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Improvised Nuclear Devices and Nuclear Terrorism

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IMPROVISED NUCLEAR DEVICES AND NUCLEAR TERRORISM[1]

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Terrorists seeking to unleash massive violence and destruction may climb the escalation ladder to the highest rungs: nuclear weapons. In this nightmare scenario, they may try to seize an intact nuclear weapon residing in a nuclear weapon state's arsenal. If, however, they are deterred by the security measures surrounding nuclear armaments, they may instead decide to acquire fissile material by purchase, diversion, or force for the purpose of fabricating a crude nuclear bomb, known more formally as an "improvised nuclear device" (IND).

Two types of fissile material could be used for this purpose, highly enriched uranium (HEU) or plutonium, but the former would be far easier to make into a successful IND, as explained in detail, below. These materials have been produced in great quantity in nuclear weapon and civilian nuclear energy programs around the world. Leaving aside material currently in nuclear weapons themselves, many hundreds of tons of fissile material are currently dispersed at hundreds of sites worldwide, where they are being processed, used, or stored, often under inadequate security arrangements. Russia alone, processes more than 34 metric tons of weapons-usable nuclear material annually. According to the conservative figures used by the International Atomic Energy Agency, only 25 kilograms of HEU or 8 kilograms of plutonium would be needed to manufacture a weapon.

It is more difficult to maintain strict control over fissile materials than over nuclear weapons. Among other challenges, while the latter can be easily identified and counted, fissile materials are often handled in difficult-to-measure bulk form, introducing measurement uncertainties that can mask repeated diversions of small quantities of HEU or plutonium from process streams and storage areas. Indeed, over the past decade a number of cases have been documented involving illicit trafficking in fissile materials; no similar cases have been confirmed involving the theft of nuclear weapons.[2] Although none of the fissile material cases involved quantities sufficient for a nuclear explosive, conceivably such transactions may have occurred without detection.

Global Stocks of Fissile Material

Because the sizes of military stockpiles of fissile materials are classified and up-to-date records of civilian stocks are difficult to obtain, it is possible only to estimate the global inventory of these materials. Nonetheless, it is clear that the amount of fissile

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[1] A more detailed discussion of this issue will be available in the forthcoming publication: Charles D. Ferguson, William C. Potter, Amy Sands, Leonard S. Spector, and Fred L. Wehling, *The Four Faces of Nuclear Terrorism* (Washington, DC: Nuclear Threat Initiative, 2004).

[2] William C. Potter and Elena Sokova, "Illicit Nuclear Trafficking in the NIS: What's New? What's True?" *The Nonproliferation Review*, Summer 2002.

material that might theoretically be accessible to terrorists is staggering. Tables 1 and 2 present an overview of the world stockpiles of HEU and plutonium, as of 1999.

In international usage, HEU refers to uranium that has been processed to increase the proportion of one isotope of uranium, uranium-235, from the naturally occurring level of 0.7 percent to 20 percent or more, the level at which use for weapons becomes practicable. Although all uranium enriched to more than 20 percent is termed "highly enriched," the ease of causing a nuclear detonation is greatly increased at higher enrichment levels. Specifically, terrorists would find it much easier to develop a workable IND with material enriched to 80 percent or more (referred to henceforth as "high quality" HEU), and military programs prefer material enriched to 90 percent or more for nuclear arms. (In Tables 1 and 2, "weapons-grade" uranium refers to uranium enriched to at least 90 percent.)

Plutonium is produced by irradiating uranium fuel in a reactor and then processing the "spent fuel" chemically, in a "reprocessing" plant to separate the plutonium from the unused uranium and unwanted radioactive byproducts. Plutonium also varies in quality. That intended for military purposes, or "weapons-grade" plutonium, is usually produced in specialized production reactors and has less than six percent of the isotope Pu-240 and much smaller percentages of other isotopes, such as Pu-238, Pu-241, and Pu-242, in order to improve weapon performance; therefore, it has about 94 percent of the isotope Pu-239, which is preferred for weapons.[3] Plutonium produced in nuclear power plants, known as reactor-grade plutonium, is irradiated for far longer periods and has higher concentrations of Pu-240, -241, -242, and -238, which are least desirable for nuclear weapons. However, as detailed in a later section of this paper, reactor-grade plutonium can nonetheless be used to develop nuclear arms. Plutonium is used principally in nuclear weapons and, in a few states, in mixed oxide (MOX) fuel for nuclear power plants. MOX fuel is a mixture of plutonium and depleted uranium oxides that can be used as a substitute for low-enriched uranium nuclear power plant fuel, the type most widely used in modern nuclear power reactors.

Material type	*Global inventory, MT*
Military plutonium	250
Civil plutonium (separated)	208
Military HEU	1,670
Civil HEU	20

Table 1: Estimated global plutonium and HEU inventories, end of 1999[4]

Figures for HEU are weapons-grade uranium equivalent

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[3] J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," *Science & Global Security*, Vol. 4, 1993, p. 113.

[4] David Albright and Mark Gorwitz, "Tracking Civil Plutonium Inventories: End of 1999," Institute for Science and International Security, http://www.isis-online.org/publications/puwatch/puwatch2000.html, accessed on December 18, 2002; Submissions of members of the International Plutonium Management Group detailing civil plutonium stocks as of December 1999, IAEA document INFCIRC/549, available at http://www.iaea.org/Publications/Documents/Infcircs/Numbers/nr501-550.shtml

Country	*Military plutonium, MT*	*Military HEU, MT of weapons-grade uranium equivalent*
Russia	130	970
United States	100	635
France	5	24
China	4	20
United Kingdom	7.6	15
Israel	0.51	not known
India	0.310	small quantity
Pakistan	0.005	0.690
North Korea	0.003-0.004	not known
South Africa	None	0.4

Table 2: Estimated military stocks of fissile material, end of 1999[5]

Even if it were assumed that half of all materials listed in Tables 1 and 2 as produced for military uses were contained in weapons, the remaining fissile material in the military sector, together with that in the civilian sector comprises a stockpile sufficient for tens of thousands of improvised nuclear devices.[6] Since 1999, global stocks of plutonium have increased, while those of HEU have probably declined. India, Israel, North Korea, Pakistan, Russia, and, possibly, China[7] have continued to produce plutonium for weapons, with Russia's annual output of between one and two tons of new, separated military plutonium comprising by far the largest increment in this area.[8] As shown in Table 3, France, Germany, Great Britain, India, Japan[9], and Russia have continued to separate plutonium from civilian nuclear power plant fuel, output that exceeds new production of military plutonium. Pakistan, India, and possibly China,

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[5] David Albright and Mark Gorwitz, "Tracking Civil Plutonium Inventories: End of 1999," op. cit.

[6] As noted earlier, the International Atomic Energy Agency defines the significant quantities of fissile material as 25 kg of weapons-grade HEU equivalent and 8 kg of plutonium. These values set the scale for the amounts of fissile material that are needed to form a nuclear weapon roughly equivalent in explosive power to the Hiroshima and Nagasaki bombs. Technically sophisticated nuclear weapons states are able to build nuclear weapons of this explosive power with less fissile material employing at least as low as 3 to 4 kg of plutonium.

[7] It is believed that China stopped producing plutonium for weapons around 1991. David Wright and Lisbeth Gronlund, "Estimating China's Production of Plutonium for Weapons," *Science & Global Security*, Volume 11, 2003, pp. 61-80; and references 23 and 31 therein. Wright and Gronlund estimated that China produced between 2 to 5 tons of weapons-grade plutonium.

[8] Russia has pledged not to use this material for nuclear weapons pursuant to an agreement with the United States under which the United States is to assist Russia in closing down its military plutonium production reactors. See Agreement between the Government of the United States of America and the Government of the Russian Federation Concerning Cooperation Regarding Plutonium Production Reactors, September 23, 1997, Article IV. The U.S. government periodically sends monitoring teams to Russia to ensure that this provision is upheld.

[9] Reprocessing of Japanese nuclear power plant fuel has been performed principally in France and Great Britain. The resulting plutonium is either stored in these countries or is being processed into MOX fuel for shipment back to Japan. In parallel, Japan is constructing its own commercial scale reprocessing facility at Rokkasho-mura.

Israel, and North Korea[10] have added to their HEU stocks for weapons. However, these additions to global stocks of HEU (probably amounting to several tons, at most, since 1999) have been offset during this period by the blending down of 200 metric tons of Russian HEU to low-enriched uranium nuclear power plant fuel, as of January 1, 2004, under a collaborative program with the United States.

HEU and plutonium outside of nuclear weapons can be found at hundreds of sites worldwide. Although fissile material in any location is a potential target for terrorists, this paper will concentrate on three settings of particular concern:

- Russia, where hundreds of tons of these materials are used, processed, or stored at dozens of Russian Federal Agency for Atomic Energy (formerly Ministry of Atomic Energy) and Ministry of Defense facilities under inadequate security;
- Pakistan, where political instability and uncertain loyalties in the nuclear chain of command might result in fissile material coming into the hands of terrorists; and
- Research reactors using HEU fuel, including some 20 Soviet-designed research reactor sites and research centers containing HEU outside of Russia in 17 nations, and several U.S.-origin research reactors outside the United States.

Country	*Separated Civil Plutonium 12/1999*	*Separated Civil Plutonium 12/2002*
Germany	0.5	0.0
France	60.0*	52.2*
Great Britain	69.5*	86.5*
India	0.7	0.7 (est.)
Japan	0.9	1.2
Russia	30.9	36.0
United States	0.0**	0.0**
Total	*162.5*	*176.6*

Table 3: Separated civil plutonium (metric tons) at reprocessing plants and other locations as of December 31, 1999 and December 31, 2002[11]

*(Includes material held for other states) ** (The United States does not separate plutonium in its civilian nuclear power program; however, it has declared 45.5 metric tons of military plutonium to be excess and irreversibly removed from military uses.)

Effects and Consequences of Detonation of an Improvised Nuclear Device

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[10] Israel's possession of a uranium enrichment capability has never been confirmed. North Korea is known to have acquired key technology for uranium enrichment from the A.Q. Khan network, discussed later in the text, but the status of its program and whether it has produced HEU is not known.

[11] These numbers are derived from information obtained at the International Atomic Energy Agency's web site, www.iaea.org, except where otherwise noted. For amount of plutonium held by India as of 1999, see David Albright, "Separated Civil Plutonium Inventories: Current and Future Directions," (Washington, DC: Institute for Science and International Security, June 2000). In the absence of new information on Indian plutonium separation, the 1999 figure is repeated for 2002, although it is likely that Indian plutonium stocks grew slowly during this period.

It is generally assumed that successful INDs would have yields in the 10-20 kiloton range (the equivalent to 10,000-20,000 tons of TNT), while INDs that fizzled – i.e., did not detonate fully – might still produce a nuclear yield, which though far less powerful, could still cause very significant damage. A twenty kiloton yield would be the equivalent of the yield of the bomb that destroyed Nagasaki and could devastate the heart of a medium-sized U.S. city, while causing fire and radiation damage over a considerably wider area. Even a nuclear yield of a few tons could, under certain circumstances, cause the destruction of a number of skyscrapers potentially resulting in many thousands of casualties, as well as, widespread contamination. Table 4 summarizes these effects.

	Radius for Indicated Effect (meters)			
Explosive Yield measured in tons of TNT equivalent (surface burst)	500 Rem Prompt Gamma Radiation	Fallout from surface blast (500 Rem total dose)	Severe Blast Damage (10 psi)	Moderate to Light Blast Damage (3 psi)
1 ton	45	30-100	33	65
10 tons	100	100-300	71	140
100 tons	300	300-1,000	150	300
1 kiloton (1,000 tons)	680	1,000-3,000	330	650
10 kilotons	1,280	3,000-10,000	710	1,500
100 kilotons	1,800	10,000-30,000	1,500	3,300
1 megaton (1 million tons)	2,400	30,000-100,000	3,250	7,100

Table 4: Nuclear Explosive Effects as a Function of Yield[12]

Unfortunately, even an IND that detonated with no yield or one that was never used but whose existence was disclosed could cause consequences of historic proportions, because terrorists could use the *threat* of a successful future nuclear detonation to blackmail target governments. Given the stakes, target-state leaders would be hard pressed not to give into the demands presented. Indeed, it is possible that a terrorist organization might be able to credibly threaten a nuclear detonation merely by demonstrating its possession of the requisite nuclear-weapon material, a possibility that underscores the critical importance of ensuring such fissile materials do not fall into the hands of such groups.

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[12] Effects for 1 ton through 1 kiloton are adapted from Kevin O'Neill, "The Nuclear Terrorist Threat," Institute for Science and International Security, August 1997, and references therein, p.6; effects for 10 kilotons, 100 kilotons, and 1 Megaton are adapted from Dietrich Schroeer, *Science, Technology, and the Nuclear Arms Race*, John Wiley & Sons, 1984, pp. 37, as based on Glasstone and Dolan, *Effects of Nuclear Weapons*, U.S. Government Printing Office, Washington, DC, 1977. According to a recently published book, thermal radiation effects have been largely under-appreciated by past studies and can ignite widespread fires in urban areas. Lynn Eden, *World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation* (Ithaca, New York: Cornell University Press, 2003).

