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Do We Really Need to Worry? Some Reflections on the Threat of Nuclear Terrorism

Peter D. ZIMMERMAN
Department of War Studies, King's College London

Abstract: *This paper considers the case for and against there being a substantial risk that a sub-state adversary might be able to carry the construction of a nuclear device to completion and delivery. It discusses works both for and against the proposition that the detonation of an improvised nuclear device (IND) or a stolen nuclear weapon is sufficiently probable that strong measures to prevent the act must be considered. Contrarian articles and books have appeared suggesting that the possibility of nuclear terrorism has been greatly exaggerated. They argue that building an IND is too difficult for even well-financed terrorists, that obtaining sufficient fissile materials is nearly impossible, and that no intact weapons will be stolen. But an examination of these works finds some to be simplistic and ridden with basic mistakes in risk analysis or misconceptions, while others are better informed but still flawed. The principal barrier to entry for either a new nuclear weapons possessor state or a sub-state group, namely acquiring fissile material, plutonium or highly enriched uranium (HEU), became less imposing with the collapse of the Soviet Union. There is a gap in our knowledge of Russian fissile inventories, which have not always been well guarded, and in this circumstance one cannot reassure the world that there has been no theft of fissile material, or that any attempt will be detected quickly enough to prevent its being made into a nuclear device. The probability of a nuclear terrorist attack in any given year remains significant. Significant investment to deter, prevent, detect, and destroy a nuclear terror plot is required.*

Keywords: *improvised nuclear device, sub-national group, highly enriched uranium, nuclear terrorist, probability.*

Introduction

Despite there being any number of skeptics, there is no theoretical reason why terrorists should not succeed in setting off a nuclear explosion, killing thousands of people in one of the great cities of

the world. The picture has become familiar: A group of – usually – young men at a remote site, some swarthy and bearded, others with fair complexions and blue eyes, hoist a heavy coffin-like box into the back of an inconspicuous unmarked white van. The van's rear doors close, and two clean-cut drivers head down the road. A day or so later the van is parked in a crowded downtown location; the driver inserts a key in a switch, sets an arming device; and both crewmembers hop out and walk to the nearest subway station.

Sometime later, after emerging from the subway many miles away, the driver dials a cell phone connected to the arming switch in the van; and then van and downtown vanish in a nuclear fireball. Many thousands of people die within seconds from blast, heat, and even prompt radiation. The first homemade nuclear explosion has been set off successfully.

There is no theoretical reason why nuclear terrorists should not succeed. The design principles for the Hiroshima weapon[1] have been published in many places, starting with the "Smyth Report"[2] officially issued shortly after the August 1945 strikes on Hiroshima and Nagasaki, and continuing in greater (though not necessarily correct) detail on the World Wide Web and in various books.[3,4]

Several contrarian articles and books have appeared suggesting that the possibility of nuclear terrorism has been greatly exaggerated, by people including Graham Allison of Harvard University, Matthew Bunn and Anthony Wier, also of Harvard, and others, including Anna Pluta, Jeffrey Lewis and myself. John Mueller of Ohio State University calls all those who believe the threat is real "alarmists".[5] Christoph Wirz and Emmanuel Egger of the Swiss government's Spiez Laboratory also question the possibility that terrorists might use nuclear and radiological weapons.[6] Perhaps the leading nuclear sceptic is Robin Frost of Simon Fraser University, who wrote an Adelphi Paper discounting the threat of nuclear terror and describing the extremely high barriers that a terrorist must overcome.[7]

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1 Gun-assembled, highly enriched uranium, construction.

2 Henry DeWolf Smyth, *Atomic Energy for Military Purposes: The official report on the development of the atomic bomb under the auspices of the United States Government, 1940-1945*. Released 12 August 1945. Princeton University Press, Princeton, NJ, 1945. Various editions and publishers are to be found. For online text see: (http://www.atomicarchive.com/Docs/SmythReport/index.shtml), accessed 1 January 2010

3 Robert Serber, *The Los Alamos Primer (Los Alamos report LA-1)*, published in hardcover with the author's corrections and comments by the University of California Press, Berkeley, CA, 1992.

4 Richard Rhodes, *The Making of the Atomic Bomb*, Simon and Schuster, New York, 1995.

5 John Mueller, *The Atomic Terrorist: Assessing the Likelihood*, prepared for presentation at the APSA Program on International Security Policy, University of Chicago, 15 January 2008. (http://polisci.osu.edu/faculty/jmueller/APSACHGO).pdf, retrieved 10 December 2009. See also Mueller's book *Atomic Obsession*, Oxford University Press USA, New York, 2009.

