Nuclear Terrorism Post 9/11: Assessing the Risks

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Robin Frost, Simon Fraser University

Robin Frost was born in South Africa a long time ago. His first degree was a Bachelor of Journalism with a joint major in psychology from Rhodes University. He then took an Honours degree (a separate, post-grad degree in SA) in psychology with distinction and full University Colours for academic achievement, also at Rhodes. He taught full-time in the journalism department for a year and then went into the graduate clinical psychology program. After completing all the course work and spending a while as an intern psychologist in a mental hospital he decided he wasn't suited to the work. Frost then taught at Rhodes for a further six months before joining Radio 702, South Africa's only effective non-state radio station, at the height of apartheid repression and the rebellion against it.

Frost spent two years there as a senior reporter and news editor/anchor before the conditions of martial law made it impossible to do an honest job of journalism. The next six years were spent in industrial training and teaching at a technical university, where he published a popular textbook on communications.

My wife and he came to Canada at the end of 1993, disturbed by the level of violence in South Africa and the potential instability around the elections. Most of his time here has been spent either unemployed or under-employed, although he was a technical writer in a software company for two years before the melt-down of 2001. After finally deciding that the academy is his natural home, he came to Simon Fraser University as a qualifying graduate student at the end of 2002 and plan to complete his MA, by thesis, in mid-2004. Frost may go on to a PhD, although his plans are not yet final. Frost's present interests are in international relations, with a particular emphasis on security studies. He have two little boys, Alric, aged 16 months, and Griffin, aged four.

Abstract

This paper is a comprehensive survey of the most potentially dangerous form of terror: nuclear terrorism. It provides a rough hierarchy of the various forms of nuclear terror and then deals with four main topic areas in detail: 1) nuclear smuggling, including the questions of the "loose nukes" of the former Soviet Union and the status of the FSU's nuclear complex; 2) terrorist nuclear weapons and the feasibility of terrorists constructing them from stolen materials; 3) radiation dispersal devices (RDDs or 'dirty bombs'); and 4) attacks on nuclear reactors.

The paper concludes that of all the possible scenarios, the detonation of a nuclear weapon is probably the least likely, for a variety of technical and political reasons, and that while attacks on nuclear reactors are feasible and could be extremely damaging, the most probable event is the detonation of an RDD using a medical or industrial radiation source, possibly obtained within North America. It is acknowledged, however, that terrorists always (unfortunately) have the capacity to surprise."

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Concern about nuclear[i] terrorism has been current since at least the late 1970s, when Louis René Beres published his seminal book, *Terrorism and Global Security: The Nuclear Threat*[ii]. Since that time two events have added incrementally to what is now a very grave level of international concern: the dissolution of the Soviet Union and its empire in 1991, and the destruction of New York's World Trade Center a decade later. The first raised the possibility, not previously contemplated, of functioning nuclear weapons falling into the hands of sub-national actors or 'rogue' states, while the second has permanently changed the view that terrorists were averse to causing mass casualties, the so-called 'proportionality principle'[iii].

In this paper we will explore nuclear terrorism in some of its many aspects and attempt a realistic evaluation of the threat. Our perspective will inevitably be North American, if not actually American, not only because of our own physical location but also because it is obvious that the United States is presently the prime target for major international terrorist groups. In our analysis we will address, and in some cases attempt to debunk, some of the following popular beliefs relating to nuclear terrorism:

1. Useable plans for nuclear weapons are in the public domain and easily obtainable

2. If terrorists obtained sufficient fissile materials, it would be relatively easy for them to construct a nuclear weapon

3. There is a constant flow of smuggled nuclear materials, including significant amounts of weapons-grade fissile materials, from the states of the former Soviet Union (FSU)

4. "Loose" nuclear weapons, including the infamous 'suitcase nukes', have been, or may at any time be, smuggled out of the FSU and into the hands of terrorists or rogue states

5. Radiological dispersal devices, or ‘dirty bombs’, would have to be built abroad, probably in the FSU or Middle East, and smuggled into the United States

6. The security around North American reactors has been updated since September 11, 2001, and is designed to protect against all reasonably foreseeable terrorist threats

It has become customary at around this point in any writing on terrorism to step into the murky waters of definition; we will try to avoid the temptation to take a dip, although a gentle paddle in the shallows is probably unavoidable. As Mark Burgess points out, “defining terrorism has become so polemical and subjective an undertaking as to resemble an art rather than a science”[iv]. Some writers, such as Konrad Kellen, would go so far as to say that the attempt is almost entirely futile: “it is a practically meaningless concept from both the operational and policy point of view and even from the analytical one”[v]. The debate is old, potentially interminable, and only occasionally interesting. For the purposes of this paper, therefore, I will use the term ‘terrorism’ in a purely operational sense to describe acts or threats of violence, which typically but not necessarily have a strong communicative or symbolic aspect and are aimed at civilian populations, carried out for political purposes by non-state organisations, in the full awareness that there may be philosophical problems with the definition and with the right to use it inconsistently whenever I like explicitly reserved. To quote Kellen once more, “analysts who try to discuss some aspects of possible future nuclear terrorism need to do so in full consciousness that they are wading into a morass of confusion and fuzziness, and readers must realize the same thing”[vi].

The most popular understanding of ‘nuclear terrorism’ probably involves a scenario in which terrorists detonate a stolen or home-made nuclear weapon in a major population centre. While this would indeed be the worst form of nuclear terrorism, it is far from the only potential type, and quite possibly the least likely. The range of activity that can be subsumed under this rubric is actually quite large, ranging, perhaps, from threats or blackmail involving small amounts of radioactive material, through environmental contamination with radioactive materials, to the detonation of “dirty bombs” (radiological dispersal devices, or RDDs), and thence to the ultimate in nuclear terrorism, the detonation of some sort of nuclear weapon.

The following is a rough hierarchy of nuclear terrorism, ordered from lowest to highest level of threat. While the list could probably be subdivided indefinitely, I have tried to delineate some of the major possible alternatives. Obviously, the ranking is somewhat arbitrary as the lethality of some events depends on a host of variables, many of them highly technical and some of them unknown or even potentially unknowable, such as the yield of a home-made fission[vii] bomb, some aspects of reactor meltdown, or the eventual number of premature deaths attributable to a radiation release. There is also the intriguing question of where to rank a credible nuclear hoax, given the immense panic and disruption it could cause if widely publicised.

1. 1. Theft or sabotage of things nuclear materials for demonstration purposes
2. 2. Attack on a nuclear reactor or other facility to spread alarm
3. 3. Capture of a nuclear reactor for blackmail
4. 4. Environmental contamination – of a city water supply, for example – with radioactive material
5. 5. Sabotage of a reactor, storage dump, or other nuclear facility short of meltdown
6. 6. A credible, widely-publicised nuclear threat that proves to be a hoax
7. 7. Detonation of an RDD
8. 8. Detonation of a low-yield home-made fission device or ‘fizzle bomb’
9. 9. Damage to a nuclear reactor including core meltdown, containment breach and large-scale radiation release
10. 10. Detonation of a functional nuclear weapon[viii]

The dissolution of the Soviet Union and its empire led to much anxious speculation around the world about the disposition of its nuclear arsenal and the security of its entire nuclear complex. Under Soviet rule, internal dissent was so ruthlessly and effectively repressed that there were no real government concerns about domestic threats to the nuclear apparatus. The security perimeters of the civilian and military arms of the nuclear weapons industry were essentially contiguous with the borders of the Soviet Union itself; the USSR did not even have specific laws against the illicit acquisition, possession, transport, and use of radioactive materials until as late as 1988[ix].

Exceptions to this rule, such as the security around the secret “atomic cities”[x], appear to have been designed to protect elements of the complex against espionage by foreign agents, rather than attack or sabotage by domestic groups.

If the Soviets paid considerable attention to preventing “outsiders from getting in,” they paid less attention to the threat of “insiders getting out.” Soviet nuclear scientists and others who worked at these facilities constituted an elite, privileged segment of Soviet society. They and their dependents enjoyed a higher standard of living than average Soviet citizens. There was little incentive for a Soviet scientist to steal fissile materials, even on the unlikely chance that he could have found a buyer. Because the Soviets seldom worried about scientists or other insiders removing fissile materials without permission, the technical control and accountancy systems needed to deter or detect theft were never adequately developed.[xi]

With the demise of the Soviet Union in 1991, the economic collapse of most of its constituent states, and the opening of its formerly all-but impenetrable borders it appeared possible that impoverished and demoralised elements of the armed forces or the nuclear workforce could actively or passively allow radioactive materials, or even nuclear weapons, to fall into the hands of terrorist groups or ‘rogue’ states.

