Living With Nuclear Energy Without Spreading the Bomb – Or Offering Terrorist Targets

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January 25, 2005

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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 (Gen IV, AFCI)?
- 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 early 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. has sought to cut off *all* civilian nuclear cooperation with Iran, arguing that any such cooperation will contribute to a bomb program – Russia and Europe do not agree
- October 2003: European foreign ministers negotiate a deal – Iran agrees to Additional Protocol, suspends enrichment and reprocessing, in return for trade deal, possible nuclear technology access
- 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 Russia now providing fuel and reactors

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.:
  - If radiation field of recycle material is more than *x* rem/hr at 1 m
  - If Pu-239 content of recycle material is less than *y* percent of total plutonium
  - If material at all steps in fuel cycle cannot be used in nuclear weapons 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

- 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 with Pu in recycling system; directly weapons-usable material never appears in cycle
- Definitely better than PUREX -- significantly reduces the threat of terrorist theft and use in 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 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
- ~135 operating research reactors in >40 countries still use HEU as their fuel (MIT reactor uses ~12 kg of 93% enriched material in its core)
- Most 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 considered seizing Kurchatov Institute – site with enough HEU for dozens of bombs

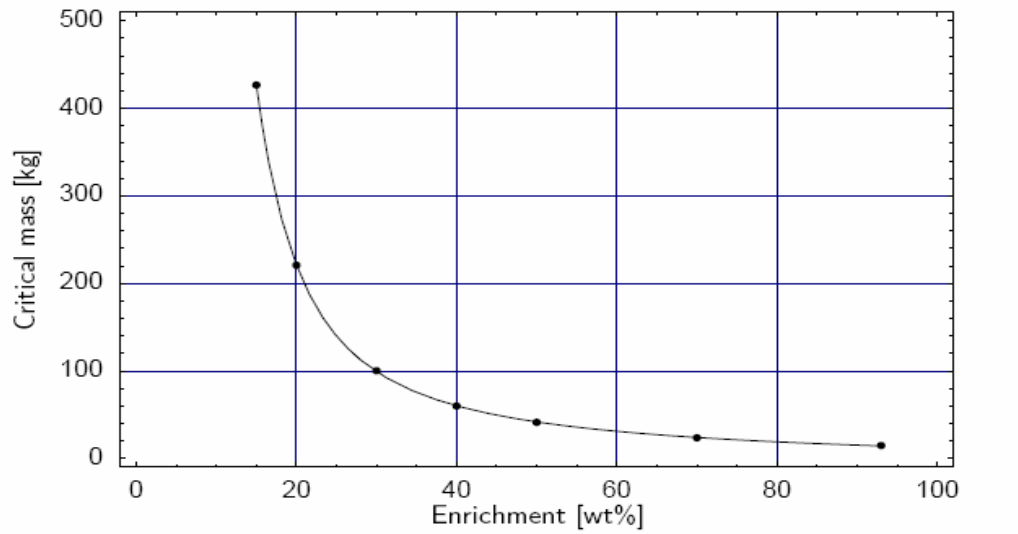
Reactor-grade plutonium is weapons-usable

- 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 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	0.0003
Pu-238	10	88	560	2600
Pu-239	10	24,000	1.9	0.02
Pu-240	40	6,600	6.8	900
Pu-241	13	14	4.2	0.05
Pu-242	89	380,000	0.1	1700
Pa-231	162	32,800	1.3	0
Np-237	59	2.1×10^6	0.021	.000139
Am-241	57	430	110	1.2
Am-243	155	7,380	6.4	.9
Cm-245	13	8,500	5.7	147
Cm-246	84	4,700	10	9×10^6
Bk-247	10	1,400	36	0
Cf-251	9	898	56	0

Source: Lawrence Livermore, Annex: Attributes of Proliferation Resistance for Civilian Nuclear Power Systems, *in* Technological Opportunities to Increase the Proliferation Resistance of Global Nuclear Power Systems (TOPS) (DOE-NERAC, 2000)

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 address problem of covert facilities
- Would have only modest impact on problem of build-up of expertise, infrastructure that could later be used in a 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)

Closing the Art. IV loophole

- 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

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…
- Secure all nuclear materials and facilities
- Minimize spread of sensitive facilities/activities
- 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, 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