The Chain of Causation

The principal elements that would have to combine for a terrorist group to detonate an IND at a high-value target, such as an American city, include the following steps:[13]

1. A terrorist group with extreme objectives and the necessary technical and financial resources to execute this scheme must organize and begin operations.
2. The group must then choose to engage in an act of nuclear terrorism at the highest level of violence.
3. These terrorists must then acquire sufficient fissile material to fabricate an IND, through gift, purchase, theft, or diversion.
4. They must next fabricate the weapon.
5. The group must transport the intact IND (or its components) to a high-value target.
6. Finally, the terrorists must detonate the IND to complete their plan. [14]

Although variants of this chain of causation can be imagined, this outline can serve as a means to determine where to apply risk reduction measures to lessen the probability that such an act of nuclear terror might occur. All of these elements must be realized for a terrorist IND attack to succeed, and intervention at any stage can be sufficient to avert catastrophe.

Terrorist Groups with Motivation and Capabilities to Manufacture and Use an IND

Although there appear to be very few terrorist organizations that are highly motivated to detonate nuclear weapons of any kind to advance their objectives,the potential number of such groups cannot be established with precision and can change over time, for example, as new groups form or as new alliances are built among existing groups. Traditional nationalist/separatist terrorist groups, such as the IRA in Ireland, the Tamil Tigers in Sri Lanka, and the Kurds in Turkey, are less likely to resort to this extreme form of nuclear terrorism because they may be constrained by the values of the their base constituencies. In addition, their own location may make them extremely vulnerable to retaliatory attacks or to concerns of harming their own people from a

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[13] Matthew Bunn, Anthony Weir, and John P. Holdren, *Controlling Nuclear Warheads and Materials: A Report Card and Action Plan*, Project on Managing the Atom, Harvard University, March 2003, discuss in detail the components of this chain of necessary conditions in their report in a section titled the "Terrorist Pathway to the Bomb."

[14] Some variants on this basic model can be imagined, such as the decision to set off the device at a less than optimal site in order to reduce the risk of detection inherent in transporting the device across borders. Collaboration among terrorist organizations is another possibility. See Morten Bremer Maerli, *Crude Nukes on the Loose? Preventing Nuclear Terrorism by Means of Optimum Nuclear Husbandry, Transparency, and Non-Intrusive Fissile Material Verification*, Ph.D. Dissertation (forthcoming), Faculty of Mathematics and Natural Sciences, University of Oslo, 2004.

nuclear attack that took place too close to their homeland areas. Nationalist/separatist groups might, however, consider the development of an IND (in contrast to its use) to be an advantageous tool for gaining international recognition and/or for blackmailing adversary governments into making concessions. Single-issue terrorist organizations are also unlikely to seek to cause massive destruction by using an IND, but extremist factions within such groups might consider doing so.

Further limiting the number of terrorist organizations that might seek to develop an IND are the financial and technical assets that the group would need to pursue this course. Because the complexity of fabricating an IND is much greater than the technical demands of making an improvised explosive device (IED) – a conventional bomb, it is likely that the technical barriers alone would dissuade most terrorists from pursuing an improvised nuclear device. Nonetheless, as discussed in more detail later, a gun-type IND could be well within the capabilities of some terrorist groups.

Among other requirements, millions of dollars would likely be needed if the group sought to purchase fissile material, bribe or threaten members of security forces guarding them, or attack a fissile material storage or processing site. While the planning for an operation to seize weapons-usable nuclear material and other non-nuclear parts of an IND could take months, the actual mating of the fissile material, especially highly enriched uranium, with the rest of the weapon could require mere days or even less time, depending on the characteristics of the material (whether in solid metallic form, needing minimal or no processing, or combined with other elements, requiring separation and chemical processing of the fissile material) and on the type of bomb design employed. Moving the IND (or its components) clandestinely to its target would be costly and complicated for most scenarios. In addition, considerable organizational skills would be required to permit the group to operate internationally.

Finally, the group would need a considerable degree of technical competence. Most analysts have assumed that to accomplish this task, the terrorist group in question would have to assemble a small team of specialists with expertise in such varied areas as nuclear physics or engineering, metallurgy, machining, and conventional explosives.[15] However, as discussed in detail in a later section, building the simplest type of IND, a gun-type device, might not require a large technical team.

At the present time, it is difficult to identify terrorist organizations whose extreme goals and substantial resources match those of al Qaeda. It is possible, however, that Chechen rebel factions might be motivated to acquire an IND to force concessions from Russia and might seek nuclear materials from sites in Russia, Central Asia, and other parts of the former Soviet Union. Central Asian national/separatist groups, such as the Islamic Movement of Uzbekistan might also consider seizing fissile materials from sites in Central Asia and using the threat to detonate an IND as a means to pursue their goals for political power and/or autonomy. In contrast to al Qaeda, however, it does not appear that any organizations in Russia or Central Asia would desire to cause massive casualties through the actual use of such a weapon.

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[15] See, for example, Carson Mark, Theodore Taylor, Eugene Eyster, William Maraman, and Jacob Wechsler, "Can Terrorists Build Nuclear Weapons?" in *Preventing Nuclear Terrorism: The Report and Papers of the International Task Force on Prevention of Nuclear Terrorism*, Leventhal and Alexander, eds., Lexington Books, 1987, pp. 55-65.

Acquisition of Fissile Material

In the chain of causation, the most difficult challenge for a terrorist organization would most likely be obtaining the fissile material necessary to construct an IND. Terrorists could attempt to exploit many acquisition routes. In particular, a state might voluntarily share fissile material with a terrorist group or sell the material to it; a senior official or governmental element with authorized access to such materials might, for ideological or mercenary motives, provide it to terrorists, without the express approval of governmental leaders; the immediate custodians of the material, for money or ideology, or under duress, might provide HEU or plutonium to the organization or assist it in seizing the material by force or stealth; or terrorists might obtain the material by force or stealth without insider help. Finally, nuclear weapon materials could come into the hands of terrorists during a period of political turmoil, including one brought on by a coup or revolution.

Deliberate transfer by a national government. Acquiring weapons-usable fissile materials directly from a sympathetic government would significantly simplify the requirements for the terrorists, obviating the need to defeat security systems protecting such materials. Presumably, to further the purposes of the transfer, the state sponsor would also provide assistance in manufacturing an IND, perhaps by providing a design or the non-nuclear components or by machining the HEU or plutonium into appropriate shapes before handing it over. Such material might be provided to terrorist groups by a state that hoped to see an IND used against an opponent, but wanted to be in a position to deny its involvement and reduce the threat of retaliation. Prior to Operation Iraqi Freedom, the Bush Administration feared Saddam Hussein might provide such support to terrorist groups. Today, the greatest sources of concern in this regard are Pakistan, North Korea, and, if it should begin/resume producing fissile material, Iran.

Regarding Pakistan, questions remain as to whether the government of Pakistan (including its current leadership) was complicit in Dr. Abdul Qadeer Khan's transfers between 1989 and 2003 of highly sensitive matériel for nuclear weapon programs in Iran, Libya, and North Korea – all of which were considered by the United States to be states sponsors of terrorism. If the government of Pakistan was involved, it was apparently unconcerned about whether terrorists might obtain fissile materials, and potentially, an IND, from these sympathetic governments. Moreover, although Pakistani President Pervez Musharraf has given his support to the U.S.-led War on Terror, including the ouster of the Taliban regime in Afghanistan and the elimination of al Qaeda, some senior elements of the Pakistani political establishment, oppose this. Musharraf was the target of two assassination attempts in December 2003. This history raises concerns that individuals supportive of radical Islamist groups may come to power in Pakistan and might give Pakistani nuclear-weapon material to a terrorist organization, although it is assumed that the Musharraf government would not do so.

Although some North Korean officials have provoked concern that North Korea might transfer nuclear materials outside of that country, their statements have not specifically mentioned transactions with terrorists. In addition, there are no known ties between the North Korean government and extremist terrorist groups. However, North

Korea has had past ties to international terrorism. Moreover, this state has sold ballistic missiles to other states of concern, and it has engaged in counterfeiting and sales of illicit drugs. Such transactions speak to the desperate condition of North Korea and raise the risk that Pyongyang may in extremis decide to sell nuclear materials either directly or indirectly to terrorist groups. In April 2004, U.S. intelligence analysts revised their estimate of the size of the North Korean nuclear arsenal, assessing that it had grown from two to eight weapons. The increase would make it possible for North Korea to sell one or perhaps two weapons, or the fissile material needed to make them, while retaining a significant nuclear deterrent.

In May 2004, news reports raised suspicions that North Korea may have sold uranium to Libya, a country that had been of proliferation concern until December 2003. According to the reports, North Korea in early 2001 may have provided Libya almost two metric tons of uranium that was not enriched for weapons use, but could have been fed into a uranium enrichment cascade that Libya had been manufacturing.[16] Although evidence has yet to emerge that North Korea has used a nuclear trading network to sell nuclear material either advertently or inadvertently to terrorist organizations, the unknown extent of the North Korean-Libyan deal is a warning that nuclear trafficking to terrorists might occur if North Korea is desperate enough and the payoff is enticing enough.

Unlike North Korea, Iran presently has ties to Islamist terrorist groups. Although Iran is widely believed to be seeking nuclear arms, there is no evidence to date to indicate that it has acquired these weapons. Moreover, there is no indication that Tehran has given WMD of any kind to terrorist organizations. Nonetheless, future transactions cannot be ruled out. A state that actively supports terrorist groups would be highly unlikely to transfer such materials to terrorists because it would risk suffering massive retaliation from the United States and its allies if the material were traced back to the state, and thus would be deterred in most situations. However, the greatest risk of such transactions would likely involve states that are facing imminent regime change. These states might have little to lose by handing the ingredients for an IND to a terrorist group as a last means of striking against an opponent. For example, some expressed concern prior to the 2003 U.S.-led war against Iraq that regime change might provoke Saddam Hussein to transfer WMD-material to non-state actors.[17] Thus, an unintended consequence of overthrowing the governments of states possessing HEU or plutonium could be to provoke them to aid or abet nuclear terrorists.

Unauthorized assistance from a senior official. Although leaders of a state may have little or no interest in transferring the wherewithal for an IND to a terrorist group or, even if they are interested, may be deterred from carrying out such transactions, senior officials within that state may be inclined to provide access to nuclear assets. These officials might be motivated by greed or ideological alignment with the terrorists, and they may act without the knowledge or approval of the state's leadership. For instance, Khan's sale of nuclear know-how to three governments, allegedly without authorization

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[16] David E. Sanger and William J. Broad, "Evidence is Cited Linking Koreans to Libya Uranium," *New York Times*, May 23, 2004, p. 1.1; David E. Sanger, "The North Korean Nuclear Challenge," *New York Times*, May 24, 2004, p. A9.

[17] William C. Potter, "Invade and Unleash?" *Washington Post*, September 22, 2002, p. B7.

from the government of Pakistan, pointed to the potential for a nuclear black market conduit to terrorists although there is no evidence to indicate that Khan's network is connected to terrorist organizations. Although Khan is not known to have dealt with terrorists, other Pakistani nuclear scientists were allegedly providing assistance to al Qaeda prior to the U.S. war in Afghanistan.[18] By the time Khan was exposed, many of the elements of a conspiracy that could have led to the transfer of fissile material to terrorists were in place.

Assistance from fissile material production workers and custodians. Some insiders at uranium enrichment or reprocessing plants are likely to have varying degrees of access to HEU or plutonium. Their motives for providing these materials to a terrorist group might include sympathy with the terrorists' goals, greed, or coercion through threats of violence or blackmail to friends, family members, or themselves. Identifying susceptible insiders and arranging for their assistance present substantial challenges. Terrorists might seek collaboration with organized crime to facilitate this method of acquisition. If, by taking advantage of the difficulty of accounting for fissile materials and/or weak security arrangements, the perpetrators were able to divert material without detection, they would gain the ability to mask their future actions – fabrication of an IND and transporting it (or its components) to the detonation site – without confronting intensive recovery efforts and heightened security at likely target locations. Poorly paid and demoralized nuclear workers and security guards in Russia might be vulnerable to subornation by terrorists or criminals. Moreover, the huge size and complexity of the Russian fissile material stockpile and production infrastructure greatly adds to the difficulty of protecting HEU and plutonium.

Seizure without insider help. Considerably greater effort and skill would be needed for a terrorist organization to seize fissile material without insider assistance, since this would mean the organization would need to train and arm a force able to defeat all security measures protecting the materials. In addition, the terrorists would have to determine what security measures they would confront and would need to map out a secure means of escape, which could involve travel over long distances. Although assaults would be more problematic against fissile material storage or processing areas deep within large, secure complexes, fissile materials are also found at sites in city centers, at smaller suburban research parks, and at isolated, stand-alone plants, where armed assaults, perhaps accompanied by diversionary attacks, would be more practicable.

