of 39 critical guarded facilities in Moscow district have adequate security systems in place)
  - “Security culture” issues – e.g., guards patrolling without ammo
  - Massive corruption, sophisticated insider theft conspiracies
  - Huge terrorist attacks (30-100 heavily armed attackers)
  - Confirmed terrorist reconnaissance on nuclear warhead sites
  - Businessman offering $750,000 for stolen plutonium

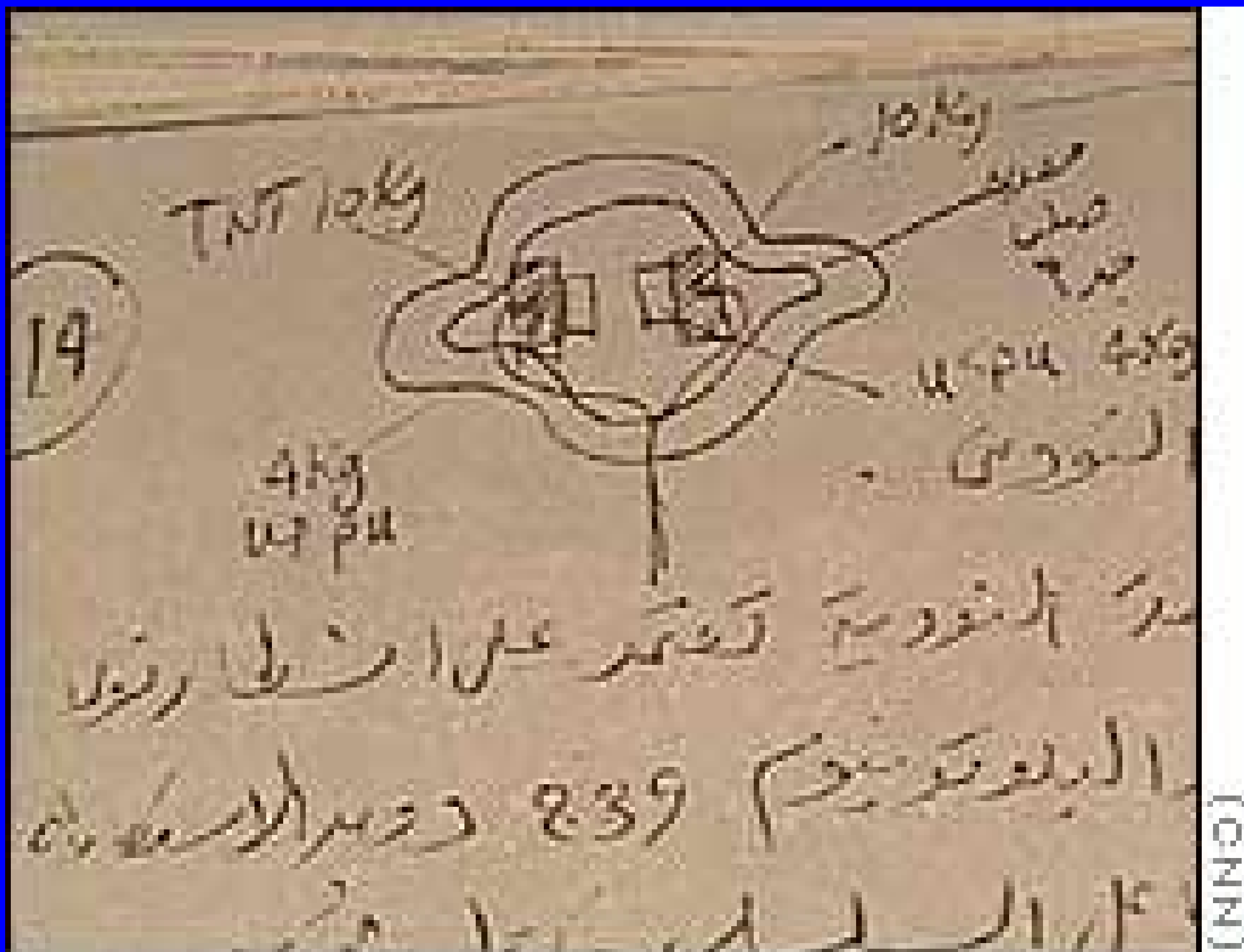
Terrorists and nuclear explosives

- With HEU, gun-type bomb – as obliterated Hiroshima – very plausibly within capabilities of sophisticated terrorist group
- Implosion bomb (required for Pu) more difficult, still conceivable (especially if they got help)