While nuclear smuggling, defined here as the smuggling of radioactive or fissile materials, parts of nuclear weapons, or intact weapons, has undoubtedly taken place, there is little consensus as to its extent or import. The International Atomic Energy Agency (IAEA) is probably the most reliable source on the topic: the following graph and table[xii] reflects all incidents of nuclear trafficking, world-wide, known to the Agency as of 2002.

It is striking that in the busiest year on record, 1994, there were only 46 known incidents of nuclear trafficking, world-wide, and that while the trade seems to have been growing slightly in recent years after a low in 1999, there were only 16 incidents in 2001. Most of the incidents have involved small quantities of non-fissile, non-weapons useable material. However, there are six individual incidents worth noting that involved significant amounts of fissiles:

- In 1992, about 1.7kg of HEU was stolen from the Luch Scientific Production Association at Podolsk, Russia

- In 1993 a Russian naval captain stole about 5kg of HEU from a submarine fuel facility in Murmansk

- 5.6 grams of 'super-grade' plutonium was discovered in the garage of a minor criminal being investigated for other offences in Tengen, Germany, in 1994

- a little less than a gram of HEU was seized in a 1994 police sting operation in Landshut, Germany,

- a sting operation in 1994 led to the seizure of "almost a pound"(!) of near-weapons grade plutonium at the Munich airport in 1994 (Plutonium approaches critical mass in quantities of more than 300 grams.[xiii] A pound is 454 grams.)

- also in 1994 about three kilograms of HEU were seized in Prague[xiv]

Even in these cases, the thefts were either by opportunists without ready buyers or as a result of police stings. (The Tengen incident remains mysterious, however.) In no case except, perhaps, the Munich airport incident, did the amount of material approach anything like the quantity required to build a fusion weapon, although they could obviously have been used, to varying effect, in RDDs.

Most writers acknowledge that there has been very little *known* smuggling of nuclear material from the former Soviet Union (FSU), that a tiny percentage, if any, of the material involved was weapons-useable, and that there has almost certainly been no smuggling of nuclear weapons. Others, however, continue to point to incidents such as the 1997 claim[xv] by former Russian Security Council chief General Alexander Lebed that in an audit he could account for only 48 of 100 (or 132)[xvi] backpack-sized nuclear weapons – the notorious 'suitcase nukes' – as reasons for serious concern.

There is probably no other topic in our purview that has generated quite so much heat, and so little light, as that of suitcase nukes – miniaturised, human-portable nuclear weapons. The anxiety about such weapons falling into terrorist hands is understandable, especially when there is such a poor ratio of fact to speculation on the matter.

Probably the most comprehensive review of open-source materials on the topic of suitcase nukes was written by Nikolai Sokov[xvii]. He first addresses the question of whether such devices exist or, indeed, have ever existed. So little is known about them, he says, that they have a "mythological quality" and "often seem a matter of fiction rather than that of fact"[xviii]. The concrete evidence about them is "sketchy and incomplete", consisting mainly of hints, inferences – such as the likelihood that the Soviet military had emulated the American development of small atomic demolition munitions (SADMs[xix]) – and allegations. Nonetheless, Sokov concludes that:

> [i]n spite of official denials, there are sufficient grounds to believe that the Soviet Union had one or more types of portable nuclear devices. Most likely, these were devices designed for the use by Special Forces (Spetsnaz), analogous to the American SADM, or using the physics package similar to that contained in artillery shells. The widely used word "suitcase" is misleading since these devices were quite heavy (no less than 60 lb, probably considerably more), but they could have been moved by one, but more likely, two people.[xx]

Even if terrorists could have obtained such weapons, however, there would have been significant obstacles to their using them. Sokov quotes Igor Valynkin, the chief of the 12th GUMO, the Main Department of the Russian Ministry of Defence tasked with handling all nuclear weapons, as saying that the devices would have had very short maintenance schedules, possibly as little as six months. If certain crucial components, such as tritium boosters, were not replaced at regular intervals the bombs would go 'stale' and their nuclear yield could drop to close to zero. Since the window of greatest opportunity for theft occurred in the early 1990s, if any weapons were diverted at this point they would by now have missed twenty or more services and would be at or near the end of their useful lives.

Furthermore, while the weapons would probably have initially been built to be placed behind enemy lines by individuals or small teams and therefore may have been easily armed, it is likely that during their frequent visits to the factory for maintenance they would have been upgraded to include permissive action links (PALs) that would make their arming by unauthorised persons impossible. In that case, even if they were still fresh, they would serve, at best, as sources for small amounts of fissile materials that could almost certainly not be reassembled into functioning weapons, although they could still be used in RDDs.

Sokov argues that stories about the loss of miniature weapons "were most probably not true, and … they were generated by incomplete information or ulterior motives". His reasons for that conclusion include the fact that "no terrorist group has used such a device or even credibly threatened its use. … Since the majority of feasible scenarios involve Chechens, and since the period of greatest risk was in the early 1990s, the inactivity of Chechens in this matter is significant."[xxi]

Sokov concludes that "[e]ven assuming that some portable nuclear devices were lost, it would be very difficult to use them, and it is almost certain that the features that make portable nuclear devices so dangerous (small size and full-scale nuclear explosion effects) will not be taken advantage of"[xxii]. Concerning the possibility that components of suitcase nukes could be used in RDDs, Sokov says that "in this case, the problem of suitcase nukes is virtually indistinguishable from the broader problem of safety and security of all Russian nuclear weapons and weapons-grade fissile materials"[xxiii].

To return to the broader topic of nuclear smuggling, those who claim that it constitutes a real risk argue that the known incidents constitute only a fraction, possibly a very small fraction, of the actual trade. An analogy with the seizure rate for smuggled illicit drugs, in which the quantity seized by customs is known to be a relatively tiny proportion of the entire trade, is frequently drawn. That logic is questionable, however, since there is no evidence of nuclear smuggling other than seizures, whereas the evidence for successful drug smuggling is ubiquitous. For example, there is still no sign that even so well-monied and unscrupulous a would-be proliferator as Saddam Hussein was able to obtain a single nuclear warhead nor even significant amounts of related materials or technology from the FSU, despite reportedly spending $10 billion, by 1996, on his attempts to acquire a nuclear capability[xxiv]. Similarly, there is no evidence that Osama Bin-Laden of Al-Qaida has been able to obtain fissile materials, let alone nuclear weapons, although there is evidence of his interest in doing so. In fact, he was probably cheated at least twice in the attempt[xxv]. The claim that "the *real* nuclear smugglers aren't being caught because they're devilishly clever" is reminiscent of the – possibly disingenuous – pre-war American statements that U.N. arms inspectors could not find Iraqi weapons of mass destruction because they were so well-hidden, which in turn was taken as further proof of Saddam's malice and cunning.

Of the known cases of nuclear smuggling, the vast majority have involved 'radioactive junk' (low grade reactor waste or other material that would be of no military use) or were outright scams, such as the 'red mercury' explosives hoax that caused such an uproar in the 1980s and early 1990s, while others, including most of the more serious cases, were actually sting operations initiated and stage-managed by Western intelligence agencies.

In sum, the visible manifest market for nuclear materials appears disorganised, chaotic, dominated by bumbling amateurs, and artificial in important respects; genuine buyers with real money seldom make an appearance, even in the few cases where weapons-usable materials are offered for sale. … Moreover … the nuclear materials flowing through international smuggling channels frequently are nothing more than artifacts of undercover operations.[xxvi]

The International Atomic Energy Agency (IAEA), concurring, says that

The great majority of detected trafficking incidents appear to involve opportunists or unsophisticated criminals, motivated by the hope of profit. … Nevertheless, it is apparent that an important fraction of cases involved persons who expected to find buyers interested in the radioactive contents of stolen sources and their ability to cause or threaten harm.[xxvii]

As we have seen, the theft of nuclear materials within the FSU and their smuggling abroad seems to be almost exclusively supply-driven; that is, there is little or no clear evidence for the demand side of the trade. This might explain why the 'Mafiya', the Russian organised crime syndicates, apparently have little or no real interest in the business. Then-CIA director John Deutch, speaking to a U.S. Senate committee in 1996, said: "We have no evidence … that large organised crime groups with international connections are involved in the trafficking of radioactive materials." [xxviii] Lee, meanwhile, quotes "European police officials", spokesmen for the Russian internal security agencies, and Russian Interpol, as saying much the same thing[xxix].

Although it continues to appear that nukes and other materials in the FSU are indeed loose, there is little or no evidence that terrorist groups *per se* are involved in nuclear smuggling. As we have already noted, for example, there is no sign that Chechen separatists, who would probably be the best-placed of all terrorist groups to take advantage of the situation in the FSU, have obtained anything beyond a small amount of cesium, their claims to the contrary notwithstanding. Leonard Spector, for example, remarks that "[f]or now, virtually all the activities in the nuclear underground are pursued at the behest of a small number of national governments rather than by criminal, dissident, or terrorist groups"[xxx].