6 Christoph Wirz and Emmanuel Egger, *International Review of the Red Cross*, 87, No. 859, September 2005, pp. 497-510.

7 Robin M. Frost, *Nuclear Terrorism After 9/11*, Adelphi Paper No. 378, International Institute of Strategic Studies,, London, 2005.

The purpose of this paper is to consider the case for and against there being a substantial risk that a sub-state adversary might be able to carry the construction of a nuclear device to completion and delivery. I will discuss works both for and against the proposition that the detonation of an improvised nuclear device (IND) or a stolen nuclear weapon is sufficiently probable that strong measures to prevent the act must be considered.

John Mueller: Pollyanna?

Acquiring fissile material, plutonium or highly enriched uranium (HEU) to fuel the bomb is the principal barrier to entry for either a new nuclear weapons possessor state or a sub-state group. Plutonium production requires a supply of spent reactor fuel, the capacity to handle extremely radioactive fuel elements, and a chemical reprocessing plant. While the chemistry of plutonium is fairly well known in the unclassified literature, extraction of the element from the spent fuel would remain a difficult task, even if the source materials were not terribly radioactive, in order to achieve the necessary purity. While "plans" for a small reprocessing plant designed by the Oak Ridge National Laboratory surfaced many years back and remain available on the Internet, the construction of the facility would likely be beyond the capability of the average sub-national group, particularly if the safety of the operators were a concern. It is also likely that the operation of a crude reprocessing plant would be readily detected because of the leakage of radioactive argon, a fission product, during its operation.

The enrichment of uranium, as evidenced by the Iranian project[8], is an industrial-scale operation, fraught with technical difficulties. It seems highly unlikely that a sub-national group would be able to construct and operate an enrichment plant, particularly without detection.

This leaves a third route: obtain fissile material directly from a possessor state either by theft, by suborning an official, or as a gift. The situation is not without precedent: A. Q. Khan[9], the father of the Pakistani nuclear weapon program, claims that China supplied Pakistan with a design for a nuclear weapon, as well as with enough HEU to make two devices. Originally, according to Khan, the HEU was meant to be a loan, to be repaid after Pakistan's centrifuges were operational; in the end, also according to Khan, the Chinese forgave the debt.

Whether or not a sub-national group can successfully detonate a self-built nuclear weapon is likely to be decided by the answers to a set of questions:

- What is the motivation for a nuclear strike? Is it high enough to sustain what is likely to be a long process, perhaps covering two or more years, and costing very many millions of dollars?

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[8] "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006), 1747 (2007), 1803 (2008) and 1835 (2008) in the Islamic Republic of Iran," IAEA Board of Governors report GOV/2010/10, 18 February 2010. Available on the Internet at (http://isis-online.org/uploads/isis-reports/documents/IAEA_Report_Iran_18Feb2010.pdf.) Accessed 22 March 2010. Also see earlier reports by the IAEA in the same series.

[9] "Pakistani Government Seeks to Investigate A.Q. Khan's Activities," (http://isis-online.org/peddlingperil/ch4/khan_investigation/), accessed 22 March 2010. See also (http://isis-online.org/peddlingperil) and the book described on the site. Accessed 22 March 2010.

- Is there a government somewhere, not necessarily a nuclear weapons possessor state, which will treat the group as a surrogate or proxy? Is there a government or large industrial concern that can and will deliver fissile material without problems?
- What technical talent can the group recruit? Does the group have access to scientists and engineers who are capable of doing the complex calculations to generate a real design, and not just a sketch?
- Does the group have adequate financial resources?
- Can the appropriate equipment needed to construct a device be obtained on the white or grey market? The black market?[10]

Mueller chooses another set of criteria by which to judge the plausibility of improvised nuclear devices. He writes down twenty "tasks" in what he calls "the most likely scenario"[11] He then posits that there is a 50-50 chance of success for each of these "tasks" and that taken together, this means that the odds of success are 1 in 1,048,576. This is truly a small number, and if taken seriously would probably mean that no further significant attention need be paid to nuclear terror scenarios.

However, this is far too simplistic.

It is true that if one raises 0.5 to the 20th power, the resulting value is quite small, less than one in a million as desired. The question, however, is not if the value for 0.5^{20} is small; of course it is. But does it bear any relationship to the problem at hand?