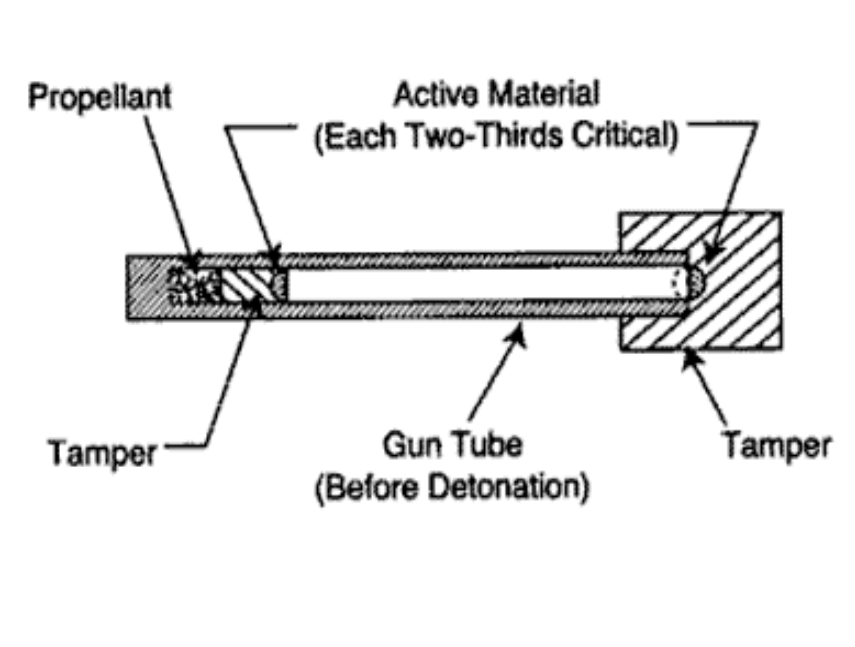
- Designed to detect, deter, and prevent *theft* of material, or *sabotage* of facilities by unauthorized insiders or outsiders (not *diversion* by the host state – that's what international safeguards do)
- Physical protection:
  - Designed to detect, slow, and interdict any theft or sabotage attempt
  - 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

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 exists in dozens of other countries as well
- IAEA has 18 documented cases of seizure of stolen HEU or plutonium in last decade
- Potential bomb material could fall into the hands of a terrorist group or hostile state at any time

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

The threat of nuclear sabotage

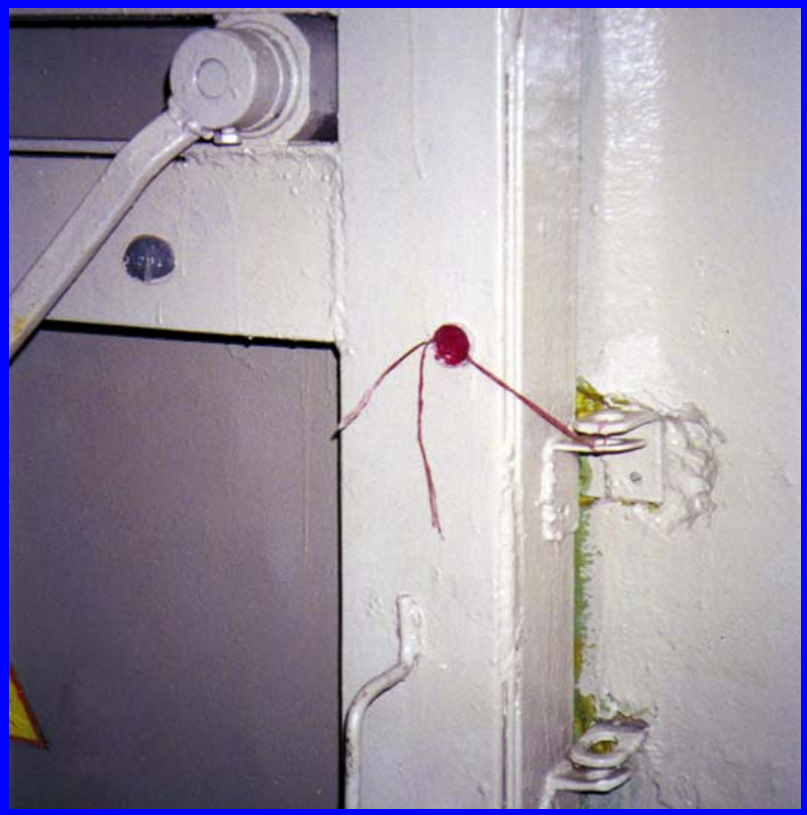
- Most nuclear power plants protected by security forces, containment vessels, and redundant safety systems
- *But*, levels of security vary widely, few civilian facilities designed to cope with threat of magnitude demonstrated on September 11
- Successful sabotage of a nuclear power plant or spent fuel pool could, in worst case, lead to mass dispersal of radioactive material, thousands of long-term cancer fatalities (assuming LNT hypothesis)
- Radiological “dirty bomb” would be much easier to do, would cause few deaths but much terror and disruption, impose high costs