Terrorists so far seem to have preferred well-known, easily obtained, and easily managed 'traditional' weapons to the risks involved in obtaining, transporting, and using radioactive materials[xxxi]. There is no guarantee that this state of affairs will obtain forever, though.

Our discussion of nuclear smuggling has until now involved a fairly narrow definition. If we expand it to include nuclear-*related* goods and materials and do not restrict it to the FSU, however, the known smuggling trade becomes much larger. Spector[xxxii] describes a number of incidents that took place prior to the Soviet Union's collapse and involving a number of states, the "most egregious" example being the rather startling smuggling between 1977 and 1980 of *an entire plant* for converting uranium to uranium hexafluoride to Pakistan in 62 truckloads by a West German businessman, who also supplied a team of engineers to supervise its final construction. Others involved items such as krytrons (high-speed switches used in nuclear weapons), hardened steel pipes for gas centrifuge uranium enrichment plants, zirconium metal, and so forth. In all of the cases the buyers were clandestinely proliferating states – Pakistan and Israel – rather than terrorists, and the materials were evidently intended for use in establishing sustainable 'indigenous' nuclear capabilities, rather than for immediate military purposes.

That the known illegal trade in fissile and radioactive materials from the FSU has thus far been small and apparently involved neither terrorists nor weapons is not necessarily cause for complacency. The FSU's nuclear complex, from its uranium mines to its weapons factories and rocket bases, remains insecure and its armed forces are chronically underfunded.

Within the complex, Russia's formerly super-secret 'nuclear cities' are a source of particular concern. Not only do they house nuclear plants and related radioactive materials under less than perfect security, sometimes under no meaningful security at all, they are also home to thousands of unemployed and demoralised former nuclear workers who might be easy targets for criminal or terrorist groups. As just one example of the state of Russian nuclear security, consider the world's largest civil plutonium stockpile at the Mayak reprocessing facility in Chelyabinsk-65, one of the 'nuclear cities'. It was said, in 1995, to house *thirty tons* of separated plutonium in "an ordinary converted warehouse, with windows in the walls and a padlock on the door"[xxxiii].

In the 1990s Russia laid off 90,000 workers, more than half the nuclear complex's total workforce, and has plans to lay off 35,000 more[xxxiv], many of whom are nearing Russia's low retirement age (55 for men) and will therefore be difficult to place in alternative employment. The risk of a serious 'brain drain' of scientists leaving Russia to assist rogue proliferators or terrorists has not been lost on either Russia or the U.S. Fortunately, it does not seem to have materialised:

A handful of Russian nuclear scientists emigrate each year, mostly to Germany, Israel, Sweden, and the United States. So far the evidence is mostly anecdotal that Russian nuclear weapons experts are contributing to bomb programs in countries labeled by the United States as "proliferation concerns." Nor is there proof that al-Qaeda or other terrorist organizations have acquired nuclear weapons and expertise from Russia.[xxxv]

The possibility remains, however. Recognising this, the U.S. has tried to help Russia secure livelihoods for its redundant nuclear workers by means of the Nuclear Cities Initiative (NCI), Initiatives for Proliferation Prevention (IPP), and the International Science and Technology Center (ISTC). These programs are intended to enhance security throughout the nuclear complex and "create alternative nonmilitary jobs for nuclear weapons-related workers who might otherwise be driven to sell their nuclear knowledge or to steal weapons-related materials and components"[xxxvi].

These programs have been notably unsuccessful. Despite the programs' stated goals, few permanent jobs have been created, although short-term contracts have kept many Russian nuclear workers financially afloat during the most difficult times, and much, even most, of the money allocated to the programs has actually been spent in the United States due to the political strings attached to the programs' funding.

The IPP, for example, describes its present status thus:

Of [the FSU weapons scientists, engineers, and technicians subject to government cutbacks], 60,000 constitute a proliferation concern. Since program inception, IPP has engaged 13,000 NIS scientists, engineers and technicians: *6700 are engaged in currently active projects* (increase of almost 1400 from FY2001). Currently there are 176 projects (64 in the closed nuclear cities of Russia) underway at 57 institutes in Russia; 14 projects underway at 6 institutes in Kazakhstan; and 13 projects underway at 9 institutes in Ukraine. [emphasis added][xxxvii]

In other words, at its present best the IPP employs a little more than ten percent of the workers deemed to be a "proliferation concern", and that number does not include the 35,000 workers that are due to be laid off between 2005 and 2012.

Russia's own conversion program for nuclear workers only created 8,100 jobs between 1998 and 2000, "far short … of the tens of thousands that will ultimately need to be created"[xxxviii]. The Russian Ministry of Atomic Energy (MinAtom) estimates that it costs $10,000 to create a permanent job for a former nuclear worker[xxxix] so that $350 million would be required to employ only those due for layoff; the U.S. Baker-Cutler report, meanwhile, estimates that "over the next eight to ten years, the cost of creating jobs in the nuclear cities could reach $700 million"[xl].

Part of the problem is that the U.S. programs are apparently seen by the current Bush administration and the Congress as foreign aid handouts to a defeated former foe, and not as investments in a vitally important aspect of American and global security. As Weiner points out, “the administration's 2001 review of U.S. nonproliferation assistance to Russia recommended a reduction in DoE cooperative nuclear security programs of 32 percent, cutting NCI by 75 percent and IPP by 10 percent”[xli].

There are also serious problems in the FSU’s non-weapons related nuclear industries. Three Russian writers, Leonid Bolshov, Rafael Arutunyan and Oleg Pavlovsky, point out that industrial and medical radiation sources in the FSU should be considered in a much more serious light than they have been until now. Unlike reactor fuel, these materials “were created by mankind for the very purpose of creating ionizing radiation … [It] includes nothing extra, not U^{238} and not a lot of construction materials. It is a highly concentrated radiation producing product.” [xlii] The control over such sources in the former USSR is said to be poor with, for example, a number of radioisotopic thermoelectric generators (RTGs, commonly used in unmanned lighthouses) that contain significant quantities of highly radioactive strontium-90 (Sr^{90}), having no physical protection and being effectively lost to any control or monitoring, or simply lost altogether.

During the Soviet era “a large quantity of powerful radiation sources” accumulated in various facilities and were either stored, “thrown out”, or sold “in an uncontrolled fashion”[xliii]. Boslshov *et al* claim that these sources would be ideal for the construction of RDDs: “The mass of radionuclides to be added to an explosive device could be very small [and there] are no technical problems in producing such types of radiological weapons”[xliv].

Clearly, if controls within the nuclear weapons complex are lax, those in the FSU’s industrial and medical fields are all but non-existent. One of the most striking and best-known demonstrations of this fact was the planting of a container of highly-radioactive $cesium^{137}$ from a medical radiation device in Moscow’s Izmailovsky Park in 1995 by Chechen separatists. It was followed by claims by a Chechen leader that it represented “just a meager portion of the radioactive materials that we possess”[xlv]. Bolshov *et al* caution that this statement might be simple braggadocio, but at the same time they remind us that “one of the largest radioactive waste storage facilities in the world is located in the territory of Chechnya”[xlvi]. (But see below for more on Chechen seperatists and nuclear terrorism.)

There is also a real risk of terrorists obtaining nuclear materials from places other than the FSU. In an article provocatively titled “Loose Nukes of the West”, Alan J. Kuperman claims that “[a] particular vulnerability is posed by civilian commerce in highly enriched uranium” which is still used at “many research and commercial facilities in North America and Europe that lack adequate security forces” [xlvii].

In fact, while Russia has been gradually tightening controls on bomb-grade materials, the United States and Europe have been slackening theirs, and a bill moving rapidly through Congress would roll back protections still further. Unless remedial action is taken, Osama bin Laden may soon have better luck shopping for nuclear bomb material in Western markets than in the former Soviet Union.[xlviii]

In a rather more scholarly and technical analysis, the Center for Nonproliferation Studies (CNS) describes the very large number of ‘orphaned’ – “lost to institutional control” – medical, industrial and research radiation sources around the world, including the U.S. and Western Europe.

> Up to 500,000 of the two million soures in the United States may no longer be needed and thus could be susceptible to becoming orphaned. In the United States, as many as 375 sources have been reported as orphaned in a single year. Over the latest five year reporting period from October 1996 to September 2001, on an annual average basis, 300 sources fell into this category. Of these, 56 percent were not recovered. … Because users tend to be disinclined to report sources as orphaned, many more sources are likely to belong to this category.[xlix]

Not all of these sources are necessarily pose a potential threat. The CNS says that of the millions of commercial radiation sources worldwide, only “a small fraction … perhaps tens of thousands, pose inherently high security risks because of their portability, dispersability, and higher levels of radioactivity”[l]. These are sources that contain “more than a few curies worth” of radioactivity, or roughly more than a gram or so, of any of seven radioisotopes: americium-241 (Am^{241}), californium-252 (Cf^{252}), cesium-137 (Cs^{137}), cobalt-60 (Co^{60}), iridium-192 (Ir^{192}), plutonium-238 (Pu^{238}), and strontium-90(Sr^{90})[li]. Some of these isotopes – Pu^{238}, Am^{241}, and Cf^{252}, which are chiefly alpha-emitters – would only be damaging if inhaled or ingested, while the others, which emit gamma radiation that can penetrate skin and many other materials, would be dangerous both internally and externally.