Coups d'état and political unrest. As in an attempted seizure of a nuclear weapon, political instability during a coup or a revolution could provide an opportunity for terrorists to gain control over fissile material. Insurgents allied to or cooperating with terrorists could trigger or be the main assault force behind a takeover of a state that has weapons-usable nuclear material. Even if such an insurrection were unsuccessful, however, nuclear sites could fall behind "enemy" lines, before fissile materials could be removed permitting their transfer to terrorists or their allies. Or, during a period of civil strife, response forces might be drawn into the conflict, leaving fissile material sites

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[18] David Albright and Holly Higgins, "A Bomb for the Ummah," op. cit.

vulnerable to assault. It is also possible that during a period of political turmoil, nuclear custodians might desert their posts or be swept aside in the tide of events.

Such scenarios are not far-fetched: although the details remain murky and there is no indication that terrorists obtained the material involved, it appears that a small quantity of HEU (about 2 kilograms of 90% enriched) located at the Sukhumi Nuclear Research Center, in the break-away Georgian province of Abkhasia, was diverted during a period of civil turmoil in the early 1990s.[19] More recently, terrorism attributed to the Islamic Movement of Uzbekistan, led to increased concern about the security of nuclear materials at the Institute of Nuclear Physics in Ulugbek, near Tashkent, and to the removal to Russia of fresh HEU fuel research reactor fuel stored there.[20]

Fabrication of an Improvised Nuclear Device

Assuming that terrorists would not have access to technologically sophisticated nuclear weapons design and fabrication infrastructures, such as those possessed by a limited number of states, terrorists who seek to build an improvised nuclear device would favor nuclear weapons designs based on first-generation, well-proven technology. First-generation nuclear weapons draw upon two designs: gun-type and implosion-type.

Gun-type device. The most basic type of nuclear weapon is a gun-type device. As its name suggests, like a gun, it fires a projectile. The projectile in this type of weapon is a piece of highly enriched uranium. Moreover, like a gun, a gun-type device would use a gun barrel to direct the projectile. To ignite a nuclear explosion, the HEU projectile would travel down the barrel to another piece of HEU. The HEU pieces would both be sub-critical; that is, each one by itself could not sustain an explosive chain reaction. Once they combined, they would form a supercritical mass.

Ideally, weapons-grade HEU would be the most effective fissile material for a gun-type device because of its very high concentration of uranium-235.[21] Gun assembly is an inefficient means of exploding HEU mainly because it is a relatively slow way (compared to implosion assembly, as described below) to form a supercritical mass and it does not appreciably compress or change the density of the fissile material.[22] Therefore, a gun-type device requires relatively large amounts of HEU and would only fission a small fraction of the HEU during the explosive chain reaction. Nonetheless, even HEU enriched to less than weapons-grade can lead to an explosive chain reaction. The Hiroshima bomb, for example, used about 60 kg of 80% enriched uranium. Also, the six

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[19] Center for Nonproliferation Studies, “Confirmed Proliferation-Significant Incidents of Fissile Material Trafficking in the Newly Independent States (NIS), 1991-2001,” CNS Reports, November 30, 2001, available at http://cns.miis.edu/pubs/reports/traff.htm, accessed on May 27, 2004.

[20] Author’s communication with U.S official, name withheld on request, Washington, DC, April 2004. An unspecified quantity of irradiated fissile material remains at the site.

[21] The neutrons that cause fission (which is how energy is released in the bomb) would not have to travel as far before interacting with a uranium-235 nucleus in a mass of weapons-grade HEU compared to lower enrichments of HEU. Thus, more fissions can occur in a given period of time inside a mass of weapons-grade HEU.

[22] The critical mass scales as the inverse of the density squared. Thus, if the density is increased by a factor of two, the critical mass required decreases by a factor of four. In contrast to the gun method, the implosion method significantly changes the density of the fissile material.

South African gun-type weapons employed less than weapons-grade material. Each of South Africa's weapons used an estimated 55 kg of about 80% enriched HEU.[23] Terrorists would probably need about 40 to 50 kg of weapons-grade or near-weapons-grade HEU to have reasonable confidence that the IND would work.[24] At the lower limit of efficiency for a gun-type device using weapons-grade HEU, a technically-sophisticated terrorist group might be able to reduce the necessary amount of material to about 25 kg; this, however, would require the use of a "reflector" made of beryllium – a difficult-to-obtain and closely regulated metal – to enhance the chain reaction.[25]

Most physicists and nuclear weapons analysts have concluded that construction of a gun-type device would pose few technological barriers to technically competent terrorists.[26] In 2002, the U.S. National Research Council in its report warned, "Crude HEU weapons could be fabricated without state assistance."[27] The Council further specified, "The primary impediment that prevents countries or technically competent terrorist groups from developing nuclear weapons is the availability of [nuclear material], especially HEU."[28] Thus, this prestigious group of scientists emphasized the dangers posed by HEU over other types of nuclear material. In September 2003, several scientists under the auspices of the Union of Concerned Scientists signed a letter, which stated that HEU is "the easiest material in the world for terrorists to use to make a nuclear bomb."[29] Moreover, commenting on the relative ease of using HEU to make a nuclear weapon, Richard Garwin and Georges Charpak wrote, "Enriched uranium is the dream material

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[23] David Albright, "South Africa's Secret Nuclear Weapons," ISIS Report, May 1994.

[24] John McPhee, *The Curve of Binding Energy*, Farrar, Straus, and Giroux, New York, 1974, pp. 189-194.

[25] The IAEA's significant quantity for HEU is an amount of uranium containing 25 kg equivalent U-235. However, this amount is based on the assumption that a state could use this material to build the more technically challenging implosion weapon.

[26] See, for example, Carson Mark, Theodore Taylor, Eugene Eyster, William Maraman, and Jacob Wechsler, "Can Terrorists Build Nuclear Weapons?,"1987, op. cit.; Luis W. Alvarez, *Adventures of a Physicist*, Basic Books, 1988, p.125; Frank Barnaby, "Issues Surrounding Crude Nuclear Explosives," in *Crude Nuclear Weapons: Proliferation and the Terrorist Threat*, IPPNW Global Health Watch Report Number 1, 1996; Morten Bremer Maerli, "Relearning the ABCs: Terrorists and 'Weapons of Mass Destruction'," *The Nonproliferation Review*, Summer 2000; Frank von Hippel, "Recommendations for Preventing Nuclear Terrorism," *Federation of American Scientists Public Interest Report*, November/December 2001, p. 1; Matthew L. Wald, "Suicidal Nuclear Threat is Seen at Weapons Plants," *New York Times*, January 23, 2002, p. A9; Robert L. Civiak, *Closing the Gaps: Securing High Enriched Uranium in the Former Soviet Union and Eastern Europe*, Report for the Federation of American Scientists, May 2002; Committee on Science and Technology for Countering Terrorism, National Research Council, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism*, National Academy Press, 2002; Richard L. Garwin and Georges Charpak, *Megawatts and Megatons: A Turning Point in the Nuclear Age?* Alfred A. Knopf, New York, 2001; Jeffrey Boutwell, Francesco Calegero, and Jack Harris, "Nuclear Terrorism: The Danger of Highly Enriched Uranium (HEU)," *Pugwash Issue Brief*, September 2002; "Scientists' Letter on Exporting Nuclear Material," to W. J. "Billy" Tauzin, September 25, 2003, Union of Concerned Scientists, available at http://www.ucsusa.org/global_security/nuclear_terrorism/page.cfm?pageID=1256, accessed on May 14, 2004, and Gunnar Arbman, Francesco Calogero, Paolo Cotta-Ramusino, Lars van Dessen, Maurizio Martellini, Morten Bremer Maerli, Alexander Nikitin, Jan Prawitz, and Lars Wredberg, "Eliminating Stockpiles of Highly-Enriched Uranium," Report submitted to the Swedish Ministry for Foreign Affairs, SKI Report 2004:15, April 2004.

[27] National Research Council, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism*, op. cit., p. 45.

[28] Ibid, p. 40.

[29] "Scientists' Letter on Exporting Nuclear Material," op. cit.

for making bombs."[30] Frank von Hippel, a physicist who had served as the Assistant Director for National Security at the White House's Office of Science and Technology Policy, wrote in 2001, "It is generally agreed, however, that educated terrorists could turn weapon-grade uranium … into a gun-type nuclear explosive."[31]

While there appears to be little doubt among the experts that technically competent terrorists could make a gun-type device given sufficient quantities of HEU, the question remains as to how technically competent do they have to be and how large of a team would be needed. At one end of the spectrum of analysis, there is the view that a suicidal terrorist could literally drop one piece of HEU metal on top of another piece to form a supercritical mass and initiate an explosive chain reaction. Nobel laureate Luis Alvarez's oft-cited quote exemplifies this view. He wrote, "With modern weapons-grade uranium, the background neutron rate is so low that terrorists, if they have 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. Most people seem unaware that if separated HEU is at hand it's a trivial job to set off a nuclear explosion … even a high school kid could make a bomb in short order."[32] However, he did not specify what he meant by "high-yield" explosion. A January 2002 *New York Times* report elaborated that "a 100-pound mass of [weapons-grade] uranium dropped on a second 100-pound mass, from a height of about 6 feet, could produce a blast of 5 to 10 kilotons."[33] It should be noted that both statements suggest that there is no guarantee that this very crude method would work all the time or would always produce such a powerful explosion. This scenario also posits that the terrorist would be suicidal. With more technical effort, the terrorist group could significantly increase its chances of generating a high-yield explosion. The basic design specifications are well-known and available through the Internet.

However, to make sure that the group could surmount any technical barriers, it would likely want to recruit team members who have knowledge of conventional explosives (needed to fire one piece of HEU into another), metalworking, draftsmanship, and chemical processing (for example, in order to extract HEU metal from other chemical forms, such as oxide or aluminum-based reactor fuel). A well-financed terrorist organization such as al Qaeda would probably have little difficulty recruiting personnel with these skills. Concerning the size of the team and the preparation time required, Albert Narath estimated, "Once the HEU in metallic form is in hand it might require only a dozen individuals with the right set of skills to accomplish the design and construction over a period of perhaps a year."[34] The approximately year's amount of preparation would allow for "rapid turn around" that is "the device would be ready within a day or so after obtaining the material." Carson Mark et al. also assessed, "Such a device could be constructed by a group not previously engaged in designing or building nuclear

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[30] Richard L. Garwin and Georges Charpak, op. cit., p. 313.

[31] Frank von Hippel, "Recommendations for Preventing Nuclear Terrorism," op. cit., p. 1.

[32] Luis W. Alvarez, *Adventures of a Physicist*, Basic Books, 1988, p.125

[33] Matthew L. Wald, "Suicidal Nuclear Threat is Seen at Weapons Plants," *New York Times*, January 23, 2002, p. A9.

[34] Albert Narath, "The Technical Opportunities for a Sub-National Group to Acquire Nuclear Weapons," XIV Amaldi Conference on Problems of Global Security, April 27, 2002.

weapons."[35] In a later analysis in November 2001, the Pugwash Council echoed this view by underscoring that "sub-national terrorist groups could accomplish the challenge."[36]

Because of its inherent simplicity, designing and constructing a gun-type device would be relatively straightforward. Testing the non-nuclear parts of the device would likely be required, and an appropriate testing area would be needed (such as a terrorist training camp where other explosives were routinely used) to avoid arousing suspicions. Assuming such tests and a sufficient amount of HEU in the appropriate form, terrorists could have a moderate degree of confidence that their IND would result in a substantial nuclear yield. It may be recalled that U.S. scientists had such great confidence in the gun-type design that they believed it was unnecessary to test it through a nuclear detonation prior to its actual use over Hiroshima. Similarly, South African nuclear weapon designers had full confidence in the gun-type weapons they had built, even though that country is not known to have conducted a nuclear test. South Africa assembled these bombs in a warehouse – a relatively small building that escaped detection throughout its many years of operation.[37] Thus, the most formidable barrier to a gun-type weapon remains the acquisition of sufficient HEU.

A terrorist group might also attempt to extract HEU from fresh or spent HEU fuel used in research or propulsion reactors. Fresh fuel can contain up to 93 percent enriched uranium. Spent HEU fuel contains a reduced concentration of uranium-235 compared to fresh fuel, but if the original enrichment were high enough or if the fuel had been only partially used – or lightly irradiated -- before it was seized, enrichment levels could easily remain close to the original concentration of uranium-235.[38] In fact, many research reactors are often used only intermittently, resulting in lightly irradiated fuel, which presents a reduced radiation safety hazard, greatly simplifying the HEU separation process.[39]

It is impossible to achieve a large nuclear explosion by employing plutonium in a gun-type device because the speed of assembly of the critical mass is too slow to allow plutonium to be used efficiently.[40] However, some authorities have concluded that a relatively small explosive yield (not greater than 10 to 20 tons TNT equivalent) could be

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[35] Carson Mark et al., op. cit.

[36] Pugwash Conferences on Science and World Affairs, "The Dangers of Nuclear Terrorism," Statement of the Pugwash Council, November 12, 2001.