“Loose Nukes” in the former USSR

- Security system designed for a single state with closed society, closed borders, pampered nuclear workers, close surveillance by the KGB, now facing multiple states with open societies, open borders, desperate, underpaid nuclear workers, culture of crime, corruption, and theft
- Old system based on “guards, guns, and gates” – to prevent American spies getting in, not material getting out
- Many facilities have no portal monitors to detect removal of material – or security cameras where it is stored
- Few facilities have accurate, measured inventory of material on hand – they don’t know how much they have
- Still widespread use of wax seals – ineffective in detecting tampering by authorized workers

Moscow building with enough HEU for a bomb -- 1994

Ineffective padlocks and seals for nuclear material in Russia

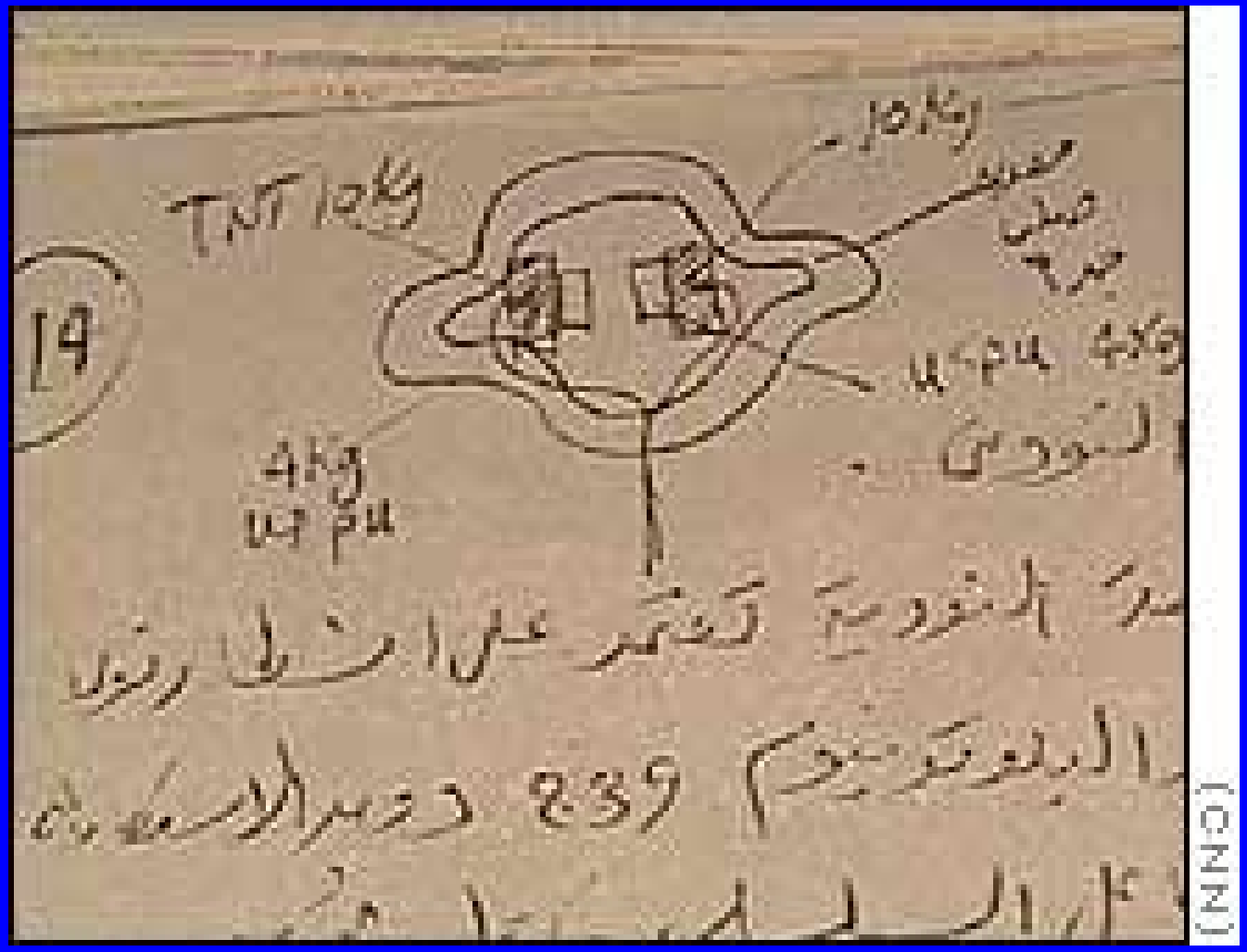


Key documented cases of theft of weapons-usable material

- 1992: 1.5 kg weapon-grade HEU, “Luch” production association in Podolsk, Russia;
- 1993: 1.8 kg 36% enriched HEU, Andreeva Guba naval base, Russia;
- 1993: 4.5 kg >19% U-235, Sevmorput naval shipyard near Murmansk, Russia;
- 1994: >360 g Pu, Munich, on flight from Moscow;
- 1994: 2.73 kg 87.7% HEU, Prague (suspected from Russia)
- 1998: 18.5 kg HEU (failed theft conspiracy), Chelyabinsk, Russia

Are there substantial cases that have not been detected?