This has obvious implications for terrorist use in RDDs. While terrorists might want to use the highly radioactive gamma sources because of their greater lethality, “even suicidal terrorists might not live long enough to deliver an RDD because they might receive lethal acute doses of these sources in the absence of adequate shielding”[lii]. Alpha emitters (including plutonium-238 metal, despite its fearsome reputation), by contrast, “could be handled safely without heavy shielding” provided the substances were neither inhaled nor ingested. The heavier plutonium isotope commonly used in bombs, Pu^{239}, is an extremely dangerous material, especially in its oxide powder form. The maximum amount of Pu^{239} that can be “indefinitely maintained in an adult without significant injury” is 0.008 microcuries (equal to 0.13 micrograms, or just more than one ten-thousandth of a gram), an almost unimaginably small amount[liii].

Orphaned radiation sources world-wide constitute a serious security problem. If any were deliberately dispersed via RDDs, the consequences could be severe. RDDs will be discussed in more depth later in this paper, but for now we will move from nuclear smuggling to the question of terrorist nuclear weapons.

Even if it is unlikely that intact nuclear weapons or significant quantities of weapons-grade fissile materials have been smuggled out of the FSU or been stolen elsewhere, we must still consider the possibility that terrorists could assemble a simple fission weapon. Opinions on this are sharply divided. Cameron probably represents the majority:

[I]f terrorists were intent on building a nuclear weapon, their biggest technical difficulty would probably be the acquisition of fissile material. The design for a crude nuclear device has been publicly accessible for 25 years and relies on technology that, while challenging in the 1940s, is almost certainly no longer so, particularly if terrorists are content with a crude nuclear weapon, of variable and uncertain yield.[liv]

J. Carson Mark *et al*, however, in a thoughtful and detailed paper, make a credible case that while building a functional nuclear weapon might be possible, it would certainly not be easy. This article will be dealt with at some length, as it is a valuable counterpoise to the frequently-repeated and rather glib assertion that 'plans' for nuclear weapons are lying around, whether physically or in cyberspace[lv], for the taking. The late Manhattan Project physicist Luis Alvarez, for example, is quoted without comment by Kuperman as having said that "terrorists, if they had such material, would have a good chance of setting off a high-yield explosion simply by dropping one half of the material onto the other half"[lvi]. (This might be – very loosely – true for a uranium bomb; however, see the discussion below for the risks of pre-initiation or 'fizzling', which are especially serious in plutonium weapons.)

Mark *et al* agree that "schematic drawings" showing the conceptual structure of a crude nuclear weapon have indeed been available for years. They argue, though, that the devil is in the details:

[T]he detailed design drawings and specifications that are essential before it is possible to plan the fabrication of actual parts are not available. The preparation of these drawings requires a large number of man-hours and the direct participation of individuals thoroughly informed in several quite distinct areas: the physical, chemical and metallurgical properties of the various materials to be used, as well as the characteristics affecting their fabrication; neutronic properties; radiation effects, both nuclear and biological; technology concerning high explosives and/or chemical propellants; some hydrodynamics; electrical circuitry; and others. … In any event, the necessary attributes [of the nuclear weapon construction team] would be quite distinct from the paramilitary capability most often supposed to typify terrorists.[lvii]

Even allowing that terrorists could somehow create or obtain adequate blueprints, there would still be substantial technical hurdles to be overcome. For example, there is the question of whether the fissile material were powdered enriched uranium oxide reactor fuel, metallic HEU fuel elements, or plutonium. Each of these materials requires different preparation and handling. For example, powdered uranium oxide fuel can be converted into uranium metal, a difficult, lengthy and specialised chemical process, or it can be used in a weapon 'as is', which J. Carson Mark *et al* consider "the simplest and most rapid way to make a bomb"[lviii]. In that case, however, "the terrorists would [still] need accurate information in advance concerning the physical state, isotopic composition, and chemical constituents" of the material, and would also require a larger quantity of material and "a larger weight in the assembly mechanism to bring the material into an explosive configuration" [lix].

The mass of uranium oxide powder would have to be very large indeed:

Even [if the powder were] at full crystal density, the amounts are large enough to appear troublesome: ~55kg (half bare crit) for 94 percent uranium oxide and ~17.5kg for plutonium. However, the density of powder as acquired is nowhere close to crystal density. To approach crystal density would require a large and special press, and the attempt to acquire [one] … might blow the cover of a clandestine operation. … The option of using low-density powder in a gun-type assembly should be probably be excluded on the basis of the large material requirements. There remains the possibility of using a rather large amount of oxide powder (tens of kilograms or possibly more) at low density in an implosion-type assembly and simply counting on the applied pressure to increase the density sufficiently to achieve a nuclear explosion. Some sort of workable device could certainly be achieved in that way. However, obtaining a persuasive determination of the actual densities that would be realised in a porous material under shock pressure (and thence the precise amount of material required) would be a very difficult theoretical (and experimental) problem for a terrorist team.[lx]

No matter what materials were used, the "the amounts of fissile material necessary would tend to be large – certainly several, and possibly ten times – the so called formula quantities", which would also make the completed device very large, "not as large as the first atomic weapons (~10,000 pounds) … but certainly more than a ton" [lxi]. It must also be noted that building an implosion bomb requires considerably more expertise, especially in the design and construction of the high-explosive components, than does a gun-type bomb.

Plutonium metal might be a more attractive basis for a nuclear weapon, if only because smaller, possibly more easily smuggled quantities are required. However, it is not suitable for use in a gun-type assembly as the risk of pre-initiation or 'fizzling'[lxii] is too high, largely because it is too difficult to achieve suitably high assembly velocities. Either pure metallic uranium or plutonium could be used in an implosion device, although it would be difficult, and require very specialised expertise, to ensure even in an implosion bomb that the velocities were high enough to prevent fizzling. A fizzled bomb could yield little more than its own mass in high-explosive equivalent, but if the assembly velocities were reasonably high, "the lowest preinitiation yield may still be in the 100 ton range, even in a crude design".

Stanislav Rodionov[lxiii] argues that while fizzling is undesirable for a military bomb, it might not be a significant concern for a terrorist. Even if a fizzled bomb yields little or no more explosive force than an equivalent mass of TNT, it could nonetheless achieve some important terrorist goals. First of all, it would demonstrate that terrorists had and were willing to use nuclear devices, with a concomitant impact upon public opinion. Second, while the explosive yield might be low, nuclear reactions are "characterized by higher effective temperatures. This results in a more powerful shockwave and thermal effects"[lxiv]. Third, a fizzled bomb would be an extremely 'dirty' bomb. Indeed, it could even be considered a nuclear-powered RDD, rather than an atomic bomb. It would produce toxic isotopes, both long- and short-lived, of cesium and strontium and, if plutonium were used, the bomb would also disperse a cloud of toxic plutonium oxide aerosol that could poison a large number of people. Like Mark *et al*, Rodionov does point out that a fairly large amount of plutonium would be required even for a simple gun-type device in which fizzle would be tolerated, or even desired: "The "threshold" amount of plutonium for such a device might exceed to some extent the mass of plutonium for an ordinary nuclear warhead."[lxv]

In conclusion, potential nuclear terrorists would encounter no serious technical problems in constructing a simple low-yield (in the order of a few tons of TNT equivalent) and low-weight (in the order of a hundred kilograms) gun-type nuclear explosive device using weapons-grade or reactor-grade plutonium. A device of this kind would have destructive and thermal kill ranges of about 100 meters. Moreover, it would produce radioactive fallout with a total intensity of a few tens of curies as well as a cloud containing a few kilograms of plutonium oxide aerosol.[lxvi]

One point in favour of terrorists building an atomic bomb is that they would presumably not be concerned by some of the many demands that are made of legitimate bomb designers, including the need to meet certain engineering and safety standards. At the same time, they would still have to ensure at least that the bomb or its high-explosive content would not accidentally detonate during transport and handling and that not too many members were sickened or killed by radiation during bomb manufacture or transport. (An organisation well-supplied with willing potential martyrs might not be too concerned about the latter risks, although the prospect of a lingering and miserable death from radiation sickness or radiation-induced cancer would probably not be nearly as attractive to potential martyrs as a swift, spectacular death in the heat of 'battle'.) While they would not have to meet military engineering standards for specifications and tolerances, "quite demanding requirements on these [safety and transport, etc] points would still be necessary"[lxvii].