How did Mueller come to the number twenty for his list of tasks? Some of the items are even compound tasks, one following another, so there could be more than twenty, and by Mueller's reasoning a still smaller chance of success. Some of them are not tasks proper, but conditions to satisfy ("There must be no inadvertent leaks". "No locals must sense that something out of the ordinary is going on".) Still others seem like padding to reach the number 20 ("A detonation team must transport the IND to the target place and set it off… and the untested and much-traveled IND must not prove to be a dud".). Since Mueller asserts that the probability of a nuclear terrorist starting a project and succeeding is less than one in a million, it is worth noting that 2^{20} is almost exactly 1,000,000 and that 0.5^{20} is, therefore, one in a million. That seems to be the totality of the logic behind the "twenty hurdles" of the Mueller papers and book. There seems to be no analysis to show that 50-50 are appropriate odds for the success of each step, and it is manifestly clear that the twenty hurdles are not statistically independent. Nevertheless, it would seem that twenty hurdles is the smallest plausible number that can provide the one chance in a million which allows

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[10] Matthew Bunn chooses a different set of criteria in his article *A Mathematical Model of the Risk of Nuclear Terrorism*, Annals of the American Academy of Arts and Sciences, 607, September 2006, pp. 103-120. Bunn's criteria are aimed at computing the probability of a terrorist nuclear attack.

[11] Mueller, p. 24

Mueller to suggest that those who believe in nuclear terrorism might, with equal logic, believe "in the tooth fairy".[12]

In any event, the odds of success for some tasks are nearly 100 percent. For example, it is not difficult to put an IND in a white van and drive it from Montana to Minneapolis, or from outside Boise to inside Boston, so long as the drivers break no traffic laws. I give that task a 90-plus percent probability.

Assembling a team of scientists and technicians is likely to be far easier than Mueller supposes. The Manhattan Project was the most exciting, and indeed glamorous, scientific project of the first half of the twentieth century, led by a constellation of great scientists. Many physicists, even today, fantasize about following in their footsteps.[13] I give this one an 85-95 percent chance, at least.

In any event, Mueller makes elementary mistakes in risk analysis at the conceptual level: He decides on a path to the goal of a nuclear device, and then decides that it is either the only, or the easiest, or the most favorable route. Along the way his analysis is flawed. Mueller suggests that smugglers would be more likely than not to turn in the nuclear gang to the authorities. But as Matt Bunn of Harvard has pointed out[14], Al Qaeda and Mexican drug lords routinely manage to move sensitive materials and people across borders, even those of highly developed countries such as the United States. Successful smugglers-for-hire generally do not betray their customers; the penalties for betrayal probably range from a severe beating to barbaric torture followed by a gruesome death.

In his articles and presentations on the probability of terrorist use of nuclear weapons, Prof. Mueller frequently lashes out at those who refuse to set the likelihood of such acts at 1 in a million, or less. We are "alarmists". And we are "imaginative".[15]

According to Mueller, my colleague, Jeffrey Lewis, and I indulge in "worst case fantasies".[16] Mueller seems never to have talked with anybody who actually built a nuclear weapon, for his understanding of the components of a simple device makes it seem far more complex than it is. Nor can I share the results of my conversations with weaponeers except to say that they do not

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[12] One in a million is a familiar number in American nuclear doctrine. The odds of a deployed nuclear weapon detonating with a yield of four pounds of TNT equivalent if the explosives are detonated at the worst possible point must be less than one in a million. This requirement is validated with engineering judgment, some testing, and a great deal of computer simulation.

[13] This claim is based on the author's own experiences inside the nuclear physics community and discussions over many years with dozens of his colleagues on the question of the production of an IND. In addition, one thing that is not conveyed by any of the academic histories is that the physics of a nuclear weapon is particularly challenging because the problem involves time scales from nanoseconds to hours, and size scales from meters to nanometers. Indeed, most weapons designers found the work to be fun.

[14] Matthew Bunn, private communication, 14 December 2008.

[15] In one short paragraph (p. 3), Mueller uses the adjective "imaginative" five times pejoratively, lumping Albert Einstein and Joseph Stalin into the category. Mueller is the only author I know of who considers imagination a defect in a scientist, or even in a political leader.

[16] Mueller, p. 3.

consider the construction of certain kinds of nuclear weapons to be beyond the skills of the kind of 20-person group Lewis and I envisioned. Lewis and I carefully assessed the budget for a nuclear terrorist, and arrived at a figure of $10 million. Mueller waves our extensive effort away with the comment that $10 million isn't enough to corrupt three people.

He must live in an expensive district for political bribery. Lewis and I estimated a budget more like a couple of million for actually building the device, including salaries and the procurement of all necessary non-nuclear components and equipment. We do not believe that recruiting the technical staff will require any bribery or corruption.