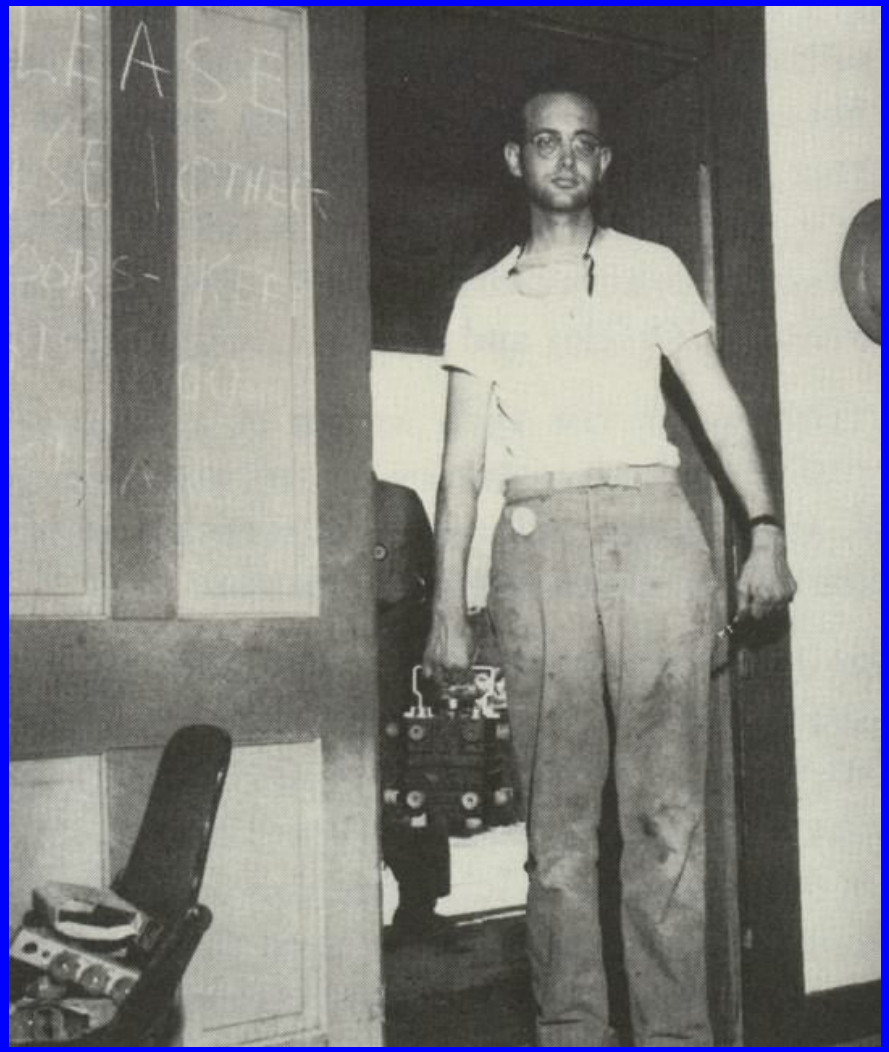
Al Qaida nuclear