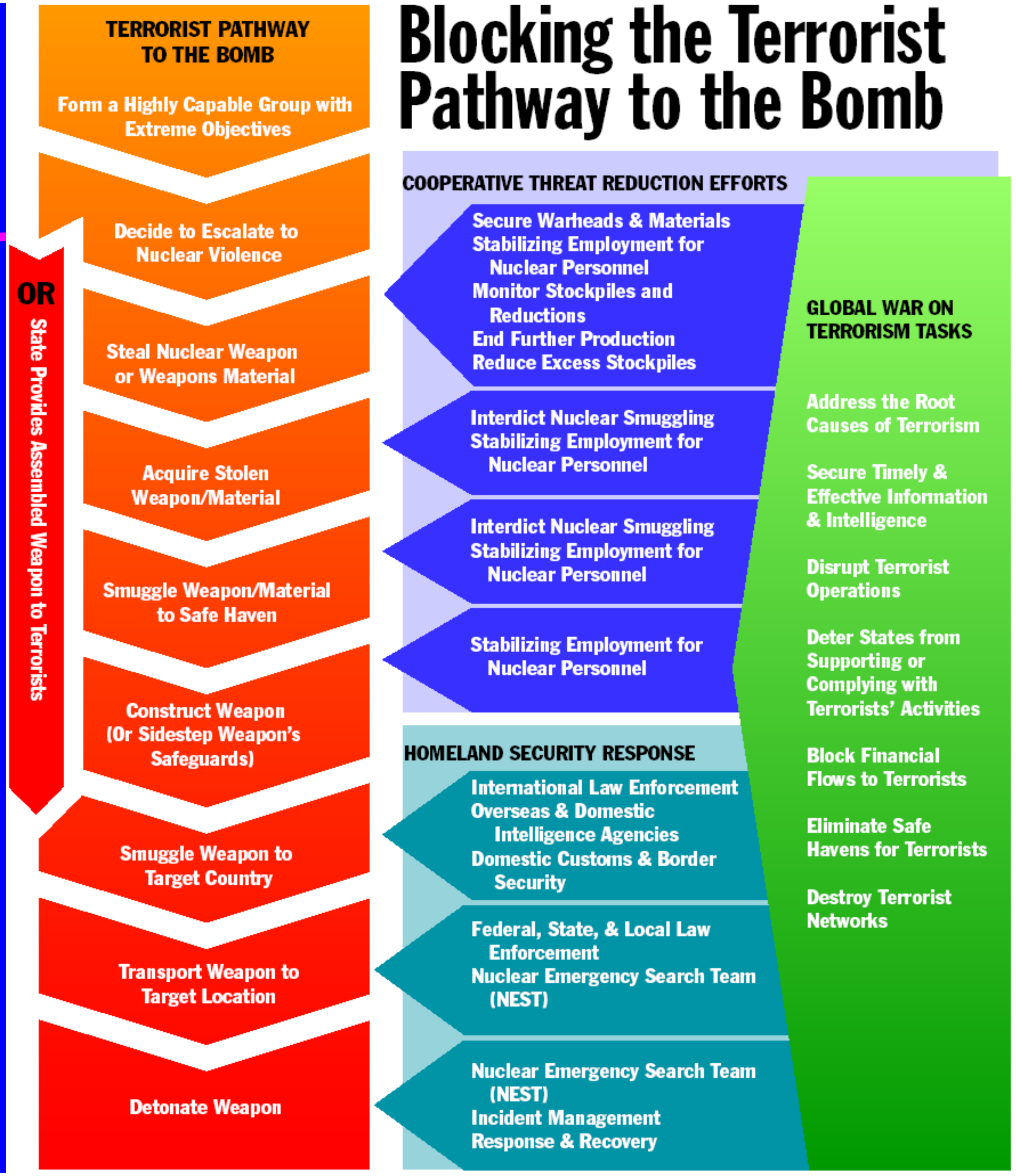


Hiroshima -- result of a gun-type bomb