Mueller assumed that he has found the shortest critical path to an improvised nuclear device. He also seems to assume that his list of tasks is so general that it includes all possible critical paths. He's clearly wrong on the first count, but even if he is right on the second – and I think he is wildly wrong – his compilation is so general that it offers no guidance to law enforcement or the terrorists except to hope for or to guard against betrayals.

Wirz and Egger: Swiss precision

Mueller then commends the work of Christoph Wirz and Emmanuel Egger.[17] Their paper must be considered in a different category than that of Mueller because both men are respected scientists, even if they are not professionally involved with nuclear weapon design and defense. Consider their fundamental argument (in what follows, their arguments are under black bullets and my replies under white bullets):

- The nuclear device designed as part of Livermore's "nth Country" experiment was not built or tested, so one has no idea of the performance of hypothetical independent nuclear designs.
    - It is true that the nth Country device was not actually built. Nevertheless, the design was simulated on computers with the result that if it had been built, it would have worked. Given the era in which the experiment was conducted – in which the "nominal" yield of an atomic bomb was 20 kt – one may reasonably speculate that Robert Selden and his colleagues were aiming for about that yield. Even then the ability to simulate World War II atomic bombs was fairly well developed; we may assume that the performance of the device was calculated as accurately as possible in that era, and it is widely accepted that the nth Country design would have exploded with significant nuclear yield.[18]
    - Selden also commented recently that "the design was 'rudimentary' in the same way that the Trinity device was 'rudimentary', when compared to modern nuclear weapons technology. The Livermore Laboratory management decided that their nuclear weapons codes were very adequate for calculating the

[17] Wirz, Christoph, and Emmanuel Egger, "Use of nuclear and radiological weapons by terrorists?" *International Review of the Red Cross* 87(859) September 2005, pp. 497-510. (www.icrc.org/Web/eng/siteeng0.nsf/htmlall/review-859-p497/$File/i rrc_859_Egger_Wirz.pdf)

[18] Robert Selden, private communication.

performance of the nth Country device, and that it was not necessary to build it or conduct a nuclear test. (And in hindsight, I agree completely.) The calculated yield of the device was in the multiple kiloton range, certainly meeting the goal of a 'militarily significant yield' which was laid out at the beginning of the experiment".

  - It does not appear that Wirz's and Egger's complaint that the device was not tested in any way indicates that it would not have worked as designed. The weapons lab had full confidence in its simulation.

- Uranium is toxic and radioactive. Uranium is hard to machine, and many of the machine tools needed for complex mechanical processes such as making neutron reflectors are subject to export controls.
  - The toxicity of uranium is vastly exaggerated in much of the open literature, particularly in articles by groups which oppose the use of depleted uranium in non-nuclear battlefield weapons and in armor. Far more dangerous substances (e.g. beryllium) are routinely handled in laboratories and factories. Similarly, even fissile uranium-235 is not particularly radioactive, and emits rather little radiation. Most of its emissions are alpha particles which can be stopped in a sheet of paper. Highly enriched uranium is, of course, very valuable, as macroscopic samples need to be assembled molecule by molecule, with the end product being used mostly in atomic weapons. It is true that uranium work hardens quickly, but so do many materials. Most of the difficulties of working with uranium metal are well known, and the procedures for such work are not especially onerous, particularly if the machinists are willing to accept the risk of martyrdom.
  - Uranium is actually not a particularly difficult metal to machine. T. O. Morris of Oak Ridge National Laboratory says that uranium is comparable to the stainless steels in machining properties.[19] It is true that uranium is pyrophoric, meaning that fine dust can spontaneously ignite. This is a complication, but not a major one.
- If terrorists had the complete set of working drawings for a nuclear device built by a nuclear weapon state (NWS), they could not build it because they would surely need to make some design changes to accommodate different fissile material and as work-arounds for impossible to acquire technology. But to do that they would have to be fully capable of coming up with an indigenous design. And this they could not do.
  - Much technical information about the components of a fission weapon has either been officially declassified or has leaked out into the public domain – even if it

[19] T. O. Morris, "Machining of Uranium and Uranium Alloys", Y-12 Plant, Oak Ridge, TN, 14 December 1981. (http://www.osti.gov/bridge/purl.cover.jsp?purl=/6580353-AVLjBU/) Accessed on 29 December 2009.

technically remains classified, and sometimes whether it is right or wrong.[20] One can conveniently divide the areas of required knowledge into "fundamental physics" and "practical engineering". The fundamental physics is not dissimilar from the physics of a "fast" nuclear reactor; the practical engineering of a deliverable, safe and reliable nuclear weapon is a different matter entirely. To the extent that modifications are required to accommodate highly enriched uranium that differs slightly from the design enrichment, they can almost be ignored so long as the fully assembled core of the device is super critical and so long as the designer is not wedded to a particular yield.