bomb design



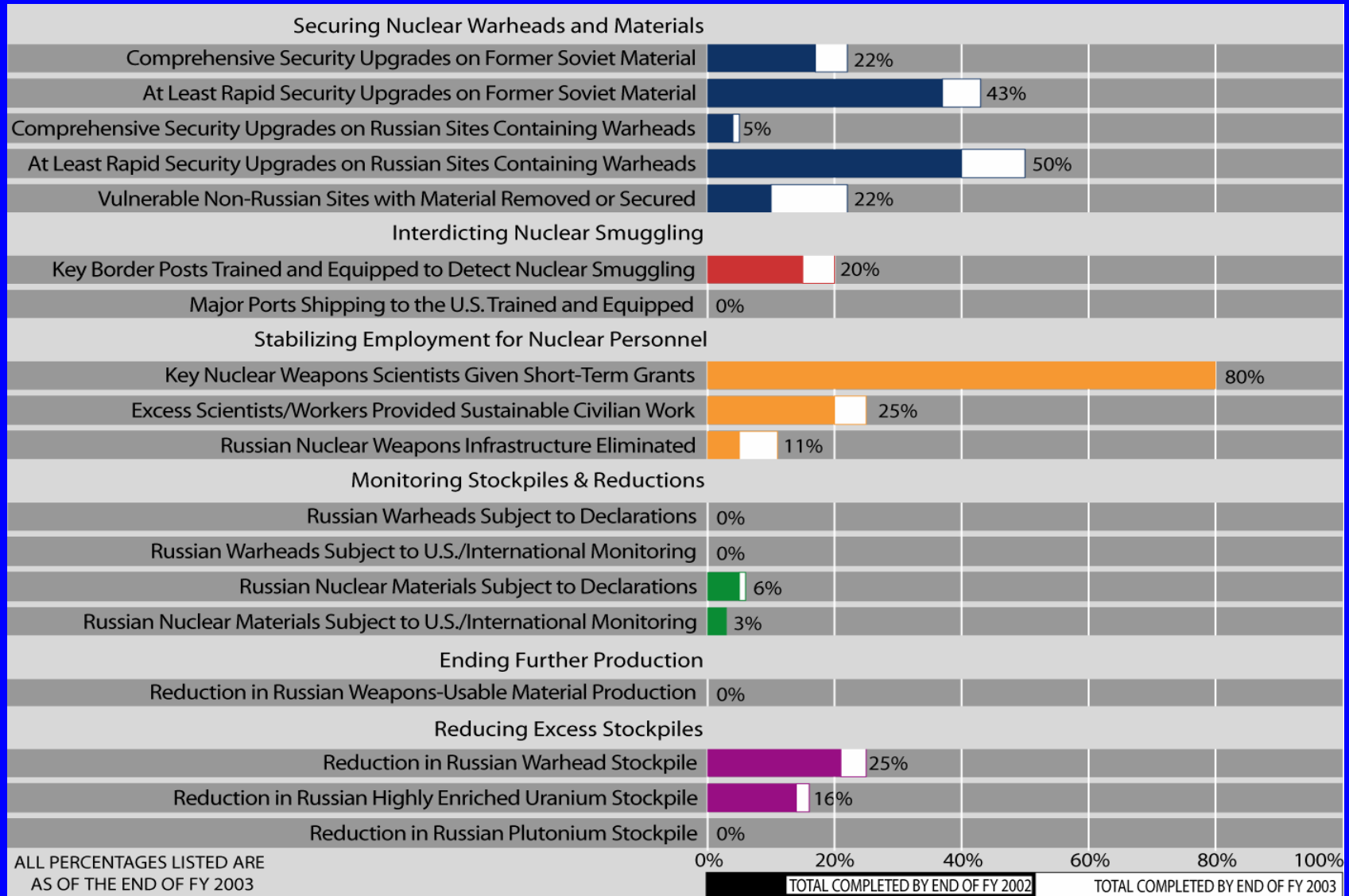
(CNN)