On the topic of more sophisticated – smaller, lighter, more efficient, and higher-yield – weapons, Mark *et al* say that:

[I]t cannot be asserted that by stealing only a small amount of fissile material a terrorist would be able to produce a device with a reliable multikiloton yield in such a small size and weight as to be easy to transport and conceal. Such an assertion ignores at least a significant fraction of the problems that weapons laboratories had had to face and resolve over the past forty years. … The production of sophisticated devices therefore should not considered to be a possible activity for a fly-by-night terrorist group. It is, however, conceivable in the context of a nationally-supported program able to provide the necessary resources and facilities and an established working place over the time required.[lxviii]

(This obviously raises the complex question of state-sponsored terrorism. We might ask, for instance, whether it is even conceivable that a state that sponsored terrorists to build a nuclear weapon would allow them to keep control of it once completed.)

The next step down the nuclear terror hierarchy is the radiological dispersion device (RDD), already adverted to elsewhere in this paper. An RDD is any device, not necessarily explosive, that is designed to distribute radioactive material over an area or throughout a population. The simplest RDD would probably be a bomb consisting of conventional explosive either wrapped or 'salted' with radioactive material instead of more conventional shrapnel such as nails or metal scrap.

RDDs could be small, easily built, relatively powerful (at least as far as conventional explosives go) and could distribute radioactive material over a fairly large area, depending on atmospheric conditions. However, some of the current public and governmental concern about RDDs might be somewhat misplaced. An RDD would not necessarily kill significantly more people than a similar bomb *sans* radioactive additions, at least not in the short term, and their objective long-term effects on public health are hard to assess. As Henry Kelly puts it, "[w]hile radiological attacks would result in some deaths, they would not result in the hundreds of thousands of fatalities that could be caused by a crude nuclear weapon"[lxix]. Similarly, Mohamed ElBaradei says:

> As with any explosion, people in the immediate vicinity could be killed or injured by the blast itself. The radioactive material dispersed, depending on the amount and intensity, could cause radiation sickness for a limited number of people nearby if, for example, they inhaled large amounts of radioactive dust. But the most severe tangible impacts would likely be the economic costs and social disruption associated with the evacuation and subsequent clean-up of contaminated property.[lxx]

ElBaradei goes on to observe, with many others, that while RDDs offer little or no advantage over conventional explosives *qua* weapons, they would nonetheless have tremendous appeal to terrorists because of the literal terror they would engender: "… a dirty bomb could be a terrorist's weapon of choice simply in order to play on public fears of all things nuclear and radioactive. Panic and chaos are a terrorist's primary objective."[lxxi]

The Federation of American Scientists (FAS) discusses three possible RDD scenarios using medical or industrial radiation sources that could be obtained relatively easily in the U.S.:

- the amount of cesium [Cs^{137}] that was discovered recently abandoned in North Carolina[lxxii]
- the amount of cobalt [Co^{60}] commonly found in a single rod in a food irradiation facility, and

- the amount of americium [Am^{241}] typically found in oil well logging systems[lxxiii]

The FAS paints a bleak picture. In the first case, if the cesium were detonated with 10 pounds of TNT:

A swath about one mile long covering an area of forty city blocks would exceed EPA contamination limits, with remaining residents having a one-in-ten thousand chance of getting cancer. If decontamination were not possible, these areas would have to be abandoned for decades. If the device was detonated at the National Gallery of Art, the contaminated area might include the Capitol, Supreme Court, and Library of Congress…[lxxiv]

In the second case, the FAS compares the effects of a cobalt RDD explosion in Manhattan to those of the meltdown of the Chernobyl reactor:

[I]n this case, an area of approximately one-thousand square kilometers, extending over three states, would be contaminated. Over an area of about three hundred typical city blocks, there would be a one-in-ten risk of death from cancer for residents living in the contaminated area for forty years. The entire borough of Manhattan would be so contaminated that anyone living there would have a one-in-a-hundred chance of dying from cancer caused by the residual radiation. It would be decades before the city was inhabitable again, and demolition might be necessary.[lxxv]

In the case of the americium RDD, the FAS posits a bomb containing just one pound of TNT being detonated near Times Square:

[P]eople in a region roughly ten times the area of the initial bomb blast would require medical supervision and monitoring… An area 30 times the size of the first area (a swath one kilometer long and covering twenty city blocks) would have to be evacuated within half an hour. After the initial passage of the cloud, most of the radioactive materials would settle to the ground. Of these materials, some would be forced back up into the air and inhaled, thus posing a long-term health hazard… A ten-block area contaminated in this way would have a cancer death probability of one-in-a-thousand. A region two kilometers long and covering sixty city blocks would be contaminated in excess of EPA safety guidelines. If the buildings in this area had to be demolished and rebuilt, the cost would exceed fifty billion dollars.

These scenarios may have been somewhat overstated, however. The U.S. Nuclear Regulatory Commission (NRC) "took issue with the consequences to public health and the extent of the contamination predicted by the FAS study. In particular, the NRC did not believe that contaminated areas would have to be condemned, although it did not give its reasons for these conclusions."[lxxvi] The NRC also apparently felt that the cesium and americium attacks were "more plausible" than the cobalt RDD event because of the better security around food irradiation facilities.

The last form of radiological terror we will discuss in detail is attacks on commercial or research nuclear reactors. Potential terrorist attacks were not on the minds of designers when most power-generating reactors in North America were built and the original operating guidelines were established, and they now represent appealing targets for a variety of reasons.

In summary, commercial reactors:

- Are attached to local and regional power grids which, as the events of August 14, 2003, suggest, are susceptible to catastrophic failure when under severe load and the system is unstable
- Are guarded by private-sector security firms and individuals with limited and ambiguous powers, possibly sub-standard training and, typically, low rates of pay
- Are often located close to major metropolitan centres
- Are capable, in certain circumstances, of total 'Chernobyl-style' meltdown even after emergency shutdown
- House large quantities of highly radioactive spent fuel under security that is typically significantly poorer than that around the reactor itself
- May be vulnerable to aircraft strikes such as those that destroyed the World Trade Centre, New York, in 2001
- Are already the objects of fairly widespread public concern regarding their safety, even under normal operating conditions, which raises the amount of potential social disruption that any terrorist incident could cause

Non-commercial – military and research reactors – have their own particular characteristics that would influence their suitability as terrorist targets:

- Regardless of their size or power, military and U.S. Department of Energy reactors are not required by the NRC to have containment buildings, although some do
- Research reactors may have little or no security

There is little consensus on reactors' vulnerability to simple external attacks without insider support. Daniel Hirsch, for example, in discussing the threat from truck bombs, cites a Sandia study that that concluded that "unacceptable damage to vital reactor systems could occur from a relatively small charge at close distances and also from larger but still reasonable size charges at large setback distances (*greater than the protected area for most plants*) [emphasis added.]." [lxxvii] While Hirsch's 1987 article is now dated, there is little reason to believe that the physical structures of nuclear plants have been upgraded to deal with a threat of this kind. However, the NRC's "design-basis threats" (DBTs) as set out in the *NRC Regulations: Physical Protection of Plants and Materials* do now allow for attacks using "a four-wheel drive land vehicle bomb"[lxxviii], although they do not specify how powerful such a bomb might be nor where it might be detonated.

The NRC Regulations have also been modified, in obvious recognition of the terrorist threat, to require plants to be protected from small, well-trained teams equipped with:

suitable weapons, up to and including hand-held automatic weapons, equipped with silencers and having effective long range accuracy, … hand-carried equipment, including incapacitating agents and explosives for use as tools of entry or for otherwise destroying reactor, facility, transporter, or container integrity or features of the safeguards system, and … a four-wheel drive land vehicle used for transporting personnel and their hand-carried equipment to the proximity of vital areas…[lxxix]

Even with the revised DBTs, however, many feel that the NRC's requirements and the level of security around reactors are still too low. The Nuclear Control Institute (NCI), for example, says of the threat of truck bombs that "we remain concerned that these protective measures are inadequate to defend against the larger bombs used by terrorists since the 1993 truck-bomb attack against the World Trade Center."[lxxx]

As far as an attack by a team of terrorists is concerned, the NCI argues that:

Current NRC security regulations do not address the magnitude of threat demonstrated by the September 11 attacks. NRC standards require that nuclear plant operators protect against a much smaller number of attackers than involved in these attacks. Yet, even under the current weak standards, the armed guards at nearly half of the nuclear plants tested in NRC-supervised security exercises have failed to repel mock terrorist attacks or prevent simulated destruction of redundant safety systems that in real attacks could cause severe core damage, meltdown, and catastrophic radioactive releases.[lxxxi]

Various observers are concerned about the level of training, equipment, and authority of the private security guards at commercial reactors. The Project on Government Oversight (POGO[lxxxii]), for example, claims to have interviewed guards at nearly a quarter (23%) of "the operating and one decommissioning nuclear power reactors, as well as a National Guardsman protecting the perimeter of a plant" and describes them as "Under-manned, Under-equipped, Under-trained, Underpaid and Unsure about the Rules" [lxxxiii]. While POGO's survey is clearly not scientific, it is still interesting.