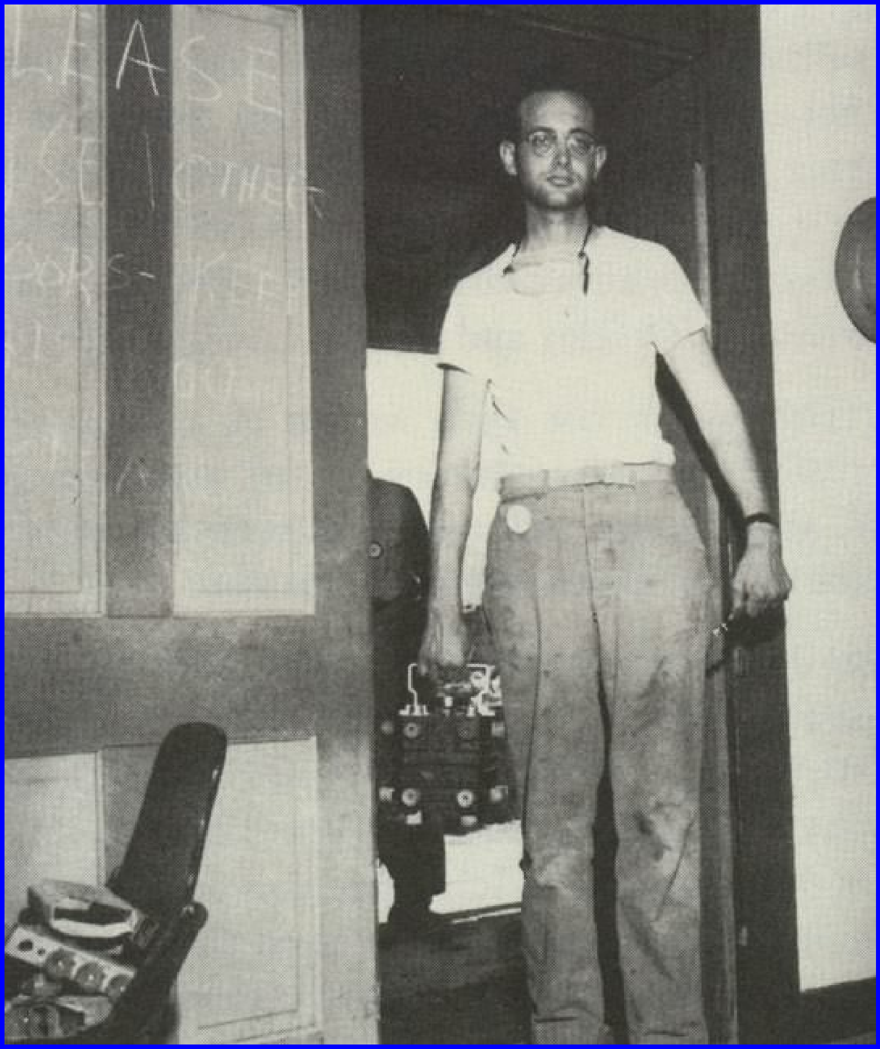
Al Qaida nuclear bomb design