- Changing the engineering details of even a World War II "Fat Man"-style weapon will be more difficult, but then again, making any kind of implosion-assembled IND is apt to be harder than building a gun-assembled system. One can ask what events might dictate changes. A leading possibility is the unavailability of the explosives needed to form lens charges, but this is unlikely, as the explosives said in public to have been used for Fat Man's lens charges are neither exotic nor uncommon. Lack of sufficient material for a neutron generator might also require some changes.
- Despite these difficulties, the best argument on this point that Wirz and Egger make is this: *some* terrorists probably could not make *some* changes potentially dictated by *some* engineering problems uncovered when trying to build an implosion-assembled nuclear weapon from a blueprint. Conversely, *some* terrorist technical teams could make *some* potentially needed revisions.

- One could not check whether the projectile and target of a gun-assembled device actually fitted together.
  - It is hard to know how to deal with such a narrow comment. Is it intended to be taken seriously? Then it can be disproved quickly. Is it, instead, intended to emphasize the need for testing? In which case it is partially correct, but Jeffrey Lewis and I stressed that our bomb factory needed to be located in a remote area without curious neighbors precisely so that a few "bangs" could be allowed to happen if needed.
  - Consider Wirz and Eggers' comment at face value. If the gun-assembled device looks like the picture in Richard Rhodes' book, *The Making of the Atomic Bomb*, in which a bullet is launched by a cannon into a hollow cylinder made up of rings of enriched uranium, neither ring assembly nor bullet will be even close to criticality under most circumstances. The solid projectile would have to be fired into the center of the ring assembly But, of course, the rings and plug would not be critical when assembled *unless* they were surrounded by a thick neutron reflector, possibly made of tungsten or some other heavy material. So long as the reflector were absent, the plug could be inserted into the center of the target

[20] See for example the Nuclear Weapon Archive website maintained by Carey Sublette: (http://nuclearweaponarchive.org/), accessed 28 December 2009.

> without exceeding one critical mass, and so without initiating a chain reaction. If the target cylinder is made of rings, they can easily be spaced so that the projectile can be checked in each ring without danger of a criticality accident. One wonders how much thought Wirz and Eggers gave to this point in the first place.

The Swiss group raises other technical issues, but none rises to the level of difficulty of either the need to prevent a criticality accident, nor of making major alterations to a design previously specified by another power.

Frost bite

Canadian analyst Robin Frost attained prominence in the nuclear sceptic group with his MA thesis from Simon Fraser University.[21] His reputation rests on his Adelphi Paper,[22] *Nuclear Terrorism After 9/11*. My colleague, Anna Pluta, and I have thoroughly analyzed the flaws in that paper in our article *Nuclear terrorism: A disheartening dissent*[23]. As with Mueller, Frost begins by setting up technical straw men, requirements appropriate to national nuclear weapons programs seeking safe, reliable, rugged and predictable nuclear weapons for use by a nation. For example, Frost posits requirements for precision far in excess of those attainable in 1944-45 when the first nuclear weapons were designed and built. I provide a single example here to illustrate the magnitude of the misconception: Frost suggests that the uranium core would have to be fabricated using "computer-guided machine tools with laser interferometer(s)" and require complex shapes machined to a tolerance of about 10^{-10} meters. This is much smaller than a wavelength of light, and it's clear that no such machine tools were available in the years 1943-45 when the first nuclear weapons were built at Los Alamos.

Frost's arguments discounting nuclear terror as a significant risk do not stand up to analysis.

An evaluation of today's situation

Nuclear terrorism began to be of concern in the specialist community in the 1970s with the publication of John McPhee's book *The Curve of Binding Energy*, a book-length series of interviews with American fission weapon designer Theodore B. Taylor.[24] Taylor, along with Mason Willrich, elaborated on the risks in their book *Nuclear Theft: Risks and Safeguards*[25]. At roughly the same period a number of fictional accounts appeared in novels, the most technically

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[21] Robin Mark Frost, *Would Terrorists Go Nuclear? Motivation and Strategy*, Thesis submitted in partial fulfilment of the requirements for the degree of Master of Arts, Simon Fraser University, 2005

[22] Robin M. Frost, *Nuclear Terrorism after 9/11*, Adelphi Paper 378, International Institute of Strategic Studies, London, 2006.