Blocking the Terrorist on the Pathway to the Bomb

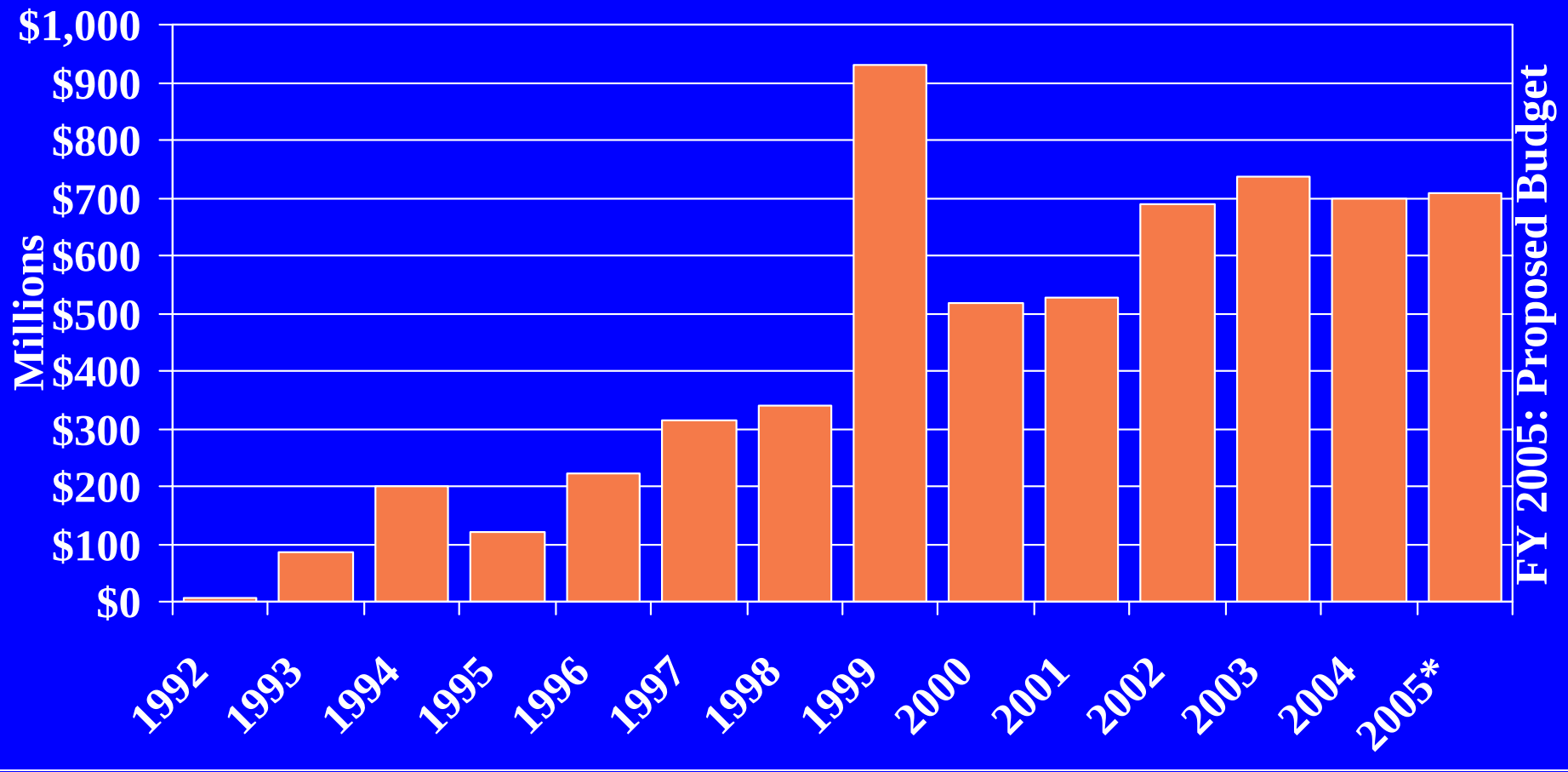
Nuclear material is not hard to carry – plutonium box for first-ever bomb



How Much Work Have U.S. Programs Completed?



U.S. Budgets for Controlling Nuclear Warheads, Material, and Expertise Overseas



Note: FY 1999 includes one-time funding of $325 million added by the FY 1999 Omnibus and Supplemental Appropriations Act to buy natural uranium to solidify the HEU Purchase Agreement, and a one-time appropriation of $200 million, which is still being drawn upon, to support Russian plutonium disposition.

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…

- Managing the Atom's web site:
  - http://www.managingtheatom.org
- A major web section we maintain for the Nuclear Threat Initiative, *Controlling Nuclear Warheads and Materials*
  - http://www.nti.org/cnwm
- Includes our two most recent reports:
  - *Securing the Bomb: An Agenda for Action* (May 2004)
  - *Controlling Nuclear Warheads and Materials: A Report Card and Action Plan* (March 2003)
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Securing Nuclear Warheads and Materials

Materials Protection Control and Accounting

Status
Budget
Key Issues & Recommendations
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Fast Facts

Status

Renovation of decaying fence

The U.S.-Russian Materials Protection, Control, and Accounting (MPC&A) program, funded by the U.S. Department of Energy (DOE), is the biggest and most successful international cooperative effort to secure and account for nuclear weapons and materials. Hundreds of tons of nuclear material and thousands of nuclear warheads are demonstrably more secure than they were a few years ago.

But much more remains to be done than has been done to date. As of mid-2002, after eight years of effort, only about 40% of the nuclear material in Russia has had even "rapid upgrades," such as bricking over windows and installing nuclear material detectors at the door, and more effective "comprehensive" upgrades are in place for less than half of that 40%.[1] (See this official chart of the program's progress over time.) Working with Russia, the United States should take immediate steps to accelerate and strengthen this effort, ensuring that all stockpiles of potential bomb material in the former Soviet Union:

- are secured and accounted for as rapidly as technology will allow;
- are secured and accounted for to standards adequate to meet the threat; and