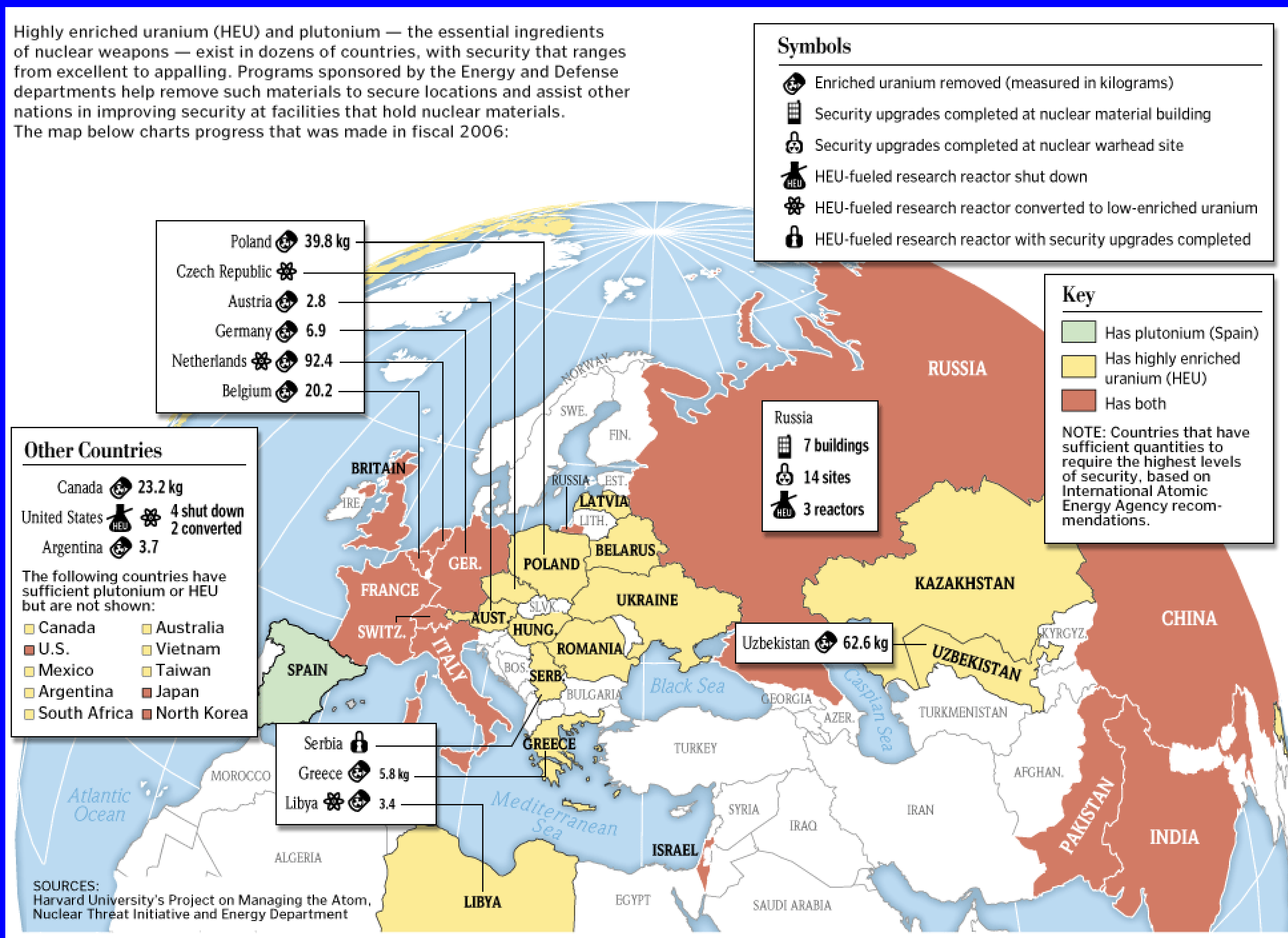
Blocking the Terrorist on the Pathway to the Bomb