Paul Leventhal of the Nuclear Control Institute has expressed similar sentiments:

Despite industry claims that the plants are protected by "well-paid, paramilitary forces," the guards at some plants are "rent-a-cops" receiving low wages, in some cases less than janitors are paid in these plants. … Allowing the plants to continue operating with inadequate security, in some cases only tens of miles from major cities like New York, Philadelphia, Cleveland, Chicago, Charlotte and Los Angeles, is unconscionable. Millions of people are at risk in the event of a successful attack causing severe damage to the reactor core or spent fuel pool at these plants.[lxxxiv]

One should also point out that hand-carried weapons can be far more potent than the 'automatic weapons' (probably assault carbines such as the M-16, AK-47, or similar) envisaged by the NRC. Shoulder-mounted anti-tank or anti-aircraft missiles are said to be easily obtained in the arms bazaars of the international black market. While it is not easy (if it is indeed possible) to find details of their possible effects on the reinforced-concrete containment buildings that house reactor cores, there is no doubt that shoulder-mounted missiles pose a very much more serious threat than the kinds of weapons and explosives described in the DBTs.

Containment structures around commercial reactors in the U.S. – military reactors, those operated by the DOE, and low-powered research reactors are exempt from containment requirements – are chiefly designed, in concert with other structures and measures, to prevent leaks of radiation from the core to the outside environment and not necessarily to protect the core from assault from without. Indeed, the NRC's own glossary[lxxxv] specifies only that containment buildings be 'gastight', with no reference to physical strength. The fact that some reactors lack even this level of security is obviously cause for concern.

Furthermore, NRC security requirements[lxxxvi] for commercial reactors generally relate to physical intrusion into a reactor and its environs by intruders travelling on foot or by vehicle, and not to 'stand-off' attacks from beyond the perimeter nor to assault from the air. While containment buildings – where they exist – are designed to contain an explosion inside the building (something that has never been tested, for obvious reasons), they may not be capable of withstanding the impact of a loaded, fully-fueled airliner of the sort that took down the World Trade Center. It is notable that the only references to aircraft in the NRC's *Regulations: Part 73 – Physical Protection of Plants and Materials*[lxxxvii] concern the transport of radioactive materials, not the possibility of accidental or deliberate strikes on reactors. Of 36 NRC regulations documents that contain the word "aircraft", only three refer to aircraft strikes or crashes: one refers to the possibility of accidental aircraft crashes at the Yucca Mountain storage site[lxxxviii], while the other two refer to the ability of fuel transportation casks to withstand accidental strikes by light aircraft and the resulting fuel fires[lxxxix]. Obviously, reactors without containment structures of any kind are almost laughably vulnerable to such attacks. Even military reactors on American soil may not be defended against airborne attacks.

The NRC's "Fact Sheet on Nuclear Security Enhancements Since Sept. 11, 2001" has only the most trivial of references to the possibility of aircraft strikes on reactors. It simply says that "the NRC has worked with the Federal Aviation Administration and the Department of Defense to put in place a Notice to Airmen advising pilots to not circle or loiter above nuclear power plants and other nuclear facilities or they can expect to be interviewed by law enforcement personnel"[xc]. (This would undoubtedly deter any terrorist in control of an aircraft…)

Writing eleven years before the World Trade Center attacks, Alexander Yefremov said that:

Nuclear facilities are not built strong enough to withstand the crash of a medium-sized aircraft. A suicide-piloted airplane crashed into a nuclear facility, therefore, would destroy it, causing a melt-down and releasing a giant lethal cloud.[xci]

The Nuclear Control Institute claims that "it is highly unlikely that nuclear-power reactor containment domes are robust enough to withstand a direct hit from a jumbo jetliner".

Dr. Edwin Lyman, NCI's scientific director, has calculated that a direct, high-speed hit by a large commercial passenger jet "would in fact have a high likelihood a penetrating a containment building" that houses a power reactor. "Following such an assault," Dr. Lyman said, "the possibility of an unmitigated loss-of-coolant accident and significant release of radiation into the environment is a very real one."[xcii]

The question of stand-off attacks, as opposed to direct assaults, is an intriguing one. Nuclear reactors are vulnerable in various ways, and it may be that a direct assault would be one of the less effective strategies. If reactors operate without cooling their cores will melt, with the explosive release of radioactive gases, aerosols and dust. Even if the fission reaction in a reactor's core were shut down by being 'scrammed' in an emergency procedure, enough radioactive decay heat to melt the core would be generated for some time thereafter[xciii]. This presents an obvious terrorist opportunity. If the primary cooling system and emergency back-up systems could be disabled, a meltdown would be guaranteed. While arrangements would vary from reactor to reactor, in most larger reactors the primary cooling system would rely on externally supplied electricity for normal operation, with diesel-powered generators in reserve for emergencies. Even at power-generating plants there is always an external electricity supply for the cooling system, simply because the plant could not continue to generate electricity if the reactor(s) were shut down for any reason, including routine maintenance.

A reasonably simple and safe (at least for the perpetrators) terrorist tactic, then, would be to destroy the incoming power supply at whatever point or points were convenient after an inside collaborator had sabotaged the emergency generators or cooling systems. Success would then depend on whether the reactor core melted faster than power could be restored. Brian Mullen remarks that "certain stand-off attacks on reactors are cheap, require little technical knowledge, reduce the exposure to security forces, and require little commitment on the part of terrorists" [xciv]. Because he does not say what form these might take – presumably for the obvious security considerations – we are left to speculate. The attack on the cooling system that we have described would fit this description, however.

The idea of an insider deliberately sabotaging cooling systems may sound far-fetched, but there have been a number of such incidents in the U.S. The following list only includes incidents up to 1982, but it is revealing:

- In 1981 a valve to the high head safety injection pumps necessary for the emergency injection of cooling water in the Beaver Valley plant near Liverpool, Ohio, was shut off, apparently intentionally

- Also in 1981, the NRC discovered a "major degradation" of the backup power supply at the Nine Mile Point reactor in New York when diesel generators failed to start due to tampering with the fuel oil filters

- In 1982 the starting system for a diesel generator at the Salem II plant in New Jersey was tampered with so that both automatic and manual start-up would have been prevented[xcv]

There is at least one recorded incident of an attack on power lines associated with a nuclear reactor. In the mid-1980s "three of four power lines leading to the Palo Verde plant were sabotaged" [xcvi]. Since Palo Verde is the largest U.S. nuclear power plant, it would probably be more accurate to say that the power lines were leading *from* the plant and that the attack was intended to disrupt electricity supplies, rather than to cause a meltdown. Nonetheless, this incident demonstrated that power lines leading to or from reactors are vulnerable and have been terrorist targets.

Prediction is always a risky business, but never more so than in this field. No-one writing about terrorism before September, 2001, for example, contemplated the use of four loaded passenger airliners as weapons nor the scale of the carnage attempted and, indeed, achieved, in that set of attacks. Nonetheless, we must at least attempt some rational analysis of the near to medium-term risks of nuclear terrorism.

First of all, it does – happily – appear that the detonation of a nuclear weapon by terrorists is probably the least likely event. Despite the poor security in the FSU, there is no evidence that any terrorist groups have obtained sufficient quantities of fissile materials to make even one weapon with nuclear yield, especially given the likely inefficiency of any home-made device. The quantities of weapons-useable materials that have been seized at borders or in stings are several orders of magnitude smaller than such a device would require. In any case, it is unlikely, although not impossible, that a terrorist group could assemble the expertise and equipment necessary to build a nuclear weapon, especially when the exact composition and quantities of the fissile materials were unpredictable.

There is no real evidence (in the open-source literature, at least) that nuclear warheads have been lost or stolen or have otherwise strayed from the FSU. Even if they have done, they would probably have to be disassembled for their components rather than used as-is. However, the continuing poor security throughout the region's nuclear complex remains a cause for grave concern, especially regarding tactical (as opposed to strategic) nuclear weapons and radiation sources other than those actually contained in warheads. There is also the risk, which so far does not seem to have materialised, of redundant workers in the nuclear complex exporting their expertise to terrorists or rogue nations.

Finally, there is the question of the political value of a nuclear threat or detonation. What demands might nuclear-armed terrorists make, and what could a government do to respond to them? Brian Jenkins points out that "[t]ranslating the enormous coercive power that a nuclear weapon would give a terrorist group into concrete political gains … poses some difficulties"[xcvii]. Governments simply could not comply with some essentially impossible demands, such as their own dissolution, that would be commensurate with the threat.