Controlling Nuclear Warheads & Materials
Overview and Budget
The Threat
SECURING NUCLEAR WARHEADS AND MATERIALS
Materials Protection, Control & Accounting
Warhead Security
Mayak Fissile Materials Storage Facility
BN-350 Fuel Security
Removing Materials from Vulnerable Sites
Converting Reseach Reactors
International Nuclear Security Upgrades
Global Standards
Interdicting Nuclear Smuggling
Stabilizing Nuclear Custodians
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Controlling Nuclear Warheads and Materials

"The gravest danger our Nation faces lies at the cross-roads of radicalism and technology. Our enemies have openly declared that they are seeking weapons of mass destruction... History will judge harshly those who saw this coming danger but failed to act." *– President George W. Bush, National Security Strategy of the United States of America, September 2002*

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The possibility that nuclear weapons or the materials needed to make them could be stolen and fall into the hands of terrorists or hostile states poses among the most urgent threats to U.S. and international security. Immediate action is needed to forestall this

Controlling Nuclear Warheads & Materials

- Overview and Budget
- The Threat
- Securing Nuclear Warheads and Materials
- Interdicting Nuclear Smuggling
- Stabilizing Employment for Nuclear Personnel
- Monitoring Stockpiles
- Ending Further Production
- Reducing Stockpiles

Threat Reduction Budgets GO

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The threat of “dirty bombs”

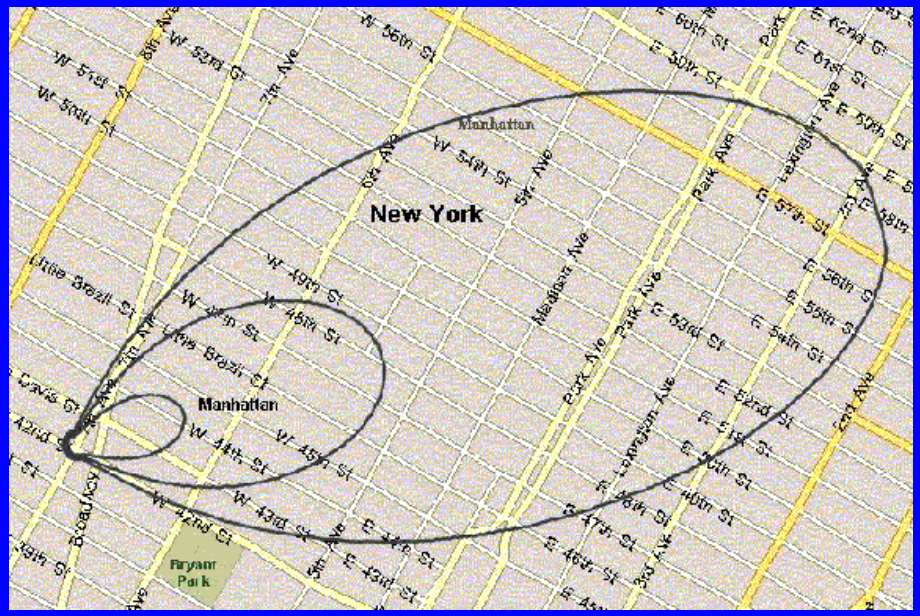
- Dirty bomb could be very simple -- dynamite and radioactive material together in a box
- Modest amounts of radioactive material easy to get – millions of radioactive sources in industrial and medical use worldwide – only a fraction pose significant hazard
- Even with a lot of radioactive material – 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 would be very costly (10s of billions)

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)

Americium dispersal in Manhattan

- Inner Ring: One cancer death per 100 people due to remaining radiation (IF everyone stays, and no cleanup)
- Middle Ring: One cancer death per 1,000 people
- Outer Ring: One cancer death per 10,000 people; EPA recommends decontamination or destruction