[37] David Albright, "South Africa and the Affordable Bomb," *Bulletin of the Atomic Scientists*, July/August 1994.

[38] Alexander Glaser and Frank von Hippel, "On the Importance of Ending the Use of HEU in the Nuclear Fuel Cycle: An Updated Assessment," Paper presented at the 2002 International Meeting on Reduced Enrichment for Research and Test Reactors, November 3-8, 2002.

[39] Edwin Lyman and Alan Kuperman, "A Reevaluation of Physical Protection Standards for Irradiated HEU Fuel," 24th International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR-2002), November 2002; Matthew Bunn, "Threat from Research Reactor Fuel," unpublished paper, as of May 2004; and Matthew Bunn and Anthony Wier, *Securing the Bomb: An Agenda for Action*, Project on Managing the Atom, Harvard University, Report Commissioned by the Nuclear Threat Initiative, May 2004, p. 37. Notably, Iraq during its crash program in 1991 to produce a nuclear bomb planned to use both fresh and irradiated HEU fuel from its research reactors. David Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities, and Policies*, (SIPRI: Oxford University Press, 1997), pp. 344-349.

[40] Plutonium's spontaneous fission rate is much greater than uranium's. Before the gun-type device would be able to assemble plutonium into a supercritical mass, the neutrons emitted by the spontaneous fission would lead to a dud or a "fizzle" yield. Fizzles result in a small nuclear yield.

produced by using plutonium in a gun-type IND. Both weapons-grade and reactor-grade plutonium would result in this fizzle yield.[41] Although this yield is about three orders of magnitude less than the yield expected from a Hiroshima-type (HEU) bomb, it is much more powerful than typical conventional explosives. Thus, terrorists detonating a gun-type IND fueled with plutonium could cause tremendous blast damage within an area encompassing several city blocks – the destruction radius from ground zero would be about 100 meters – and could "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."[42] This aspect of the weapon's impact would, in effect, be similar to a very large radiological dispersal device, and would be especially dangerous, inasmuch as small quantities of plutonium, if inhaled, are known to cause cancer. In sum, although weapons-usable HEU poses the greater threat by far because it could power a devastating gun-type device, plutonium could conceivably be used by terrorists to produce a significant, but a lower order level of, damage.

Implosion-type. To cause a nuclear explosion, an implosion-type device squeezes a sphere of fissile material from a relatively low density subcritical state to a high density supercritical state. If the implosion does not occur smoothly, the bomb will be a complete dud or result in a fizzle yield much lower than expected from a properly designed implosion weapon. Thus, in contrast to a gun-type device, an implosion-type device requires more technical sophistication and competence. A terrorist group, for example, would need access to and knowledge of high-speed electronics and high explosive lenses, a particularly complex technology. This equipment is necessary to result in a fast and smooth squeezing of the fissile material into a supercritical state. Unlike a gun-type device, an implosion-type device can employ HEU or plutonium because the speed of assembly is fast enough to allow the use of plutonium. An improvised implosion-type weapon would probably require approximately 25 kg of weapons-grade HEU or roughly 8 kg of plutonium in the highest density, or alpha, phase. For comparison, the implosion bomb exploded over Nagasaki contained 6 kg of weapons-grade plutonium.

As noted earlier, weapons-grade plutonium is the most desirable type of plutonium both from the perspective of a weapon scientist employed by a state and for a terrorist organization, since it is most readily detonated. Even reactor-grade plutonium could result in an explosive chain reaction, however, depending on the skill of the weapons designers and builders.[43] Because reactor-grade plutonium would have a much

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[41] Stanislav Rodionov, "Could Terrorists Produce Low-Yield Nuclear Weapons?" in National Research Council, National Academy of Sciences, in Cooperation with the Russian Academy of Sciences, *High-Impact Terrorism: Proceedings of a Russian-American Workshop* (Washington, DC: National Academies Press, 2002), pp. 156-159. The 10 to 20 ton explosive yield estimate is for a relatively fast gun-assembly speed of about 300 m/s. For a more modest 100 m/s assembly speed, the yield would be about five times less or a few tons; Rodionov, p. 158.

[42] Ibid, p. 159.

[43] In 1997, the U.S. government re-emphasized earlier pronouncements that reactor-grade plutonium can fuel nuclear weapons. See, U.S. Department of Energy, Office of Arms Control and Nonproliferation, *Final Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives*, DOE/NN-0007, Washington, DC, DOE, 1997, pp. 37-39. In its report on nuclear terrorism, the U.S. National Research Council in 2002 stated, "Reactor-grade plutonium can be used to fabricate workable nuclear devices." See, Committee on Science and Technology for Countering Terrorism, National Research Council, "Nuclear and Radiological Threats," Chapter 2 in *Making the*

higher chance of pre-ignition, the bomb yield would likely be much less than that of a weapon made from weapons-grade plutonium. Nonetheless, even if terrorists were only able to achieve a "fizzle" yield from the device, it would be far greater than the yield from a powerful conventional explosion, thus giving the terrorists a potent weapon. Commenting on the yield of a fizzle reactor-grade implosion device, Garwin and Charpak write, "The major problem is that the much larger amount of plutonium-240 [in the reactor-grade material] than in weapons-grade plutonium makes even the implosion system very likely to preinitiate – and when it does so, it lowers the yield of the simplest system to as little as 2,000 tons of explosive, in contrast to a design yield of 20,000 tons (which would still be achieved a portion of the time)."[44]

Implosion-type weapons, using reactor-grade plutonium, weapon-grade plutonium, or HEU, would pose design and construction challenges much greater than that faced in building of a gun-type HEU device. Iraq's nuclear weapon scientists, for example, appear to have required several years to achieve the ability to construct a workable nuclear weapon design based on implosion. Even if terrorists obtained a design that was known to work, however, manufacturing the components for the device and ensuring that they all worked together with the necessary precision would be a daunting technical challenge, requiring considerable time and extensive testing of the non-nuclear "triggering package," both of which would increase the risk of detection. Given these challenges, terrorists would likely have far less confidence that their implosion-based device would work than they would have in the case of a far simpler gun-type assembly using HEU. Additionally, since it is assumed that terrorists will have only limited quantities of plutonium available, a full-scale nuclear test undertaken simply to prove the design of the weapon the terrorists had built seems highly unlikely. More probable is that the first detonation using plutonium would be at a target, with the expectation that even if the device failed to produce a nuclear yield, its very existence would cause profound fear in the target state and permit blackmail based on the real or pretended existence of additional weapons.

Could a reasonably technically competent small group design and build an implosion device? Although open source evidence does not indicate terrorist success to date, a U.S. government sponsored experiment in the 1960s sheds light on the technical capabilities required.[45] Deciding to prove that designing a first-generation-type nuclear weapon does not require Nobel laureates, the Lawrence Livermore National Laboratory hired a couple of young Ph.D. physicists who had no prior experience with nuclear weapons to conduct the Nth Country experiment. These physicists, using access to only open source information, were able to design a workable implosion-type weapon in less than three years. They pursued the implosion design because they decided that a gun-type device was too simple and, thus, not enough of a challenge.

In sum, given a choice between building a gun-type or an implosion-type device, terrorists probably would choose to construct a gun-type device because it is more likely to result in a nuclear weapon producing a large explosive yield. However, if nuclear

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Nation Safer: The Role of Science and Technology in Countering Terrorism, National Academy Press, 2002, p. 40.

[44] Richard L. Garwin and Georges Charpak, *Megawatts and Megatons: A Turning Point in the Nuclear Age?* Alfred A. Knopf, New York, 2001, p. 315.

[45] Dan Stober, "No Experience Necessary," *Bulletin of the Atomic Scientists*, March/April 2003, pp. 57-63.

terrorists only had access to plutonium, they would be forced to build an implosion-type device to achieve high yields, or they could try to construct a low-yield gun-type device.[46]

Transporting the IND (or its components) to the Target Site

Assuming that nuclear terrorists were able to acquire the necessary fissile material and manufactured an IND, they would then have to cross the next barrier to IND use. That is, they would have to find a way to deliver an IND to a target without being caught and stopped. The distance between the point of acquisition and the target could be quite substantial. If the loss of fissile material were detected, a massive hunt for the material would be launched, involving law enforcement and military personnel from many nations, assisted by nuclear specialists. This would be accompanied by greatly intensified security over transportation links and points of entry. Unfortunately, for many scenarios, material might be diverted without detection for some time or the diversion might not be acknowledged, providing the opportunity for the terrorist organization involved to cover its tracks and move the material to a safe location, where manufacture of the IND could be undertaken.

Transportation of an IND once completed would not present insurmountable difficulties. Although an IND would likely be heavy – perhaps weighing up to a ton -- trucks and commercial vans could easily haul a device in that range. In addition, container ships and commercial airplanes, such as those used to transport heavy equipment, could provide delivery means. As of late 2003, only about 2 to 3% of the containers entering the United States are thoroughly checked. Nonetheless, terrorists would need extensive resources and networks of collaborators to move their IND over long distances, adding to the complexity of their plot. However, detecting uranium or even plutonium in transit is difficult.

Every means of delivery, however, exposes terrorists to some risk of discovery. To reduce or eliminate this risk, a terrorist group might choose to detonate an IND on the spot where it was assembled. A devastating blast even in such a location would cause grave damage and many deaths – and provide terrorists the opportunity to threaten to destroy more impressive targets with INDs it could claim to possess. Terrorists might try to assemble and detonate a gun-type device, but probably not a more-sophisticated implosion-type device, at a fissile material storage site, assuming that this site contained sufficient quantities of readily usable HEU metal and that the terrorists were suicidal and that the assault team included members versed in the relevant technical skills of gun devices.[47]

Detonation of the IND

Inasmuch as, by definition, terrorists constructing an IND would be familiar with its design, the act of detonating the device would be relatively straightforward and

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[46] Rodionov, 2002, op. cit., pp. 156-159.

[47] Matthew L. Wald, "Suicidal Nuclear Threat is Seen at Weapons Plants," *New York Times*, January 23, 2002, p. A9. Also, as discussed in an earlier section, there is a "good chance" that terrorists could set off a nuclear explosion by dropping one piece of HEU onto another.

present few technical difficulties. However, as discussed above, an implosion device presents a much greater chance of producing a dud or fizzle yield than a gun device.

Nuclear Materials Security at the State Level

Very few organizations have the necessary motivation and resources, and any organization making the attempt would have to surmount a series of extremely challenging obstacles. That being said, much would depend on the ability of the terrorist organization to recruit a suitable, technically competent team and on the state of physical protection and accounting covering the fissile materials needed for weapons. If effective, national safeguards can defeat almost all paths to terrorist acquisition of these materials, except in the case of the transfer of such materials by a sympathetic government (which might also provide assistance in nuclear weapon design and fabrication). As outlined earlier, the settings posing the greatest risk of terrorist acquisition of a nuclear weapon are found in Russia, Pakistan, at certain research facilities around the globe with HEU stocks, and, possibly, at plutonium processing and storage facilities in Japan.

Russian HEU and Plutonium. The huge quantity of fissile material in Russia poses a uniquely dangerous risk of terrorist acquisition of weapons-origin material for an IND. As of March 2003, the U.S. Department of Energy estimated that Russia possessed roughly 600 metric tons[48] of weapons-usable plutonium and HEU outside of nuclear weapons, enough to make over 20,000 nuclear warheads, stored at over 50 military and civilian sites.[49] Numerous assessments, citing the general state of decay of Russia's nuclear infrastructure, decades of inadequate nuclear materials accounting, and the impoverishment of Russian nuclear workers and scientists, have concluded that most of this material is inadequately secured.[50] Echoing such concerns about the security of Russian fissile materials, in March 2003, the General Accounting Office (the investigative arm of the U.S. Congress) found that the key U.S. program for securing fissile materials in Russia, the Material Protection, Control, and Accounting (MPC&A) program of the Department of Energy (DOE) had made "uneven progress."[51]

These findings have been accompanied by repeated reports of trafficking in Russian-origin weapons-usable nuclear materials. Analysts at Stanford University estimate that about 40 kilograms of weapons-usable material has been stolen from the

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[48] U.S. General Accounting Office, "Weapons of Mass Destruction: Additional Russian Cooperation Needed to Facilitate U.S. Efforts to Improve Security at Russian Sites," GAO-03-482, March 2003, p. 15.

[49] The Department of Energy has used the 600 ton figure for many years. It appears that new Russian production of several tons of separated plutonium annually (from military and civilian programs), together with fissile material removed from nuclear weapons and added to Russia's out-of-weapons fissile material stockpile roughly balance the 30 tons of HEU per year that is removed from that stockpile through dilution of HEU into non-weapons-usable low enriched uranium, pursuant to the U.S.-Russian HEU Purchase Agreement, discussed below. Thus while the total quantity of Russian fissile material in and out of weapons is declining, the amount outside of weapons appears to be holding relatively constant at the 600 metric ton level.

[50] National Intelligence Council, "Annual Report to Congress on the Safety and Security of Russian Nuclear Facilities and Military Forces," February 2002.