[23] *Survival*, 48, June 2006, pp. 55-69.

[24] John McPhee, *The Curve of Binding Energy*, Farrar, Straus and Giroux, New York, 1974 (Note: various editions available).

[25] Mason Willrich and Theodore B. Taylor, *Nuclear Theft: Risks and Safeguards*, Ballinger Publishing Company, Cambridge, MA, 1974.

sophisticated of which was *Gadget* by Nicolas Freeling (written with my technical assistance)[26]. Best-selling author Tom Clancy followed up with the less-convincing *The Sum of All Fears*[27] in which terrorists steal a complete weapon. There have been other fictional treatments as well.[28]

When I collaborated on *Gadget* and gave Congressional testimony on nuclear terror back in the 1970s, I hardly dreamed that in 2010 I would still be writing on the same topic; neither did I think that no nuclear attack would come in the intervening 35 years.

But no improvised nuclear device has yet exploded, and there have been no credible reports of an advanced plot to build such a device under way. This is not to say that there have been no credible reports of terrorist groups seeking a nuclear capability. Given this record, why have competent analysts continued to raise the possibility that somewhere there is or could be a nuclear plot brewing?

Serious attention was revised with the collapse of the Soviet Union and the perception that Soviet nuclear weapons and fissile materials were not well guarded. Given a collapsed state with tens of thousands of nuclear devices protected in some cases by not much more than a padlock on a wooden shed, fissile material guarded not much better than potatoes, and senior officers going unpaid for extended periods, it seemed perfectly reasonable to assume that truly modest amounts of money might serve to corrupt the few people needed to extract either fissile material or a complete weapon.

Harvard professor Graham Allison's study *Nuclear Terrorism: The Ultimate Preventable Catastrophe*[29] raised the perceived threat level, and provided one solution: lock up all fissile materials, plutonium and highly enriched uranium, under conditions such as those used to protect the American gold reserves in the vault at Ft. Knox, Kentucky.

The problem with this "Harvard solution" is that we do not know how much fissile material exists[30], so even if all of it were locked up, we could not prove it, nor confidently rely on the notion that all of it were under control. Indeed, the stock of separated plutonium in the former Soviet Union is estimated by David Albright and his co-authors at from 106 metric tonnes to 156 metric tonnes, an enormous range.[31] The same authors suggest that the FSU may have a stockpile ranging from 735 to 1,365 metric tonnes. This includes the 500 tonnes sold to the US to be down-blended to make reactor fuel.

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[26] Nicolas Freeling, *Gadget*, Coward, McCann & Geoghegan, New York, 1977. Also UK edition and several paperback editions.

[27] Tom Clancy, *The Sum of All Fears*, Putnam, New York, 1991 (many editions and publishers).

[28] For example, the disappointing James Mills' *The Seventh Power*, EP Dutton, 1976, ISBN-13: 9780525200505.

[29] Graham Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe*, Times Books, New York, 2004.

[30] Nuclear Threat Initiative on-line Research Library: Russia: Fissile Material Production and Disposition, (http://www.nti.org/db/nisprofs/russia/fissmat/overview.htm), accessed 2 January 2010.

[31] David Albright, Frans Berkhout,William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies*, New York, Oxford University Press Inc., 1997, p. 58.

The enormous gap in our knowledge of Russian fissile inventories far exceeds the uncertainties in the inventories of other nuclear states, whether or not they have nuclear weapons programs. It is probable that the Russian government also does not have good enough records to assess how much fissile material it has produced. The uncertainty in Russia's fissile inventories dwarfs the IAEA significant quantities[32] for HEU and plutonium (25 kg and 5 kg, respectively). Many experts believe that these quantities are too high to provide adequate warning. Clearly the uncertainties in the FSU stockpiles leave a lot of wiggle room for the theft of one or more significant quantities without detection.[33]

In 1993, 4.5 kilograms of 20 percent enriched uranium used for naval reactor fuel were stolen from the Sevmorput ship yard in Murmansk, Russia. A Russian special investigator on the case suggested that in his country "potatoes are guarded better".[34]

Nevertheless, the vigorous actions by the United States to assist Russia and the other states of the FSU to round up and safeguard known stocks of weapons-usable material during the late 1990s and the 2000s have borne fruit. Highly enriched uranium in Kazakhstan was flown out to storage sites in the United States during the 1994 Operation Sapphire and to the US or Russia on subsequent occasions.[35,36] HEU from members of the former Warsaw Treaty Organization (Bulgaria, for example) has also been returned to its country of origin.[37] Access to weapons-grade uranium has been generally restricted since the dissolution of the Soviet Union, but much remains to be done.