Nuclear material is not hard to carry – plutonium box for first-ever bomb



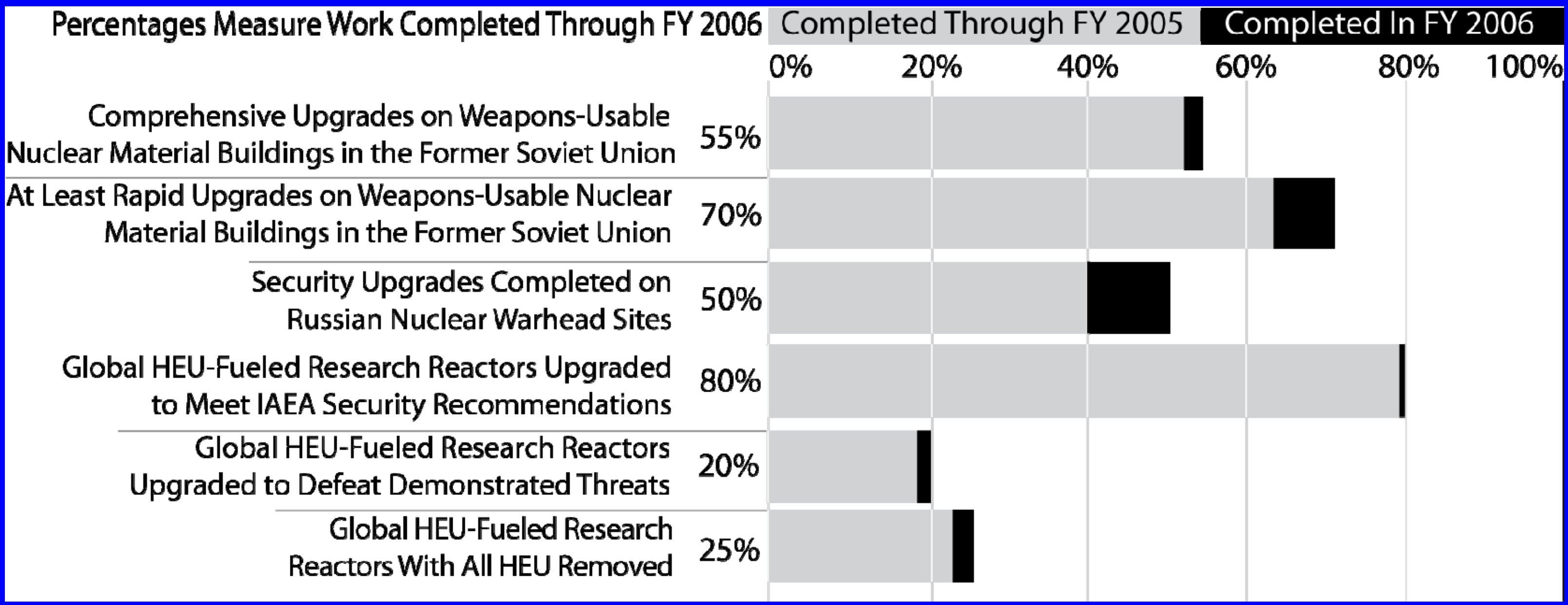
Programs to address the threat are making real progress: one year's work



Source: Washington Post

But much more remains to be done…

Progress of U.S.-Funded Programs to Secure Nuclear Stockpiles



Source: Author's estimates, described in Securing the Bomb 2007

Summing up

- *If* we take decisive action now to strengthen the nonproliferation effort, and
- *If* we pursue the most proliferation-resistant approaches,
- Good reason to be optimistic that we can have substantial nuclear growth without substantial increases in the risk of nuclear proliferation
- The nonproliferation regime has suffered serious blows in recent years, but is more successful and more resilient than most people realize
- But there's an immense agenda ahead if we are to reduce the risks of nuclear proliferation and nuclear terrorism

The vision: where do we want to be in 10-20 years?