Map source: Testimony by Henry Kelly, Federation of American Scientists

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

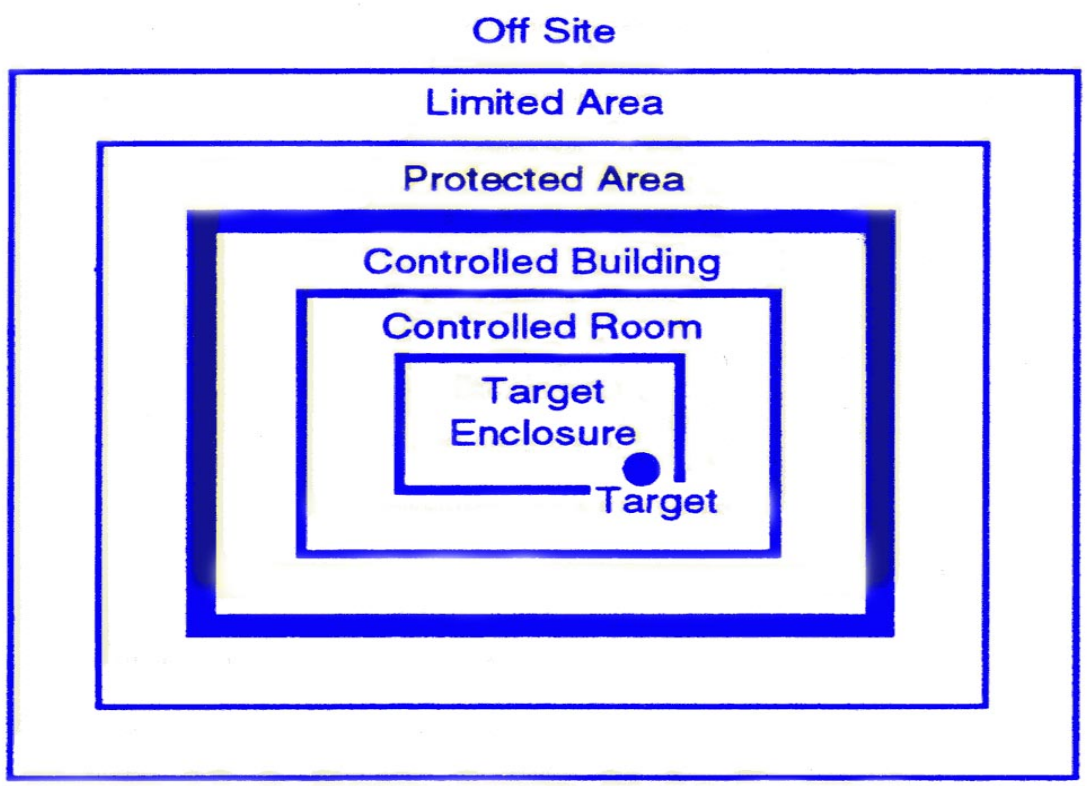


Figure 17–2. Basic Areas At An Example Facility

Multiple possible adversary pathways through each layer

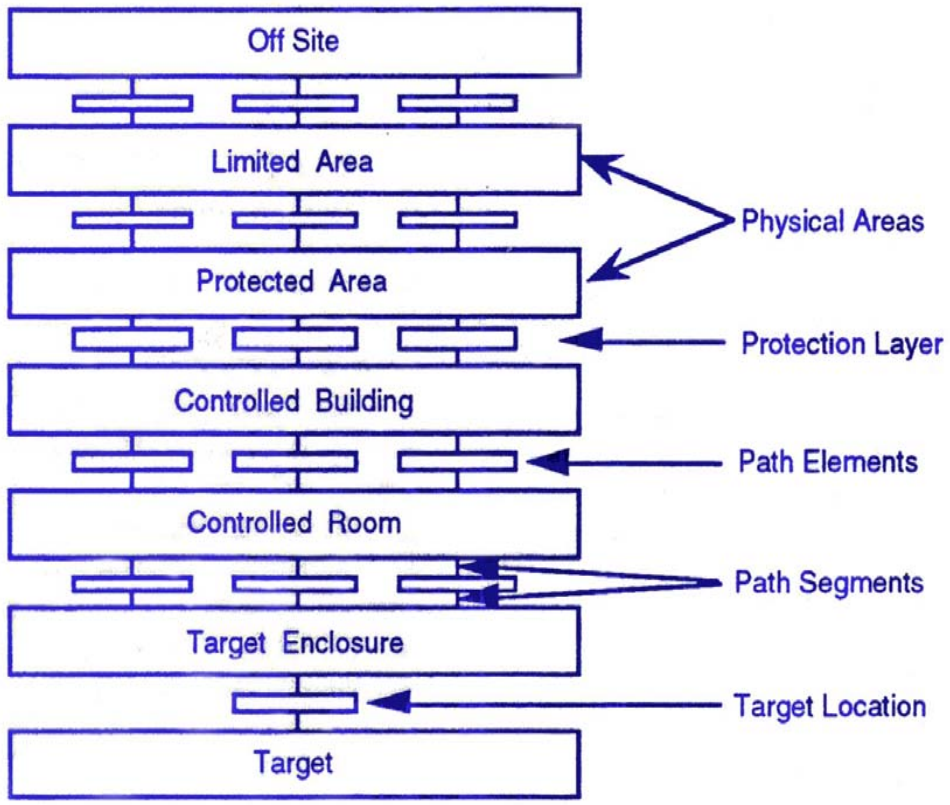


Figure 17–7. ASD Concept

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

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 rarely attempted