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[32] (http://www.iaea.org/Publications/Booklets/Safeguards/pia3810.html.) Accessed 2 January 2010. "SIGNIFICANT QUANTITY – The approximate quantity of nuclear material in respect of which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded".

[33] I am not making the mistake of believing that an uncertainty in the absolute quantity of material on hand translates directly into an inability to detect the extraction of a large fraction of a significant quantity; to a great extent, that depends on the safeguards and detection systems for catching a movement of fissile material. Nevertheless, the uncertainty in inventory does make an accurate physical inventory that demonstrates that all fissile material is properly secured next to impossible, since one does not now the total amount to be expected from a physical inventory.

[34] Global Security.Org (http://www.globalsecurity.org/military/world/russia/murmansk.htm), accessed 3 January 2010. Oleg Bukharin and William Potter, "Potatoes were guarded better", *Bulletin of the Atomic Scientists*, May/June 1995, pp. 46-50. (http://books.google.com/books?id=PgwAAAAAMBAJ&pg=PA46&lpg=PA46&dq=highly+enriched+uranium+murmansk+potatoes&source=bl&ots=2PAh06RYs4&sig=k3Xfixi0E8fmwpoZQ0-WBqCj8Y8&hl=en&ei=RdhAS KICdGgnQfGsvX4CA&sa=X&oi=book_result&ct=result&resnum=1&ved=0CAgQ6AEwAA#v=onepage&q=highly%20enriched%20uranium%20murmansk%20potatoes&f=false accessed 3 January 2010.)

[35] Nuclear Threat Initiative archived web page (http://www.nti.org/db/nisprofs/kazakst/fissmat/sapphire.htm, accessed 2 January 2010.)

[36] World Nuclear News, 20 May 2009, (http://www.world-nuclear-news.org/ENF-Kazakh_HEU_returned_to_Russia-2005094.html, accessed 3 January 2010.)

[37] National Nuclear Security Administration, press release 17 July 2008, (http://nnsa.energy.gov/2075.htm, accessed 3 January 2010.)

For now it is safe to say that there is a lot of fissile material rattling around, and that we do not know how much a physical inventory should show, let alone what it would show. In this circumstance it is not possible to reassure the world that there has been no theft of fissile material, or that any attempt will be detected quickly enough to prevent its being made into a nuclear device. Safeguarded vaults for fissile material are necessary, but they are not sufficient.

While Al Qaeda has been at the top of the list, the Japanese group *Aum Shinrikyo*, now known as Aleph, has demonstrated both an interest in the acquisition of weapons of mass destruction and an ability to execute a limited and barely successful attack using Sarin gas. *Aum* also sought to develop a complete nuclear weapons program at an outback ranch in Australia.[38] The cult purchased half a million acres (approx. 200,000 hectares) of ranch land from which they proposed to mine uranium and where they planned to enrich it and produce weapons. This seems fantastic and impossible, but the group actually invested more than $600,000 of 1994 dollars in the project. It succeeded in extracting small amounts of uranium from the ore deposits on the site. Of course, it did not succeed in any of its grandiose aims, but it tried. Had the money been invested in the "downstream" activities, it seems likely to me that *Aum* could have produced a simple weapon design, obtained most of the necessary hardware to machine uranium, and at least built a mock-up of a gun-assembled nuclear weapon for the same investment. Finding a source for sufficient fissile material probably would have cost several times the initial investment, even in the looser environment of the early 1990s. Despite the fact that *Aum* was badly damaged in the wake of its attack on the Tokyo subway system, it remains in existence.

Matthew Bunn of Harvard has developed a simple mathematical model to estimate the annual risk of a nuclear terror attack succeeding.[39] A major driver is the number of groups N_n which might attempt such a strike. We know that there have been at least two well-funded terror groups which gave serious consideration to the idea. This is two more than John Mueller believes would be interested. Setting the number of potential groups at two, Bunn estimates a "significant acquisition attempt roughly once every other year,[40] and a probability $P_{c(10\ yr)}$ of 29 percent. Bunn also arrives at an annual probability of 5.6 percent for an incident.

Others, notably physicist Richard L. Garwin and former US Defense Secretary William Perry, have estimated the probability of a nuclear terror attack somewhere in the world as 90 percent over a decade.[41] That is 20 percent per year, a frighteningly high number, and one which would require immediate and vigorous action to reduce.