[51] U.S. General Accounting Office, "Weapons of Mass Destruction: Additional Russian Cooperation Needed to Facilitate U.S. Efforts to Improve Security at Russian Sites," GAO-03-482, March 2003, (hereinafter "GAO Report"), p. 25.

NIS.[52] Most of the material involved in these reported incidents was recovered, but the total attempts at theft or diversion remains unknown. Other analysts have pointed out that some evidence indicates that criminal organizations are becoming more interested in smuggling nuclear and radioactive material from the NIS.[53]

The United States has some half dozen major programs to help Russia secure, consolidate, and eliminate fissile materials. Table 5 summarizes these programs. While many of these programs have made important progress in reducing the threat posed by these materials, all are far from completion, and the acute dangers posed by Russian HEU and plutonium will continue for much of the remainder of this decade, if not beyond. A particular concern is that the Department of Energy's MPC&A program has yet to provide even rudimentary security improvements for more than half of Russia's fissile materials and has provided comprehensive security upgrades for only 23 percent of this material. The Department appears to have made little progress in gaining access to key locations where the largest quantities of these materials are housed, Russia's weapons assembly and disassembly facilities and key locations within that country's nuclear weapons complex.[54]

The U.S. programs to secure, consolidate, and eliminate fissile materials in Russia originated in the early to mid-1990s at a time when the most dangerous proliferation threat appeared to be that posed by the spread of nuclear weapons to dangerous states, including Iran, Iraq, Libya, and North Korea. However important those threats may have been – and, in some cases, they remain significant – the gravest and most immediate nuclear threat to the United States and its allies today comes from terrorists, that is, from non-state actors seeking weapons of mass destruction, not from states, themselves. In this context, inadequately secured HEU enriched to 80 percent or more – the material whose loss to terrorists is by far the most likely to lead to a nuclear explosion on U.S. or allied territory – looms as a unique danger.

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[52] Lisa Trei, "Database exposes threat from 'lost' nuclear material," Stanford Report, March 6, 2002, http://news-service.stanford.edu/news/march6/database-36.html, accessed on March 12, 2002.

[53] Potter and Sokova, 2002, op. cit., pp. 113-116.

[54] DOE officials respond that within the Russian system, these are the locations that are the most secure, even if they do not meet the level pursued in U.S. assistance programs; that for this reason, terrorists would be least likely to seek fissile materials at these sites; and that the Department has had considerable success in enhancing security at the initially more vulnerable facilities in other parts of the Russian nuclear complex. Nonetheless, the stated goal of the MPC&A program is to improve security at these sites and this goal remains far from achievement. Author's interview with senior DOE official, name withheld on request, Washington, DC, April 2004.

Program	Goal	Status	Completion Date
Securing Fissile Material			
Material Protection, Control, and Accounting (MPC&A)	Secure fissile material outside weapons	Rapid upgrades completed on 43% of material; comprehensive upgrades complete on 22% of material	2008
Mayak Fissile Material Storage Facility	Secure 50 tons of weapons-grade plutonium, but could secure HEU, as well	Loading to begin in 2004 depending on completion of transparency agreement	2020?
Eliminating Fissile Materials			
HEU Purchase Agreement	Down-blend 500 metric tons of weapons-grade HEU for sale as commercial nuclear power plant fuel	About 200 tons of HEU rendered unusable for nuclear weapons as of end of 2003; additional conversion at the rate of 30 tons/year	2012
MPC&A HEU Consolidation and Conversion	Consolidate and down-blend HEU from research centers and reactors in former Soviet Union and Eastern Europe	4.3 tons of HEU rendered unusable for nuclear weapons as of end of 2003; an additional 4 tons to be eliminated by the end of 2005	2005
Plutonium Disposition	Use 34 tons of weapons-origin plutonium as power reactor fuel, rendering it very difficult to use for weapons	First use in a Russian reactor scheduled for 2008, depending on resolution of liability agreement and completion of MOX fuel facility	2025
Ending Production of Fissile Materials			
Elimination of Weapons-Grade Plutonium Production	End production of 1.2 tons/yr of weapons-grade plutonium by providing fossil fuel plants as alternative sources of heat and power for three Russian production reactors	Revised agreement signed between the United States and Russia in 2003; DOE expects to complete design work for fossil fuel plants by end of 2004 and then provide Congress with an updated cost estimate	2011
Elimination of Civilian Plutonium Separation *No U.S. or international program*	End added accumulation of 1+ tons/yr of separated plutonium from Russian VVER nuclear power plants	No program	N/A

Table 5: U.S. Programs to Secure and Reduce Russian Fissile Materials

HEU is doubly dangerous because, unlike plutonium, it is used extensively in Russia in applications other than nuclear weapons and thus more exposed to potential theft or diversion by terrorist groups.[55] Although the largest stores of HEU and plutonium in Russia outside of weapons are found at nuclear weapon assembly and dismantlement sites and at former fissile material production facilities, and although both

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[55] This situation would change if MOX fuel were to be widely used, thereby creating significant transportation and processing of plutonium and unirradiated plutonium-bearing MOX fuel. Under the U.S. Plutonium Disposition program, Russia is to convert 34 tons of weapons plutonium into MOX over a seventeen year period and use the fuel in nuclear power reactors, thereby embedding the plutonium in highly radioactive spent fuel, rendering it far less accessible for potential use in nuclear weapons. The transportation and processing activities involved in this program, however, would create potential security risks that would need to be carefully addressed.

are found in some research institutes, high-quality HEU is far more widely dispersed beyond these locations because of its additional uses:

- HEU is used as fuel in some 40 operational research reactors, test reactors, and critical assemblies in Russia.[56] Although the enrichment levels vary depending on the reactor or critical assembly, at least nine reactors rated above 1 MW power (a threshold above which a research reactor is considered of relatively high proliferation concern) employ 90 percent enriched HEU. In addition, many of these reactor sites contain stores of fresh HEU fuel or lightly irradiated spent HEU fuel.[57]
- HEU is used in Russian submarine, cruiser, and icebreaker propulsion reactors; a proportion of the fuel for these vessels is reportedly enriched to 80 percent or more.[58] Most of the discharged submarine fuel would contain enrichment levels between 21-45%, far below the more easily weapons-usable 80% or greater enrichment levels; only two classes of Russian submarines (November 645 and Alfa classes) were believed to have used weapons-grade HEU as fuel. While tons of Russian naval spent fuel are stored under highly insecure conditions, in northwest Russia and in the Russian Far East, only a very small proportion of this spent fuel would contain weapons-grade or near weapons-grade HEU. However, reportedly, the Kirov battle cruiser (now called the Admiral Ushakov) and the Russian icebreakers use weapons-grade HEU as fuel. Thus, from a prevention of nuclear terrorism perspective, these vessels deserve greater security protection than almost all of the Russian submarine fuel – both fresh and spent fuels.
- High-quality HEU may also be used in the floating reactors that Russia plans to employ in the Arctic region and potentially sell to other countries. Although the enrichment level of the floating reactors' fuel has not been openly published, some analysts believe that because the reactor design is based on the design of the icebreakers' reactors, weapons-grade HEU might be employed.[59]
- HEU of varying enrichment levels is also found in large quantities in fuel fabrication facilities, i.e., facilities where marine propulsion and research reactor fuels are manufactured from bulk HEU and at sites where these fuels are designed.

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[56] Oleg Bukharin, Christopher Ficek, and Michael Roston, "U.S.-Russian Reduced Enrichment for Research and Test Reactors (RERTR) Cooperation," RANSAC Policy Update, Summer 2002, p. 3.

[57] Both fresh and lightly irradiated HEU fuels are comparably dangerous because the radiation barrier in the lightly irradiated fuel would generally not be great enough to be lethal in the relatively short period of time required to process the fuel to extract HEU and fashion an IND.

[58] Don J. Bradley, *Behind the Nuclear Curtain: Radioactive Waste Management in the Former Soviet Union*, edited by David R. Payson, Battelle Press, Richland, Washington, 1997, p. 283; Oleg Bukharin and William Potter, "Potatoes were Guarded Better," *Bulletin of the Atomic Scientists*, May 1995; Chunyan Ma and Frank Von Hippel, "Ending the Production of Highly Enriched Uranium for Naval Reactors," *The Nonproliferation Review*, Spring 2001; p. 91; and Mohini Rawool-Sullivan, Paul D. Moskowitz, and Ludmila N. Shelenkova, "Technical and Proliferation-Related Aspects of the Dismantlement of Russian Alfa-Class Nuclear Submarines," *The Nonproliferation Review*, Spring 2002, p. 164.

[59] Alexander Glaser and Frank von Hippel, "On the Importance of Ending the Use of HEU in the Nuclear Fuel Cycle: An Updated Assessment," Paper presented at the 2002 International Meeting on Reduced Enrichment for Research and Test Reactors, November 3-8, 2002.

- In addition, weapons-grade HEU is processed in very large quantities under the U.S.-Russia HEU Purchase Agreement. The agreement provides that over the course of twenty years, Russia is to blend down 500 metric tons of HEU from or intended for nuclear weapons into low enriched uranium. The latter material is suitable for use as nuclear power plant fuel, but no longer usable for nuclear weapons. The blended-down material is to be purchased by the United States Enrichment Corporation, for some $12 billion. As of early 2004, the HEU Purchase Agreement has resulted in the blending down of 201 metric tons of Russian HEU, and each year, 30 metric tons of the material must be taken from four weapon-disassembly sites, transported long distances by rail, and introduced into processing plants for blending. Significantly, for the first leg of this journey, the material transported is HEU metal, the form of HEU that could be most readily used by terrorists for an IND.
- At least one important research center near Moscow currently stores hundreds of kilograms of HEU metal, which despite years of effort, have yet to be fully secured at a central storage site.
- The Department of Energy has focused on a number of these danger points. Its Material Consolidation and Conversion program is gathering up smaller quantities of HEU from disparate sites in Russia and from Soviet-supplied research reactors abroad and down-blending the material to non-weapons-usable low-enriched uranium. Over 4 metric tons of HEU have been rendered safe to date. The Department's MPC&A program has assisted the Russian Navy to secure virtually all fresh HEU submarine fuel, and it has given high priority to securing HEU fuel fabrication and development facilities.

Despite these valuable initiatives, the unique threat posed by Russian high-quality HEU has not been expressly recognized within the Department of Energy or within the U.S. government, more broadly. As the Department seeks access to new sites within the Russian nuclear complex, for example, it has not placed sites holding high-quality HEU at the top of its list, nor at sites where it does have access, nor has it given first priority to securing high-quality HEU. Similarly, U.S. government as a whole has failed to establish priorities among the suite of U.S. nuclear assistance programs for Russia to make securing high-quality HEU the paramount concern.

Most notably, the Department of Energy and the U.S. government, more generally, are devoting hundreds of millions of dollars and significant diplomatic energies to the program for the eventual elimination of 68 metric tons of excess weapons plutonium (34 tons each of U.S. and Russian material), while devoting only a small fraction of these resources ($25 million in Fiscal Year 2004) to accelerate the down-blending of HEU beyond the amounts currently covered by the HEU Purchase Agreement. In the latter area, they have achieved very limited results – an increase of only 1.5 tons in the annual blend-down rate for each of the next ten years – even though a large-scale expansion of HEU blend-down activities could be implemented far more rapidly and at much lower cost than the plutonium disposition effort, while eliminating far greater quantities of fissile material.[60] Similarly, the recently commissioned Mayak

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[60] For a summary of developments, see Nuclear Threat Initiative, "Reducing Excess Stockpiles: The U.S.-Russia Highly Enriched Uranium Purchase Agreement," op. cit.

Fissile Material Storage Facility at Ozersk, constructed under the U.S. Department of Defense Cooperative Threat Reduction Program for a cost of more than $400 million, is to house 50 tons of Russian weapons-grade plutonium under highly secure conditions. As constructed, however, it could also house 200 tons of weapons-grade HEU – one third of the fissile material that the Department of Energy is attempting to protect through its MPC&A program, and the material of greatest interest to terrorists – but there does not appear to be a U.S. effort currently under way to press Russia to use the facility for this purpose.