> Nor could terrorists enforce permanent policy changes unless they maintained the threat indefinitely. And if a government could not be assured that the threat would be dismantled once the demands were met, it would have little incentive to negotiate. … I am suggesting that it is not easy for terrorists, even if they are armed with nuclear weapons, to achieve lasting political results. They might find nuclear weapons to be as useless as they are powerful.[xcviii]

Attacks on nuclear reactors constitute a much more serious threat. Several observers have pointed out that security at most North American commercial plants is poor and that the NRC's design-basis threats do not cover several plausible terrorist attack scenarios, such as the use of shoulder-launched missiles. Security at spent-fuel storage pools, which contain highly radioactive materials, is even worse. Furthermore, the NRC's current Regulations apparently do not require plants to be safe from aircraft strikes and, even if they did, it would almost certainly be infeasible to either physically retrofit plants with that capability or to install anti-aircraft measures around all nuclear reactors. Finally, at least one writer has suggested that relatively safe and easy 'stand-off' attacks on reactors are possible, although we remain uncertain as to what these might be.

Nonetheless, there is at least some security at nuclear power plants – significantly more than there is at most sites employing radioactive sources for medical or industrial purposes – and attacks on reactors (the mysterious 'safe and easy' stand-off attacks excepted) are risky and their outcome uncertain.

The risk – in the sense of likelihood, not potential damage – from radiation dispersal devices, therefore, is greater than that of attacks on reactors, and the payoff for terrorists would not necessarily be that much less. Controls on medical or industrial radiation sources are generally poor world-wide, especially when the sources have lost their commercial value, and several relatively widely-used isotopes would make very dangerous ingredients for RDDs. The most difficult part of the entire operation, probably, would be obtaining the source, and all the evidence suggests that that would not be excessively difficult, even in North America or Western Europe, while in the FSU some powerful sources are literally lying around for the taking. If the terrorists were knowledgeable enough to choose material that required little shielding, such as plutonium or americium, the RDD could be compact, relatively light, hard or impossible to detect, and capable of reaping a harvest of social disruption, economic damage, and the death, both immediately and in the long term, of hundreds or thousands of people.

If I were forced to make a prediction, I would expect to see the detonation of an RDD using an industrial or medical radiation source, possibly although not necessarily an alpha-emitter, somewhere in North America within the next eighteen months. Having said that, I must emphasise that prediction is almost invariably foolish, and that terrorists, unfortunately, always have the capacity to surprise.

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Yefremov, Alexander *The Atom Bomb on the Black Market*, (Moscow: Novosti Press Agency Publishing House, 1990)

[i] The term ‘nuclear’ is frequently reserved for events or materials related to nuclear fission. We will use it here in the looser sense to refer to all radioactive materials and issues.

[ii] Beres, Louis R. *Terrorism and Global Security: The Nuclear Threat* (Boulder, Colorado: Westview Press, 1979)

[iii] See, for example, Brian M. Jenkins, “Is Nuclear Terrorism Plausible?” in in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: Lexington Books, 1987). Jenkins argues that “terrorists want a lot of people *watching*, not a lot of people *dead*.” (p. 29) This position is clearly no longer sustainable.

[iv] Mark Burgess, “Terrorism: The Problems of Definition”, Center for Defense Information (CDI) August 1, 2003, http://www.cdi.org/friendlyversion/printversion.cfm?documentID=1564&from_page=../program/document.cfm, viewed August 3, 2003.

[v] Kellen, Konrad “The Potential for Nuclear Terrorism: A Discussion” in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: Lexington Books, 1987) p. 106

[vi] Kellen, “Potential for Nuclear Terrorism”, p. 106

[vii] We will assume that while it might be remotely feasible for terrorists to assemble a low-yield fission device of some sort, a home-made thermonuclear or fusion device is still beyond the realm of possibility.

[viii] After Konrad Kellen “The Potential for Nuclear Terrorism: A Discussion” in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: 1987) p. 107; and Siegfried S. Hecker, “Nuclear Terrorism” in Committee

on Confronting Terrorism in Russia (Sigfried S. Hecker, Chair) *High Impact Terrorism: Proceedings of a Russian-American Workshop* (Washington: National Academy Press, 2002) p.151

[ix] Rensselaer W. Lee III, *Smuggling Armageddon: The Nuclear Black Market in the Former Soviet Union* (New York: St. Martin's Press, 1998) p. 2

[x] Chelyabinsk-65, known as "Mayak," Krasnoyarsk- 26, Krasnoyarsk-45, Tomsk-7, and Sverdlovsk-44, the nuclear weapons laboratories (Arzamas-16 and Chelyabinsk-70), and the nuclear weapons assembly/disassembly sites (including Penza-19, Sverdlovsk-45, and Zlatoust-36)

[xi] Kevin O'Neill "The Risk of Theft: Protecting Fissile Materials in the Former Soviet Union" p. 70

[xii] International Atomic Energy Agency, (no author credited) "Inadequate Control of the World's Radioactive Sources", (http://www.iaea.or.at/worldatom/Press/Focus/RadSources/rads_factsheet.pdf, viewed July 18, 2003)

[xiii] "Plutonium", Encyclopedia Britannica, Deluxe CD-ROM Edition, 2003,

[xiv] All incidents recorded in Allison, Graham T., *et al*, *Avoiding Nuclear Anarchy: Containing the Threat of Loose Russian Nuclear Weapons and Fissile Materials* (Cambridge, MA: The MIT Press, 1996) p. 11

[xv] Cf. Rensselaer W. Lee III, *Smuggling Armageddon: The Nuclear Black Market in the Former Soviet Union* (New York: St. Martin's Press, 1998) p. 125

[xvi] Accounts of his statement differ.

[xvii] Nikolai Sokov "Suitcase Nukes": A Reassessment", Center for Nonproliferation Studies, Monterey Institute of International Studies, September 23, 2002 (http://cns.miis.edu/pubs/week/020923.htm, viewed August 11, 2003)

[xviii] Sokov, "Suitcase Nukes"

[xix] Pronounced 'saddems'(!)

[xx] Sokov, "Suitcase Nukes"

[xxi] Sokov, "Suitcase Nukes"

[xxii] Sokov, "Suitcase Nukes"

[xxiii] Sokov, "Suitcase Nukes"

[xxiv] Graham T. Allison, Owen R. Corte Jr., Richard A. Falkenrath, Steven E. Miller *Avoiding Nuclear Anarchy: Containing the Threat of Loose Russian Nuclear Weapons and Fissile Materials* (Cambridge, MA: The MIT Press, 1996) Footnote 18, pp. 28 – 29

[xxv] David Albright, Corey Hinderstein, and Holly Higgins "Does Al Qaeda Have Nuclear Materials? Doubtful, But…" Institute for Science and International Security (ISIS) website, March 2002 (http://www.isis-online.org/publications/terrorism/doubtful.html viewed June 15, 2003)

[xxvi] Lee, *Smuggling Armageddon*, pp. 124 – 125. See also Gavin Cameron, *Nuclear Terrorism: A Threat Assessment for the 21st Century* (New York: St. Martin's Press, 1999) pp. 5, 8

[xxvii] International Atomic Energy Agency, "Inadequate Control of the World's Radioactive Sources"

[xxviii] John Deutch, quoted in Lee, *Smuggling Armageddon*, p. 19

[xxix] Lee, *Smuggling Armageddon*, p. 19

[xxx] Leonard S. Spector, "Clandestine Nuclear Trade and the Threat of Nuclear Terrorism" in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: 1987) p. 78. This is obviously an older reference, but I have not encountered anything to contradict it. Even Al-Qaida, with all its resources, is not known to have obtained fissile materials or other bomb parts. The sparse documentation concerning nuclear weapons that has been found indicates Al-Qaida's interest in the topic, but nothing more.

[xxxi][xxxi] This question will be discussed in more detail later in this paper.

[xxxii] Spector, "Clandestine Nuclear Trade", p. 81

[xxxiii] Allison *et al*, *Avoiding Nuclear Anarchy*, p. 41

[xxxiv] Sharon S. Weiner "Preventing Nuclear Entrepreneurship in Russia's Nuclear Cities", *International Security* 27.2 (2002) pp. 126 – 158, p. 135

[xxxv] Sharon S. Weiner, "Preventing Nuclear Entrepreneurship", p. 135

[xxxvi] Sharon S. Weiner "Preventing Nuclear Entrepreneurship", p. 128

[xxxvii] Initiatives for Proliferation Prevention (IPP) "Welcome to the Program" (http://ipp.lanl.gov, viewed July 16, 2003. This site uses frames so a more specific URL

cannot be given.)

[xxxviii] Sharon S. Weiner, p. 130

[xxxix] Sharon S. Weiner, p.