Using Bunn's methodology but different assumptions, one will obtain estimates of the annual probability of a nuclear terror attack ranging from about one percent to at least the Garwin-Perry

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38 Kaplan, David E. and Andrew Marshall, *The Cult at the End of the World*, Arrow Books Limited, Random House UK Ltd (paperback edition), London, 1997, pp. 157-161.

39 Matthew Bunn, "A Mathematical Model of the Risk of Nuclear Terrorism", *The ANNALS of the American Academy of Political and Social Science* 67**,** 1 (2006), pp. 103-120.

40 *Ibid.*, p.106

41 Hearing of the Energy and Water Subcommittee of the US House Appropriations Committee: Subject: Weapons Activities Oversight, 29 March 2007.

number. None of these results is encouraging, and none would lead one to the prescription of John Mueller, that one simply discount the nuclear threat and focus on other problems.

Doing something

Two of my young colleagues, Michael Levi and Simen P. Ellingsen, both formerly at King's College London, have independently produced remarkable and very different works on ways to prevent nuclear terrorism.

Ellingsen's often technical and mathematical Ph.D. thesis[42] focuses on rational choice theory and evaluates various courses of action available to the defense and to the terrorists themselves. His most surprising conclusions are that it may be possible to convince potential nuclear terrorists that "refraining from a certain course of action is in her own interest".[43] Ellingsen conceives deterrence as in the nature of a cost-benefit equation, and assumes that terrorists are capable of such rational action; he does not consider deterrence by retaliation since nuclear terror is apt to come without a well-defined return address, even if the group in question is known. In particular, despite my own earlier optimism, it will be difficult to identify the source of the fissile material with enough certainty to retaliate.

He also analyzes the benefits of investments in safeguarding highly enriched uranium and plutonium. Ellingsen found that uranium was so much to be preferred for an improvised nuclear device (because gun assembly is possible) as compared to plutonium (which requires implosion assembly, a more difficult technology) that the United States, and presumably other countries, have vastly over-invested in protecting plutonium as compared to the investment in protecting uranium.

Levi,[44] on the other hand, deals more with the details of detecting the diversion of special materials and other specific measures for obtaining and understanding strategic warning. His is a more policy-focused work, more accessible to non-specialists, and in parts an important contribution to mitigating the problem.

Both manuscripts are book length, and it is not possible to summarize either or both here.

Conclusion: Yes, be worried

Mueller discounts the consequences of an improvised nuclear device in odd ways. He suggests that a one kiloton ground burst in New York's Central Park would barely damage the buildings on the boundaries of the park. That is true, but the same bomb detonated a kilometer or two away could kill tens of thousands or even one hundred thousand people. If the explosion took place in the financial business district of London or New York – or Paris or Singapore – in the middle of the working day, there could be several hundred thousand dead or wounded from the immediate effects. And the fallout from any of these explosions, even the one in Central Park, would kill

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42 Simen Andreas Ellingsen, *Nuclear Terrorism and Rational Choice*, thesis submitted for the Degree of Doctor of Philosophy, King's College London, University of London, Department of War Studies, 2009.

43 *Ibid.* p. 171.

44 Michael Levi, *On Nuclear Terrorism*, Harvard University Press, Cambridge, MA, 2007.

many tens of thousands more. And Mueller decries the statement that such a bomb could “destroy” a major city; he points out that only a small fraction of the city would be destroyed, just as only a fairly small part of Hiroshima died from a larger bomb.

I find myself horrified at the effects of even a very small nuclear explosion in a city. Perhaps that is because I have worked at the Nevada Test Site and walked the terrain where, fifty years ago, the United States tested atomic bombs against real buildings, homes such as those Americans live in and cars such as those we drove then.

The important fact to face is that – despite the nuclear Pollyannas who argue that the construction of an improvised nuclear device is too difficult for even a well-financed terrorist, that obtaining sufficient fissile materials is nearly impossible, that the theft of an intact weapon is not going to happen (any longer), and that we may safely relegate nuclear terrorists to the fantasies of nuclear alarmists and the subjects of bad television and movies – the probability of a nuclear terrorist attack in any given year remains significant. Whether the probability is 20 percent, 5 percent, or even as low as one percent, the consequences of an incident are enormous. Significant investment to deter, prevent, detect, and destroy a nuclear terror plot is required. So is investment and research into ways to mitigate the effects of an attack, should all of our defenses fail and a nuclear detonation occur in one of the great cities of the world.