Although high-quality HEU deserves the greatest attention in addressing the danger of terrorist construction of an IND, securing plutonium also remains highly important. As noted in the previous section, it, too, could be used for an IND, although the device would be considerably more difficult to design and construct. In this regard, at a time when the United States is spending hundreds of millions of dollars to secure and eliminate fissile materials, Russia continues to increase its stocks of separated military and civil plutonium at a combined rate of roughly three metric tons (360 weapons, using IAEA standards) per year. The Department of Energy has an active program to end production of Russian *military* plutonium, which DOE and the Ministry of Atomic Energy expect to complete by 2011, but there is no similar initiative to halt the separation of plutonium from spent fuel produced in certain Russian civil nuclear power plants.[61] Although the United States has given the lion's share of assistance for nuclear material security to Russia, other countries have provided significant assistance with respect to particular physical protection issues, including the safeguarding of decommissioned Russian submarines and spent fuel. For an extended discussed of this assistance to Russia supported by the Global Partnership Against the Spread of Weapons and Materials of Mass Destruction, see the "Global Partnership Update" Web site (http://www.sgpproject.org) compiled by the Strengthening the Global Partnership coalition headed by the Center for Strategic and International Studies (CSIS).[62]

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[61] This activity takes place at the RT-1 reprocessing plant, at the Mayak Production Complex in Ozersk. The United States has proposed to assist Russia in the construction of spent fuel storage capacity at the site where plutonium separation is now taking place (the RT-1 facility) contingent upon Russia agreeing to end its nuclear cooperation with Iran, but Russia has not agreed to this arrangement. In its December 2002 National Strategy to Combat Weapons of Mass Destruction, the Bush Administration declared that it "will continue to discourage the worldwide accumulation of separated plutonium…." See National Strategy to Combat Weapons of Mass Destruction, National Security Presidential Directive 17 (unclassified version), December 11, 2002, p. 4. To date, this prescription will lead to new U.S. initiatives aimed at discouraging Russia to end the separation of plutonium from nuclear power plant fuel.

[62] See, also, Chapter IV in Ferguson et al., *The Four Faces of Nuclear Terrorism*.

Pakistani Fissile Material. Pakistan now produces both HEU and plutonium for weapons, although the bulk of its arsenal is thought to consist of HEU-based warheads. The relatively small quantity of fissile material in Pakistan (perhaps enough to make 30 to 50 weapons, including weapons already assembled, adding up to perhaps one metric ton) would make accounting and control of these materials significantly easier than is the case in Russia.[63]

The principal danger that Pakistani fissile materials might fall into the hands of terrorists stems from the presence of extremist Islamic groups in that country and in the surrounding region, a history of political instability, uncertain loyalties of senior officials in the civilian and military nuclear chain of command, and a nuclear material security system that likely is less robust than those in more advanced countries.[64]

Little information has been revealed concerning Pakistani security measures covering fissile materials. An NBC Nightly News and a press report in January 2004, however, disclosed that the United States has been assisting Pakistan with improving the security of Pakistani nuclear material. It has been widely reported that during peacetime, Pakistan keeps the nuclear and non-nuclear components of its nuclear weapons separate. If true, this measure would greatly complicate efforts to seize an intact nuclear device and might also complicate the diversion of fissile material in the form of weapon components, since, presumably, these receive the highest possible security within the Pakistani system.[65] Fissile materials that are in process, however, may be at greater risk. Through manipulation of material balances and other stratagems, insiders might be able to divert small quantities of fissile material from production and/or processing facilities over a period of months and avoid detection. The A.Q. Khan affair and the assistance provided by two Pakistani nuclear scientists to al Qaeda in 2001 demonstrate that the threat of a conspiracy by insiders must remain a significant concern.

Soviet-Origin HEU and U.S.-Origin HEU in Research Reactors. As noted earlier, some civilian nuclear programs use HEU in research reactors, as well as critical and subcritical assemblies.[66] These programs include scientific research and production of radioisotopes for commercial applications. Although the majority of the approximately 280 research reactors operating in 56 countries today do not use HEU for fuel, many are still fueled with this material. Indeed, in 2000, the latest date for which IAEA figures are available, almost 100 research reactors worldwide used HEU of 90

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[63] Robert S. Norris et al., "Pakistan's Nuclear Forces, 2001," *Bulletin of the Atomic Scientists*, January/February 2002.

[64] See Gaurav Kampani, "Nuclear Watch—Pakistan: The Sorry Affairs of the Islamic Republic," NTI Web site, January 2004, http://nti.org/e_research/e3_38a.html, accessed on January 30, 2004.

[65] David Albright, "Securing Pakistan's Nuclear Infrastructure," in *A New Equation: U.S. Policy Toward India and Pakistan after September 11*, Carnegie Endowment for International Peace, Working Papers, Number 27, May 2002.

[66] Subcritical and critical assemblies are used for research and nuclear engineering training purposes and typically contain relatively small amounts of nuclear material compared to cores for research or commercial reactors.

percent enrichment – weapons-grade HEU – and about 20 employed 50 percent to 90 percent enriched uranium.[67]

The large number of research reactors using HEU fuel produced and supplied by the Soviet Union and, later, Russia is of particular concern. The U.S. government has identified more than 20 research facilities in 17 countries containing Soviet- or Russian-supplied HEU fuel.[68] These countries include Belarus, Bulgaria, China, Czech Republic, Egypt, Germany, Hungary, Kazakhstan, Latvia, Libya, North Korea, Poland, Romania, Ukraine, Uzbekistan, Vietnam, and Yugoslavia. Of these, there are 14 operational reactors in the 11 countries of the Czech Republic, Germany, Hungary, Kazakhstan, Libya, North Korea, Poland, Ukraine, Uzbekistan, Vietnam, and Yugoslavia.[69]

Recognizing the potential dangers of dispersing weapons-grade HEU fuels, the Soviet Union began in 1978 to produce and export 36 percent enriched fuel in lieu of more highly enriched material, when the new fuel was compatible with particular research reactor designs of its customers. Almost all of the research and test reactors operating in former client states, such as Hungary, Poland, and Vietnam, have shifted to 36 percent fuel, which they use today.[70] Those two that have not converted to lower enriched fuel are the Libyan research reactor, which as discussed below, has returned its HEU fuel to Russia, and the EWG-1 reactor in Kazakhstan, which is believed to no longer receive high-quality HEU from Russia.[71] However, many reactor sites still house unused fresh, previously exported high-quality HEU fuel or spent high-quality HEU fuel, which retains its utility for an IND and is no longer so radioactive as to make handling the fuel difficult. The exact number of these facilities has not been openly reported. Furthermore, at least nine research reactors rated at over one Megawatt power (a threshold that is significant from the proliferation standpoint) in Russia itself are known to still use weapons-grade HEU as fuel.[72] Almost 40 research units (reactors and critical and subcritical assemblies) within Russia employ HEU ranging from 36% to 90% enrichment.[73]

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[67] International Atomic Energy Agency, *Nuclear Research Reactors of the World*, Data Series 3, Vienna, 2000.

[68] T. Dedik, I. Bolshinsky, and A. Krass, "Russian Research Reactor Fuel Return Program Starts Shipping Fuel to Russia," Paper for the 2003 International Meeting on Reduced Enrichment for Research and Test Reactors, Chicago, Illinois, October 5-10, 2003, available at http://www.td.anl.gov/Programs/RERTR/RERTR25/PDF/Dedik.pdf, accessed on February 18, 2004.

[69] "Research Reactors," World Nuclear Association, August 2003, available at http://www.world-nuclear.org/info/printable_information_papers/inf61print.htm, accessed on May 27, 2004.

[70] Ibid, p. 4-5. The bare critical mass for 36% enriched HEU is greater than 200 kg, indicating that it might be impracticable for terrorists to acquire such large amounts of this material and be able to fashion it into a workable weapon.

[71] "Research Reactors," World Nuclear Association, August 2003, available at http://www.world-nuclear.org/info/printable_information_papers/inf61print.htm, accessed on May 27, 2004; Alexander Glaser and Frank von Hippel, "On the Importance of Ending the Use of HEU in the Nuclear Fuel Cycle: An Updated Assessment," Paper presented at the 2002 International Meeting on Reduced Enrichment for Research and Test Reactors, November 3-8, 2002; Author's e-mail interview with Kenley Butler, Center for Nonproliferation Studies, Monterey Institute of International Studies, May 28, 2004.

[72] Bukharin et al., "U.S.-Russian Reduced Enrichment for Research and Test Reactors (RERTR) Cooperation"; Robert L. Civiak, *Closing the Gaps: Securing High Enriched Uranium in the Former Soviet Union and Eastern Europe*, Report for the Federation of American Scientists, May 2002.

[73] "Research Reactors," World Nuclear Association, August 2003, available at http://www.world-nuclear.org/info/printable_information_papers/inf61print.htm, accessed on May 27, 2004.

Recognizing these dangers, the United States and Russia have worked together on several successful operations to bring fresh and/or spent HEU fuel back to Russia, where the material has been blended down into non-weapons-usable low enriched uranium.

- In August 2002, in an operation known as "Project Vinca," approximately 48 kilograms of unirradiated HEU fuel was quietly removed from a research reactor site at the Vinca Nuclear Institute, in Belgrade, Former Republic of Yugoslavia, and transported to the Research Institute of Atomic Reactors at Dmitrovgrad, Russia.[74] The HEU from Vinca will be blended down at Dmitrovgrad and processed for use as power reactor fuel.[75] However, a large quantity of irradiated HEU remains at Vinca.[76]
- In September 2003, a similar HEU removal operation occurred in Romania. The Romanian, Russian, and U.S. governments worked together with the IAEA to remove 13.6 kilograms of fresh Soviet-origin 80 percent enriched uranium from the Pitesti Institute for Nuclear Research, in Bucharest. Transport and security for the operation cost $400,000. In addition, the United States agreed to help pay for the conversion of the Pitesti reactor from HEU to low-enriched uranium fuel.[77]
- In December 2003, another cooperative repatriation effort airlifted 16.9 kilograms of unirradiated 36% enriched HEU from a decommissioned research reactor at the Institute of Nuclear Research and Nuclear Energetics outside of Sofia, Bulgaria, to secure storage at Dmitrovgrad.[78] The operation took six months of planning by Bulgarian, U.S., Russian, and IAEA officials and cost $440,000, paid by the United States.[79]
- In March 2004, Soviet-origin fresh HEU fuel was repatriated to Russia from Libya. The 88 fuel assemblies contained about 17 kg of 80% enriched uranium and had been stored at the Tajoura Nuclear Research Center near Tripoli. DOE provided $700,000 for the airlift operation, which was arranged by the IAEA. The agency also checked and sealed the HEU cargo and re-verified the contents when the material arrived at the All-Russian Scientific Research Institute of Atomic Reactors (VNIIAR) in Dmitrovgrad, Russia.[80]
- On May 26, 2004, Secretary of Energy Spencer Abraham launched the Global Threat Reduction Initiative, which has the goal of repatriating all Soviet-origin

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[74] Philipp C. Bleek, "Project Vinca: Lessons for Securing Civil Nuclear Material Stockpiles," *The Nonproliferation Review*, Fall-Winter 2003, pp. 1-23.

[75] "Fact Sheet on 'Project Vinca'," August 23, 2002.

[76] Bleek, "Project Vinca: Lessons for Securing Civil Nuclear Material Stockpiles"

[77] Susan B. Glasser, "Russia Takes Back Uranium from Romania," *The Washington Post*, September 22, 2003, p. A16.

[78] U.S. Department of Energy, "U.S. Nonproliferation Efforts Continue as Nuclear Material is Removed from Bulgaria," press release, Washington, D.C., December 24, 2003.

[79] Veselin Toshkov, "U.S., Russian experts remove uranium from Bulgarian reactor to keep it out of terrorists' hands," *Associated Press*, December 24, 2003.

[80] Center for Nonproliferation Studies, "HEU from Libyan Nuclear Reactor Repatriated to Russia," *NIS Export Control Observer*, April 2004, p. 9; Spencer Abraham, Secretary of Energy, Speech at the International Atomic Energy Agency, Vienna, Austria, May 26, 2004.

fresh HEU fuel to Russia by the end of 2005. Moreover, DOE plans to work with Russia to repatriate all Soviet-origin spent nuclear fuel by 2010. [81]

- On May 27, 2004, the Department of Energy press office announced that "preparations are well advanced for the first shipment to Russia of irradiated fuel containing HEU from a research reactor in Tashkent, Uzbekistan."[82]

While the completed repatriation efforts addressed immediate material security concerns at these high-risk sites, each project was a complex, expensive operation that required many months, and sometimes years of planning and occasioned much controversy between responsible agencies in the U.S. and other governments.[83] Despite the importance of these initiatives, critics have pointed out that at the current rate of implementation, it could take decades to remove all the weapons-usable nuclear material from high-risk sites. Moreover, it remains to be seen if the new DOE initiatives will have the necessary institutional champions and resources to overcome the many bureaucratic obstacles which have long impeded implementation of less ambitious HEU initiatives in the past within the United States and Russia.

The United States is still seeking to repatriate U.S.-origin HEU supplied to dozens of other countries, according to a February 2004 audit by the DOE Inspector General. The audit found, "As of August 2003, the Department [of Energy] was likely to recover only about half of the approximately 5,200 kilograms of HEU covered by the [Foreign Research Reactor Spent Nuclear Fuel] Acceptance Program. Moreover, there was no effort to recover an additional 12,300 kilograms of HEU dispersed to foreign countries which was not included in the Acceptance Program." Identified impediments to recovery of the HEU include the voluntary nature of the program, the view of many countries that the program "was costly and disruptive," and the fact responsibility for administering the program resides with DOE's Environmental Management office, which is not charged with advancing U.S. nonproliferation goals. Responding to the Inspector General's report in February 2004, DOE stated that it "plans to place a priority on accepting eligible material from reactors and countries where the material – whether HEU or low enriched uranium – may pose environmental or proliferation risks."[84] On May 26, 2004, Secretary of Energy Abraham stated that as part of the GTRI, DOE "will take all steps necessary to accelerate and complete the repatriation of all U.S.-origin research reactor spent fuel under our existing program from locations around the world within a decade."[85]

Al Qaeda's cooperation with its affiliates and like-minded organizations

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[81] Spencer Abraham, Secretary of Energy, Speech at the International Atomic Energy Agency, Vienna, Austria, May 26, 2004; Matthew L. Wald and Judith Miller, "Energy Department Plans a Push to Retrieve Nuclear Materials," *New York Times*, May 26, 2004, p. A16; Peter Slevin, "Plan Launched to Reclaim Nuclear Fuel," *Washington Post*, May 26, 2004, p. A21.