[xl] Baker and Cutler, *A Report Card on the Department of Energy's Nonproliferation Programs with Russia*, (Washington, D.C.: Secretary of Energy Advisory Board, U.S. Department of Energy, January 10, 2001), p. A-1, cited by Sharon S. Weiner, p. 85

[xli] Sharon S. Weiner, p. 145

[xlii] Leonid Bolshov, Rafael Arutunyan and Oleg Pavlovsky, "Radiological Terrorism" in *High Impact Terrorism*, p.141

[xliii] Bolshov *et al*, p.143

[xliv] Bolshov *et al*, p.147

[xlv] Dzhokhar Dudayev, quoted Bolshov *et al*, p. 147

[xlvi] Bolshov *et al*, p. 147

[xlvii] Alan J. Kuperman, "Loose Nukes of the West", Washington Post, Wednesday, May 7, 2003, Page A31, reproduced on http://www.nci.org/index.htm (framed site, no specific page URLs), viewed July 20, 2003

[xlviii] Alan J. Kuperman, "Loose Nukes of the West"

[xlix] Charles D. Ferguson, Tahseen Kazi, Judith Perera, "Commercial Radioactive Sources: Surveying the Security Risks", Occasional Paper No. 11, Centre for Nonproliferation Studies, Monterey Institute for International Studies, January 2003, p. 17 (http://cns.miis.edu/pubs/opapers/op11/op11.pdf, viewed May 27, 2003)

[l] Ferguson *et al*, "Commercial Radioactive Sources", p. v

[li] Ferguson *et al*, "Commercial Radioactive Sources", p. v

[lii] Ferguson *et al*, "Commercial Radioactive Sources", p. v

[liii] "Plutonium", *Encyclopedia Britannica*, Deluxe CD-ROM Edition 2003, no author credited.

[liv] Cameron, *Nuclear Terrorism*, p. 131

[lv] This article was written in 1987, before the advent of the public Internet, in other

words, and so it is possible, although exceedingly improbable, that detailed specifications for nuclear weapons are now more easily available to terrorists. (I have not tried to find any, for obvious reasons.) Still, the plans are certainly stored on computers and those computers are likely to be networked, with a portal to the Internet somewhere in the system. Perhaps we should simply hope and pray that any security loopholes have been closed before the nuclear cat leaps from its digital bag…

[lvi] Luis Alvarez, quoted in Alan J. Kuperman, "Loose Nukes of the West"

[lvii] J. Carson Mark, Theodore Taylor, Eugene Eyster, William Maraman, Jacob Wechsler "Can Terrorists Build Nuclear Weapons?" in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: Lexington Books, 1987) pp. 58-59

[lviii] Mark *et al* (1987), p. 60

[lix] Mark *et al* (1987), p.59

[lx] Mark *et al* (1987), p. 61

[lxi] Mark *et al* (1987), p. 50

[lxii] The beginning of a nuclear chain reaction in a weapon before the desired supercritical mass/density is achieved. This can take place while the 'bullet' is travelling towards the 'target' in a gun-type bomb, for example. Fizzling is theoretically possible in any nuclear weapon, although good design can minimise the risk..

[lxiii] Stanislav Rodionov "Could Terrorists Produce Low-Yield Nuclear Weapons?" in: Committee on Confronting Terrorism in Russia, Sigfried S. Hecker, Chair, *High Impact Terrorism: Proceedings of a Russian-American Workshop* (Washington: National Academy Press, 2002)

[lxiv] Rodionov (2002), p. 158

[lxv] Rodionov (2002), p. 159

[lxvi] Rodionov (2002), p. 159

[lxvii] Mark *et al* (1987), p. 63

[lxviii] Mark *et al* (1987), pp. 63-64

[lxix] Testimony of Dr. Henry Kelly, President Federation of American Scientists before the Senate Committee on Foreign Relations March 6, 2002

[lxx] Mohamed ElBaradei, Director-General, International Atomic Energy Agency, "Dirty

Bombs: Assessing the Threat?", *Washington Post*, 2 July 2002, p A15, viewed on IAEA website http://www.iaea.org/worldatom/Press/ Statements/2002/ebWP2002.shtml August 4, 2003

[lxxi] Mohamed ElBaradei, "Dirty Bombs"

[lxxii] It has been difficult to find exact details of this event. According to Wired News (http://www.wired.com/ news/conflict/0,2100,53110,00.html, viewed July 10, 2003), a medical gauge containing a "pea-sized" piece of cesium was found in a scrap yard in North Carolina in February, 2002.

[lxxiii] Testimony of Dr. Henry Kelly, President Federation of American Scientists (FAS) before the Senate Committee on Foreign Relations March 6, 2002 (http://www.fas.org/ssp/docs/kelly_testimony_030602.pdf, viewed May 23, 2003)

[lxxiv] Dr Henry Kelley, testimony before Senate

[lxxv] Dr Henry Kelley, testimony before Senate

[lxxvi] 'Interview with U.S. government official' in Charles D. Ferguson *et al*, "Commercial Radioactive Sources: Surveying the Security Risks" p. 22

[lxxvii] Nuclear Regulatory Commission, "Weekly Report to the NRC Commissioners," April 20, 1984, enclosure E, p.3, quoted in Daniel Hirsch, "The Truck Bomb and Insider Threats to Nuclear Facilities" in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: 1987) p.209

[lxxviii] Nuclear Regulatory Commission, "NRC Regulations (10 CFR), Part 73 – Physical Protection of Plants and Materials" (http://www.nrc.gov/reading-rm/doc-collections/cfr/part073/full-text.html, viewed May 23, 2003)

[lxxix] NRC *Regulations*, 73.1(a)i

[lxxx] Nuclear Control Institute, "Are Reactors Adequately Protected Against Attack?", (www.nci.org (framed site, more specific URLs impossible), viewed June 11, 2003)

[lxxxi] NCI, "Are Reactors Adequately Protected?"

[lxxxii] For more information on POGO, see their "About Us" page at http://www.pogo.org/p/x/aboutus.html

[lxxxiii] POGO.org, "Nuclear Power Plant Security: Voices from Inside the Fences", (http://www.pogo.org/p/environment/ eo-020901-nukepowerb.html#guards, viewed 12 June, 2003)

[lxxxiv] NCI press release quoting Paul Leventhal, NCI president "President Says Terrorists Had Diagrams Of Nuclear Power Plants; Nrc Must Move Now On Major Upgrade Of Security Against Attack" (http://www.nci.org/, framed site, specific URL not possible, viewed 11 June, 2003)

[lxxxv] "A gastight shell or other enclosure around a nuclear reactor to confine fission products that otherwise might be released to the atmosphere in the event of an accident." (http://www.nrc.gov/reading-rm/basic-ref/glossary/
containment-structure.html, viewed August 14, 2003

[lxxxvi] c.f. Nuclear Regulatory Commission "Physical Protection Areas" (http://www.nrc.gov/what-we-do/safeguards/
areas.html, viewed July 8, 2003)

[lxxxvii] Nuclear Regulatory Commission (NRC) *Regulations: Part 73 – Physical Protection of Plants and Materials*, (http://www.nrc.gov/reading-rm/doc-collections/cfr/part073/full-text.html, viewed August 18, 2003)

[lxxxviii] Federal Register Notice December 14, 2001 Nuclear Regulatory Commission 10 CFR Parts 2, 19, 20, 21, etc. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada; Final Rule

[lxxxix] Federal Register Notice March 20, 2000 Nuclear Regulatory Commission 10 CFR Part 72 RIN 3150-AG 18 List of Approved Spent Fuel Storage Casks: TN-32 Addition

[xc] Nuclear Regulatory Commission (NRC) "Fact Sheet on Nuclear Security Enhancements Since Sept. 11, 2001", (http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/security-enhancements.html, viewed Augst 17, 2003)

[xci] Alexander Yefremov, *The Atom Bomb on the Black Market*, (Moscow: Novosti Press Agency Publishing House, 1990), p. 31

[xcii] Nuclear Control Institute, "Are reactors adequately protected?",

[xciii] c.f. Argonne National Laboratory "Improving Nuclear Reactor Safety: The Melt Coolability and Concrete Interaction Program" (http://www.anl.gov/OPA/factsheets/r18-02.htm, viewed July 10, 2003)

[xciv] Robert K. Mullen, "Nuclear Violence" in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: 1987) pp. 241-242

[xcv] Daniel Hirsch, "The Truck Bomb and Insider Threats to Nuclear Facilities" in Paul Leventhal and Yonah Alexander (eds.) *Preventing Nuclear Terrorism* (Lexington, MA/Toronto: 1987) pp.211 - 212

[xcvi] U.S. News & World Report "A Nuclear Nightmare", September 17, 2001 (cited by

POGO.org, “Nuclear Power Plant Security” and NCI (http://www.nci.org/01/09/09-3.htm, viewed August 19, 2003)

[xcvii] p. 33

[xcviii] p. 32