- Nuclear weapons and stockpiles of nuclear explosive material (separated plutonium and HEU) drastically reduced worldwide
- All nuclear weapons and nuclear explosive material worldwide sustainably secured and accounted for, to stringent standards
- A strengthened safeguards system in place, capable both of detecting diversions from declared activities, and detecting covert activities
- Effective export control systems in place worldwide, greatly reducing proliferators' access to technology to support a nuclear weapons program

The vision: where do we want to be in 10-20 years? (cont.)

- Nuclear complexes reconfigured to size appropriate to post-Cold War missions, with budgets sufficient to sustain them, excess nuclear experts sustainably re-employed
- Sufficient monitoring and transparency to confirm above steps have been taken
- Sustained or expanded energy contribution from nuclear power, with reduced proliferation impact – including reduction in proliferation-sensitive activities, no spread of such activities to additional states
- Political and security measures taken to reduce states' demand for nuclear weapons and strengthen the nonproliferation regime

For further reading…

- Website of the Managing the Atom project:
  - http://www.managingtheatom.org
- A major web section we maintain for the Nuclear Threat Initiative, *Controlling Nuclear Warheads and Materials*
  - http://www.nti.org/securingthebomb
- Includes our most recent report:
  - *Securing the Bomb 2007* (September 2007)
- *For regular e-mail updates from Managing the Atom, or to explore volunteer internships, write to* atom@harvard.edu

Extra slides if needed…

The threat of “dirty bombs”

- Dirty bomb could be very simple -- dynamite and radioactive material together in a box
- Modest amounts of radioactive material easy to get – millions of radioactive sources in industrial and medical use worldwide – only a fraction pose significant hazard
- Even with a lot of radioactive material – kilograms of plutonium or spent fuel – usually few would die from acute radiation poisoning, few hundred to few thousand from cancer many years later (undetectable against cancer background)
- *But*, fear of anything “nuclear” could create panic, would have to evacuate area for extended period, cleanup and disruption could be very costly (10s of billions worst case)

Dealing with the "dirty bomb" threat

- Better control, accounting, security for radioactive sources:
  - Focus on most dangerous sources
  - Retrieve, safely dispose of disused sources (10K in U.S. so far)
  - >100 countries worldwide have inadequate controls
- Radiation detection at ports, borders
- Improved capacity to detect, assess, respond to attack
- Develop improved urban decontamination technologies
- Most important: communication strategy to limit panic, tell public how to respond – complicated by past gov't lies
  - Possible need for credible non-government spokesmen (e.g., C. Everett Koop rather than chairman of NRC)

Vulnerability assessment: a systems engineering approach to security

- Vulnerability assessment is a formal technique using event trees similar to those of probabilistic risk assessment, used for identifying key weaknesses in facility security systems and most cost-effective approaches to improving them
- Basic steps
  - Identify unpleasant events to be protected against (e.g., sabotage of power plant resulting in radioactive release, theft of bomb material)
  - Estimate likely characteristics of adversaries (insider/outsider, numbers, armament, training, etc.) -- "design basis threat"
  - Identify possible ***pathways*** by which adversaries might attempt to cause unpleasant events (e.g., possible routes from outside facility to location of bomb material)
  - At each step, estimate the security system's ability to ***detect, delay,*** and ***defend*** against the adversaries' actions -- goal is to ensure that system can reliably detect the adversaries early on, and delay them long enough for a force that reliably overcome them to respond