[82] Jeanne Lopatto, Department of Energy Press Office, "United States and Russian Federation Cooperate on Return of Russian-origin Research Reactor Fuel to Russia," U.S. Newswire, May 27, 2004.

[83] For a discussion of the obstacles to repatriation of Soviet-origin HEU, see Matthew Bunn and Anthony Wier, "Removing Material from Vulnerable Sites," updated January 12, 2004, http://nti.org/e_research/cnwm/securing/vulnerable.asp, accessed on February 18, 2004. See, also, Bleek, "Project Vinca: Lessons for Securing Civil Nuclear Material Stockpiles"

[84] U.S. Department of Energy, Office of Inspector General, Office of Audit Services, "Recovery of Highly Enriched Uranium Provided to Foreign Countries," DOE/IG-0638, February 2004.

[85] Spencer Abraham, Secretary of Energy, Speech at the International Atomic Energy Agency, Vienna, Austria, May 26, 2004.

throughout the world gives the terror network the global reach that would be required to obtain weapons-usable HEU for an IND from an overseas site, such as a research facility with weak security, and transport it to a target in the United States. In this regard, al Qaeda's close connections with the Islamic Movement of Uzbekistan (IMU) could serve as the beginning of an extremely dangerous alliance for nuclear terror.[86] Given an opportunity in the form of lax security at a nuclear facility, the IMU might well have the capability to obtain Soviet-origin fissile material from sites in Uzbekistan and Kazakhstan. The IMU also undoubtedly has the capability to transport nuclear material via well-used smuggling routes to an al Qaeda safe haven in Afghanistan or Pakistan. From there, after processing, al Qaeda operatives could take the material to the United States or another target country and assemble it into an IND.

One site of particular concern in Central Asia is the Institute of Nuclear Physics in Ulugbek, about thirty kilometers northeast of Tashkent. It possesses small amounts of HEU fuel for the VVR-SM reactor enriched to 36%. The reactor was converted from 90% to 36% enriched fuel in 1989. Importantly from the standpoint of the risk of an IND, HEU enriched to 90%, removed from the Photon Radioelectrical Technical Plant, may still be present onsite – within spent nuclear fuel assemblies. The Institute has received security upgrades through cooperative programs with the IAEA, Australia, Sweden, the United Kingdom, and the United States, which mitigate the situation somewhat, but most observers believe removal of the irradiated fuel is essential to eliminate this risk.[87] Since early 2002, this site has been believed to be near the top of the U.S. list of vulnerable sites with Soviet-origin HEU. On March 12, 2002, DOE and the Ministry of Foreign Affairs of Uzbekistan signed an agreement to being the process of repatriating spent fuel and other supplies of nuclear fuel to Russia. In October 2003, U.S. government officials expressed optimism that the first fuel shipments back to Russia will occur before the end of 2003.[88] In late May 2004, DOE announced that irradiated fuel shipments from this site to Russia should commence soon.

Fissile Material Security in Other Settings. As suggested earlier, fissile materials are found in hundreds of locations around the globe under varying levels of security. Although the risks posed by these materials are greatest in the three settings just described, their presence in many other contexts also creates potential targets for terrorists. Without offering a comprehensive analysis, here, it is worth briefly noting some of these other venues where the materials can be found, and where the need for high security is essential.

-- Nuclear weapon programs outside Russia and Pakistan. All nuclear weapon programs must produce, process, and machine fissile materials, steps that often also include their transportation among different sites. In many cases, nuclear testing also involved the transportation of fissile materials, where assembled into test devices at the

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[86] For an overview of IMU's organization, objectives, and connections with Al Qaeda, see "Islamic Movement of Uzbekistan," Center for Nonproliferation Studies web site, http://cns.miis.edu/research/wtc01/imu.htm, accessed on January 30, 2004.

[87] "Uzbekistan: Institute of Nuclear Physics," Center for Nonproliferation Studies NIS Nuclear and Missile Database, NTI web site, http://www.nti.org/db/nisprofs/uzbekis/inp.htm, accessed on January 30, 2004.

[88] T. Dedik, I. Bolshinsky, and A. Krass, October 2003, op cit.

test site. In addition, fissile materials are used in nuclear weapon research activities, which may employ still other locations and transportation links. For countries reducing their nuclear arsenals, comparable challenges can arise as materials are removed from weapons and stored, in some cases after additional processing. Each of these settings demands the highest levels of security against theft and diversion. In states with smaller nuclear arsenals – France, Great Britain, China, France India, Israel, North Korea – this challenge is inherently more manageable than for the United States and Russia, because of the smaller scale of activities involved. Nonetheless, in less developed states, underlying weaknesses in national infrastructure, e.g., in rail and highway transportation systems, in communications, and in the level of guard force education and training, may erode security efforts

Even in the United States, where security over fissile materials is generally deemed to be very stringent and where the issue has received added attention since September 11, 2001, evidence has emerged indicating that serious deficiencies may exist at some facilities within the U.S. nuclear weapons complex. In April 2000, responding to internal DOE reports of these findings, then-Secretary of Energy Bill Richardson ordered that "all weapons-grade materials be removed from T.A. 18 [the Technical Area at Los Alamos where the repeated mock attacks demonstrated vulnerabilities] and delivered to the Nevada Test Site by 2003."[89] None of T.A. 18's weapons-grade material had been relocated as of May 2004, however. DOE issued such a security planning upgrade in May 2003, but "it is not scheduled to take full effect until 2009."[90] The GAO had criticized the new DBT, which the organization found to be less demanding that those assessed by other U.S. government experts.[91]

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[89] Hertsgaard, "Nuclear Insecurity," op. cit. p. 188. Critics of Levernier complained that he had always directed his mock terrorists to exploit weak links. His supporters retort that, of course, "red team" members would not be doing their jobs if they did not target weaknesses. Reportedly, in one of the mock attacks, the red team hauled away weapons-grade material in a Home Depot garden cart. Some laboratory authorities charged that this cart was unfairly used because it was not on the list of approved items for the mock attack. In response, Anson Franklin, a National Nuclear Security Administration spokesperson, stated, "Any implication that there is a 50 percent failure rate on security tests at our nuclear-weapons sites cannot be supported by the facts and is not true. The impression has been given that these tests are staged like football games with winners and losers. But the whole idea of these exercises is to test for weaknesses – we want to find them before any adversaries could – and then make adjustments." Ibid., pp. 180-182.

[90] Ibid, p. 188.

[91] Matthew Wald, "Nuclear Weapons Program Could Get Own Police Force," *New York Times,* May 8, 2004, p. A13. In 1997, DOE considered adopting the "stored weapons standard" for protection of U.S. weapons-usable fissile material (in other words, requiring that weapons-usable fissile material should be guarded as strictly as stored nuclear weapons). At that time, however, the actual requirements for material security were not changed. By analyzing open source U.S. government documents, Stanford University professor George Bunn has pieced together a definition of the stored weapons standard.[91] First, the standard defines the "design basis threat," or DBT, which is a credible threat that authorities must design their storage sites to withstand. The DBT for stored nuclear weapons or weapons-usable material would in rough terms posit "a violent external assault by a group using weapons and vehicles, possibly with inside assistance." To try to defeat this DBT, the stored weapons standard would require, among other safeguarded details, "a strong, secure storage vault with a single entry surrounded by two layers of strong fences and an open, lighted area where no one could hide. Access to the vault should be limited to personnel with a need for access, who are cleared through full-field background investigations and accompanied by another such person (the 'two-person' rule). Such access limitations should be enforced by both armed guards and electronic monitoring devices, supported in case of need by nearby armed backup forces. All of these personnel should be trained to deal with design basis threats, and their competence

Doubts have also been raised about lax security at the Y-12 National Security Complex at Oak Ridge National Laboratory, where large quantities of HEU for U.S. nuclear weapons are stored and processed. Representative Christopher Shays (R-Connecticut), Chairman of the House Subcommittee on National Security, Emerging Threats, and International Relations, said in 2003, "My concerns about Los Alamos … pale in comparison to the Y-12 facility at Oak Ridge, Tennessee. This is a very vulnerable site. [It has] too many structures and not enough buffer zone [around it]."[92]

In May 2004, Secretary of Energy announced that the fissile material stored at T.A. 18 would be transferred to a highly secure facility, that increased security at Y-12 will be considered, and that the Department of Energy would further refine its design basis threat to recognize a higher level of potential terrorist capabilities. The implementation of the first and second measures is expected to take many months, and the measures to meet a new DBT may take five years or more.[93]

In sum, fissile material security in elements of some nuclear weapon programs outside of Russia and Pakistan remains far from ideal. Even if the magnitude of such dangers does not reach the gravity of those seen in the latter two states, given the potential consequences of loss of fissile material to terrorists, it is extremely important that such gaps be addressed quickly and fully.

-- *Naval Propulsion Systems.* Several navies power ships with HEU. About 170 nuclear-powered vessels (including submarines, naval surface ships, and civilian vessels) are currently operational, all of which use pressurized-water reactors (PWRs) for propulsion. All U.S. and British nuclear ships, including submarines, use HEU fuel enriched to 93.5% U-235. French ballistic missile nuclear-powered submarines (SSBNs) and France's single nuclear-powered aircraft carrier use HEU fuel enriched to 90%, while French attack nuclear-powered submarines (SSNs) use LEU fuel enriched to 7%. China, alone among the world's nuclear navies, uses only LEU fuel for its naval reactors, probably enriched between 3% and 5%. The nuclear submarine planned by India is likely to use nuclear fuel similar in enrichment to that of many Russian submarines, probably around 20%.[94]

Weapons quality HEU used in the navies noted above is not present only at naval fueling areas, but also at sites where the HEU is produced, in fuel fabrication plants, and in transit to nuclear submarine bases. In addition, spent fuel, which may contain uranium enriched to 80 percent or more is found at storage sites and in transit to those locations. No cases have been reported outside of Russia involving thefts of, or illicit trafficking in,

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checked periodically in exercises like war games." George Bunn, "U.S. Standards for Protecting Weapons-Usable Fissile Material Compared to International Standards," *The Nonproliferation Review*, Fall 1998, pp. 137-143; quoted material from p. 138.

[92] Hertsgaard, "Nuclear Insecurity," op. cit. p. 190.

[93] Wald, "Nuclear Weapons Program," op. cit.; Ralph Vartabedian, "Security Upgrade for Nation's Nuclear Labs: Energy Secretary's Plan to Lessen the Chance of a Terrorist Attack is Said to Include Closure of Sites, Improved Safeguards and Plutonium Removal," *Los Angeles Times*, May 7, 2004, p. A28.

[94] Chunyan Ma and Frank Von Hippel, "Ending the Production of Highly Enriched Uranium for Naval Reactors," *The Nonproliferation Review*, Spring 2001. Russia is said to have plans to lease nuclear submarines to other countries. Such transfers to support non-explosive military uses of nuclear materials are not prohibited under the nuclear Non-Proliferation Treaty. James Clay Moltz, "Closing the NPT Loophole on Exports of Naval Propulsion Reactors," *The Nonproliferation Review*, Fall 1998, pp. 108-114

naval fuel. Nonetheless, Russia's experience – including the concerns of Russian Navy officers that led them to seek U.S. help in securing Russian nuclear submarine fuel – highlight the potential dangers in this sphere.

-- *Plutonium in civil nuclear power programs and HEU in non-military research reactors in industrially advanced countries.* Until the late 1970s, it was widely assumed among nuclear energy planners that global uranium resources would be rapidly depleted and that it would be necessary to use plutonium, in the form of MOX fuel, as an alternative to low-enriched uranium fuel in most nuclear power programs. Because of slower-than-expected growth of nuclear power and the continuing discovery of new economically exploitable uranium reserves, however, uranium supplies have remained abundant, while the costs of producing MOX fuel have increased significantly. These economic factors, together with concerns over the proliferation dangers posed by the widespread use of plutonium fuels, have led most nuclear-power using states to abandon such separation and "recycling" of plutonium, in favor of the "once-through fuel cycle," in which spent nuclear power plant fuel is stored on an interim basis until emplaced in a permanent storage facility, usually planned for a stable geologic formation.[95]

For a variety of reasons, however, as noted in an earlier section of this paper, several states continue to pursue plutonium separation for civil nuclear energy purposes, most notably France, Great Britain, Russia, and Japan. Of these, however, only France has a successful recycle program that balances supply (newly separated plutonium) with demand (the fabrication and use of MOX fuel). Great Britain has no domestic program for using MOX fuel and its plutonium is stored after separation. Russia likewise has no domestic MOX program for civil plutonium. Although it stores spent fuel from its VVER-1000 reactors and RBMK units, it continues to reprocess spent fuel from VVER-440 reactors and store the resulting plutonium.[96] Japan has contracted with France and Great Britain for the reprocessing of Japanese spent fuel; although Japan has a program for using the resulting plutonium as MOX in its nuclear power reactors, that program has been virtually frozen because of domestic opposition and other challenges. As a result, separated Japanese plutonium continues to accumulate in France and Great Britain, without certainty that it will ever be used. Notwithstanding this accumulation of tens of metric tons of separated plutonium awaiting use in these countries, Japan has continued to work on a large-scale plutonium separation facility at Rokkasho-mura, which was scheduled to open in July 2006. However, concerns over the cost of the project have resulted in delays, leading to substantial uncertainty over when the facility will reprocess commercial spent fuel. Once approved for operation, the facility could process about 800 metric tons of spent fuel annually, separating up to 7 tons of plutonium each year.

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[95] The Netherlands, Germany, Sweden, Spain, and the United States have cancelled domestic plutonium separation plans and/or have reduced or ended contracts for the separation of plutonium abroad and its return in the form of MOX. During the Communist period, Soviet satellite states were obliged to return spent fuel to Russia, where it was reprocessed; the resulting plutonium was not returned, but stored in Russia.

[96] Under the U.S.-Russia Plutonium Disposition Program, Russia *is* planning to use MOX fuel in a number of its nuclear power reactors and hopes to build new, more advanced plutonium-fueled reactors. For the foreseeable future, however, all plutonium from these programs will come from stocks originating in the Russian nuclear-weapons sector, not material separated from civilian spent nuclear power reactor fuel.

India also separates plutonium from spent nuclear power plant fuel. Its plan calls for the use of the plutonium in advanced, breeder reactors. Usually fueled with fuel containing about 20 percent plutonium, breeder reactors use excess power to irradiate additional uranium, thereby "breeding" new plutonium. All other states, except Russia, have abandoned this technology as uneconomical.

Table 3, above, highlighted the impact of these activities. From 1999 through 2002 (the latest year for which complete figures are available from the IAEA) separated plutonium stocks in the foregoing countries increased by 14 metric tons, from 162.5 metric tons to 176.6 metric tons, enough material to produce about 1,700 weapons (assuming 8 kilograms of plutonium per weapon and some fabrication losses) – more than the combined arsenals of all of the nuclear weapon states other than Russia and United States. This sizeable accumulation of separated plutonium, for which in most cases there is no planned use, stands in sharp contrast to extensive and costly Russian, G8, and U.S. efforts to eliminate fissile materials in other settings.

Regarding HEU use in research reactors in advanced countries, as discussed above, the United States and Russia are working actively to reduce the use of HEU in research reactors they have previously exported (or to which they have provided fuel) and to repatriate and eliminate fresh and spent HEU fuels from these locations. In addition, both countries are gradually reducing the use of HEU fuels at home. Nonetheless, for years to come, more than a dozen major research reactors, located mostly in G8 countries (including the EU), will continue to use HEU fuels. The list includes several, such as the Petten High Flux Reactor (HFR) in the Netherlands, that have formally agreed to switch to low-enriched fuels once they are available, as well as a number that are likely to use HEU fuels indefinitely, because of the unique research and/or isotope production these facilities support. Resisting the trend toward converting research reactors to low-enriched fuel, the German FRM-II reactor in Munich has been designed to use weapons-grade HEU fuel. The reactor owners have agreed to reduce the enrichment to 50% by December 2010, but meanwhile, the reactor will use bomb-grade HEU.

Leaving aside whether the continued use of HEU by this group of reactors is justified – a matter which has been the subject of considerable debate in many cases – these facilities, which often have substantial inventories of HEU and are sometimes located in relatively open research centers, require the highest levels of security. With these concerns in mind, the United States Nuclear Regulatory Commission has increased security requirements at research reactors in the United States after September 11, 2001.[97] However, there are concerns that more needs to be done to protect these facilities against nuclear terrorist attack or sabotage. It is also noteworthy that the United States is trying to purchase HEU from Russia for use in U.S. research reactors, a two-edged arrangement, which reduces HEU stocks in Russia, but facilitates the continued use of such material in U.S. research reactors at a time when both countries are urging other states to convert to less dangerous low-enriched uranium fuels. The Fiscal Year 2003 Omnibus Bill passed by Congress provided up to $14 million for DOE to direct toward this activity. As of May 2004, negotiations over the potential purchase have not been successful, but there is still interest in the U.S. government to pursue an agreement.[98]

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[97] U.S. Nuclear Regulatory Commission, "Nuclear Security Enhancements Since September 11, 2001," Fact Sheet, September 2003.

[98] Author's phone interview with DOE official, name withheld on request, May 2004.

Given the vast quantities of fissile materials in all of the foregoing settings – Russia; Pakistan; Russian- or U.S.-supported research reactors around the globe; the nuclear weapon programs of the other seven nuclear-armed states; marine propulsion systems; and plutonium and HEU found in civilian nuclear programs – it appears that would-be nuclear terrorists, intent on acquiring material for an IND, enjoy a "target-rich environment."

International Standards for Protecting Fissile Material

One area where much work remains to be done is establishing standards for effective physical security over fissile materials. Practices vary significantly from nation to nation and the voluntary guidelines of the IAEA, known as INFCIRC/225, are so vague that some states have been able to comply without requiring that the guards protecting fissile material be armed.[99] Among other shortcomings, the guidelines do not specify the threat that sites holding fissile materials must protect against. Although those guidelines are incorporated into the 1980 Convention on the Physical Protection of Nuclear Materials (CPPNM), that instrument extends only to nuclear materials in international transit, not to the protection of fissile materials within states. In 1998, the United States proposed that the CPPNM be amended to broaden its scope to require rigorous physical protection standards within states, but as of this writing, the parties to the Convention have not achieved consensus. The 40-member Nuclear Suppliers Group requires the application of INFCIRC/225 to all items group members export to other states, but the vagueness of the standards undercuts the effectiveness of this rule.[100]

In April 2004, seeking to intensify international controls over activities that could contribute to WMD proliferation and terrorism, the UN Security Council unanimously adopted Resolution 1540. Adopted under Article VII of the UN Charter to address a threat to international peace and security, the resolution is legally binding on all UN member states. A key provision of the resolution directly relevant to WMD terrorism states that "all States, in accordance with their national procedures, shall adopt and enforce appropriate effective laws which prohibit any non-State actor to manufacture, acquire, possess, develop, transport, transfer or use nuclear, chemical or biological weapons and their means of delivery, in particular for terrorist purposes, as well as attempts to engage in any of the foregoing activities, participate in them as an accomplice, assist or finance them."[101] The resolution goes on to state that member countries will need to implement domestic legislation, if they do not already have this in place, to implement these requirements and provides for a report to be made to the Council in two years reviewing the progress that has been made in this regard.

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[99] George Bunn, "U.S. Standards for Protecting Weapons-Usable Fissile Material Compared to International Standards," *The Nonproliferation Review*, Fall 1998, pp. 137-143.

[100] See, George Bunn, "Raising International Standards for Protecting Nuclear Materials from Theft and Sabotage," *The Nonproliferation Review*, Summer 2000, p. 146. See also George Bunn and Matthew Bunn, "Strengthening Nuclear Security Against Post-September 11 Threats and Sabotage," Institute of Nuclear Materials Management, Spring 2002, and George Bunn and Fritz Steinhausler, "An Integrated Approach to Adapt Physical Protection to the New Terrorism Threats," Center for International Security and Cooperation Conference Report, September 2002.

[101] UN Security Resolution 1540, April 28, 2004, http://ods-dds-ny.un.org/doc/UNDOC/GEN/N04/328/43/PDF/N0432843.pdf?OpenElement, accessed on May 28, 2004.

Unfortunately, the Council's action does not set specific standards, leaving open the possibility that states will adopt weak controls that fall far short of what is needed.

Priority Recommendations

At least four steps should be undertaken as priority measures: (1) pursue an HEU-first strategy; (2) secure, consolidate, and/or eliminate HEU in Russia and globally; (3) focus on the South and Central Asia peril; and (4) promote adoption of stringent, global security standards.

1. Pursue HEU-First Strategy

Because of the relative ease of construction of an IND with HEU, U.S. and international nonproliferation assistance programs in Russia should implement an HEU-first strategy that would secure, consolidate, and down-blend all excess stocks of HEU before disposing of weapons-grade plutonium as reactor fuel. Specifically, priority should be given to (1) the acceleration of down-blending of Russian HEU to a non-weapons usable enrichment level; and (2) the use of the recently opened high security Mayak Fissile Material Storage Facility for the storage of up to 200 tons of HEU.

2. Secure, Consolidate, and/or Eliminate HEU in Russia and Globally

Significant quantities of fissile materials exist in Russia and globally which are not needed, are not in use, and, in many instances, are not subject to adequate safeguards. From the standpoint of nuclear terrorism, the risk is most pronounced with respect to stockpiles of HEU in dozens of countries. It is imperative to secure, consolidate, and, when possible, eliminate these HEU stocks. The principle should be one in which fewer countries retain HEU, fewer facilities within countries posses HEU, and fewer locations within those facilities have HEU present. Important components of a policy guided by this principle include conversion of research reactors to run on low-enriched uranium, rapid repatriation of all U.S.- and Soviet/Russian-origin HEU (both fresh and irradiated), international legal prohibitions of exports of HEU-fueled research and power reactors, and down-blending of existing stocks of HEU to LEU. A policy to accomplish these objectives must be informed by an understanding of the significant bureaucratic, technical, economic, political, and national security impediments to HEU consolidation and elimination, and the development of compelling incentives to overcome these obstacles.

3. Focus on the South and Central Asian Peril

The international community should be more attentive to the nuclear terrorism danger with respect to INDs in South and Central Asia, a zone where Islamic militant groups are active and where the risk of their gaining access to nuclear materials -- especially from unreliable elements within the Pakistani establishment or from certain vulnerable sites in Kazakhstan and Uzbekistan -- is highest. It is of urgent importance, therefore, to remove the relatively small, but nuclear terrorism (and proliferation) significant, quantity of fissile material from Central Asia, and to enhance Pakistani fissile material protection, control, and accounting. Means to accomplish the former objective are identified in the preceding paragraph; the latter objective should be pursued by maximizing, consistent with the requirements of the NPT, the sharing of unclassified technology to help Pakistan securely manage its nuclear assets. The NPT-recognized nuclear weapons states also should develop contingency plans, including the use of nuclear recovery teams, to help secure Pakistani nuclear assets in the event of instability. Under most circumstances, such recovery efforts would require the cooperation of knowledgeable Pakistani authorities.[102]

4. Promote Adoption of Stringent, Global Security Standards

Renewed efforts are required to establish binding international standards for the physical protection of fissile material. An important means to accomplish that objective is to amend the Convention on the Physical Protection of Nuclear Material to make it applicable to civilian nuclear material in domestic storage, use, and transport. Ideally, the amendment would oblige parties to provide protection comparable to that recommended in INFCIRC 225/Rev 4 and to report to the IAEA on the adoption of measures to bring national obligations into conformity with the amendment. However, because amending the Convention is likely to require an extended negotiation, it is desirable for as many like-minded states as possible to agree immediately to meet a stringent material protection standard, which should apply to all civilian and military HEU.

Conclusion

Implementation of the four measures noted above will not eliminate entirely the risk that terrorists will manufacture and detonate a crude but effective nuclear device. That risk will persist at some level as long as stocks of fissile material exist. The timely pursuit of these recommendations, however, should significantly reduce the likelihood of occurrence of one especially high consequence form of nuclear terrorism.

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[102] The authors are grateful to George Perkovich for sharing his perspective on this point. Personal correspondence, March 31, 2004.

List of published studies and papers

All papers and studies are available as pdf-files at the Commission's website: www.wmdcommission.org

No 1 "Review of Recent Literature on WMD Arms Control, Disarmament and Non-Proliferation" by Stockholm International Peace Research Institute

No 2 "Improvised Nuclear Devices and Nuclear Terrorism"
by Charles D. Ferguson and William C. Potter

No 3 "The Nuclear Landscape in 2004: Past Present and Future"
by John Simpson

No 4 "Reviving the Non-Proliferation Regime"
by Jonathan Dean

No 5 "Article IV of the NPT: Background, Problems, Some Prospects"
by Lawrence Scheinman

No 6 "Nuclear-Weapon-Free Zones: Still a Useful Disarmament and Non-Proliferation Tool?" by Scott Parrish and Jean du Preez

No 7 "Making the Non-Proliferation Regime Universal"
by Sverre Lodgaard

No 8 "Practical Measures to Reduce the Risks Presented By Non-Strategic Nuclear Weapons"
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