Modeling the layers of the protection system

Figure 17–2. Basic Areas At An Example Facility

Source: Sandia National Laboratories

Multiple possible adversary pathways through each layer

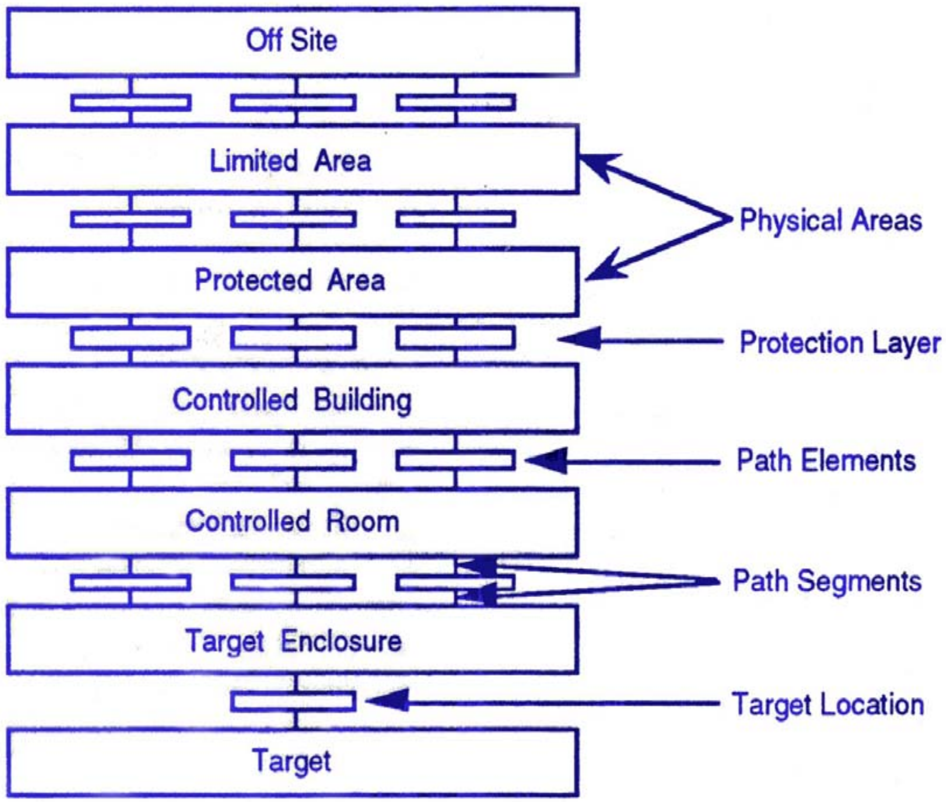


Figure 17–7. ASD Concept

Source: Sandia National Laboratories

Estimating probability of adversary sequence interruption – each pathway

Estimate of Adversary Sequence Interruption	Prob. of Guard Comm.		Response Force Time (in Seconds) Mean	SD
	0.95		300	90

Task	Description	P(Detection)	Location	Delays (in Seconds): Mean	SD
1	Cut Fence	0	B	10	3
2	Run to Building	0	B	12	3.6
3	Open Door	0.9	B	90	27
4	Run to Vital Area	0	B	10	3
5	Open Door	0.9	B	90	27
6	Sabotage Target	0	B	120	36
7					
8					
9					
10					
11					
12					

Probability of Interruption:	0.476

Source: Sandia National Laboratories

Estimating probability of adversary interruption: parsing the example

- This facility has a response force that takes 300 seconds (5 minutes) to arrive
- But the facility has no ability to detect adversaries cutting the fence – first hope of detection is when they blow through the door of the building
- After that door, it's only 220 seconds to a successful sabotage
- So, the protection system has less than a 50-50 shot at preventing sabotage on this pathway, against adversaries as capable as those predicted
- Possible fixes: add detection capability at the fence (likely cheapest); put in stronger vaults, etc. to increase delay time after going through door; decrease response force arrival time (e.g., move them closer to facility).

Assessing vulnerability assessment: problems with complexity

- Key issues are similar to those for PRA – system too complex to predict (and get probability data on) each sequence; unforeseen system interactions and common-mode failures particularly problematic
- ***In particular,*** predicting actions of intelligent adversaries extraordinarily difficult: assessors try to "brainstorm" all the possible attacks, but attackers may do something else
- Insiders particularly difficult to protect against: they know the system and its weaknesses (may be among assessors)
- Importance of realistic ***performance testing*** – does the system really protect, when faced with a credible adversary force (and/or insider) trying to overcome it?
- Assessment of ***absolute*** magnitude of vulnerability less reliable than identification of key areas for improvement