Toward a Comprehensive Safeguards System: Keeping Fissile Materials out of Terrorists' Hands

By
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The nexus of terrorism and nuclear weapons is today's greatest security concern. The importance of keeping fissile materials out of the hands of terrorists is now generally accepted. The difficulty of doing so is not. Lack of appreciation, especially for the technical difficulties, is hampering our ability to build a comprehensive safeguards system and prevent nuclear terrorism.

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What is the likeliest route for terrorists to acquire a nuclear weapon? Theft or diversion of an intact weapon from a nuclear state is the most direct, but not the most probable. A recent National Academies report (National Research Council 2002) and several other extensive studies (Falkenrath, Newman, and Thayer 1998; Ferguson et al. 2004) stress the importance of protecting nuclear weapons but conclude that improvised nuclear devices (IND) built from stolen or diverted fissile materials, either plutonium or highly enriched uranium (HEU), pose a greater threat. The general consensus of nuclear weapons experts is that terrorists would face significant but not insurmountable challenges to build a primitive but devastating nuclear device and that it would most likely be delivered to the intended target by truck, boat, or light airplane.

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Fortunately, the technologies and materials required to enrich uranium or construct reactors to produce plutonium are considered beyond the reach of even the most sophisticated terrorist groups today. Moreover, procurement and construction activities are not easily carried out clandestinely, although recent revelations of the sophistication of A. Q. Khan's proliferation ring raise concerns. So the good news is that terrorists are unlikely to make weapons-usable HEU or plutonium from scratch. The bad news is that they can potentially steal it or buy it because of huge amounts available worldwide, with some being inadequately secured. Keeping these materials out of the hands of terrorists is a much greater challenge than securing nuclear weapons.

The challenge of preventing theft or diversion of fissile materials is now widely recognized. Presidents Bush and Putin addressed the matter in their 2005 Bratislava accord (Bush and Putin 2005). The G-8 leaders pledged cooperation to this end in their Gleneagles Statement on Nonproliferation that same year (G-8 Statement 2005), and it is also addressed by UN Security Council Resolution 1540 on Nonproliferation (United Nations Security Council 2004). Moreover, several comprehensive treatises detail this challenge and offer potential solutions (Falkenrath, Newman, and Thayer 1998; Albright and O'Neill 1999; Ferguson et al. 2004; Allison 2004, 2005; Bunn and Weir 2005; Perkovich et al. 2005; National Research Council 2006a, 2006b). Allison (2005) captured the essence of these studies with his challenge to governments around the world to keep fissile materials just as secure as treasures in the Kremlin Armory and gold in Fort Knox.

Securing all fissile material around the world, however, is considerably more challenging than locking it up to a "gold standard." The first section of this article describes those challenges, which are both technical and political. Plutonium and HEU are used in weapons, research, power reactors, and some industrial applications in forms that can be turned into weapons-usable materials with routine chemical processing. Such materials are processed, shaped, transported, stored, and used, and some inevitably wind up in waste streams. After exploring why securing fissile material is more difficult than is generally appreciated, I then go on to assess the components of a comprehensive safeguard system, addressing both the general and specific challenges posed by the current threat environment.

Five Characteristics of Fissile Materials

In this section, I present five reasons why securing fissile material is more difficult than generally appreciated. The characteristics of nuclear material must be understood to establish a comprehensive safeguards system.

Existing inventories of fissile material are far larger than the amount required for a nuclear bomb

Most states with nuclear weapons have stopped producing weapons-grade plutonium and HEU; in fact, the United States and Russia are reducing their inventories because they exceed current weapons requirements. The Institute of Science and Security (ISIS) reports that approximately 1.9 million kilograms of HEU and 1.83 million kilograms of plutonium exist worldwide (Albright 2005). Approximately 1.4 million kilograms of plutonium are found in highly radioactive spent fuel and would not be very attractive to terrorists. The remaining 2.3 million kilograms of weapons-usable fissile material, however, must be protected. But to truly prevent a nuclear terrorist attack, we must be able to account for a few tens of kilograms out of more than 2 million available worldwide.

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The results of a recent study on plutonium in the United States underscore the problem of numbers (U.S. Department of Energy (DOE) 1994). The United States produced or acquired 111,400 kilograms of plutonium since 1943. In 1994, the total inventory was 99,500 kilograms. Although there are explanations for the "missing" 11,900 kilograms, the uncertainties between physical inventories and accounting are many times the amount required for a bomb.[1] This same study shows that even in the United States, where nuclear safeguard technologies and methodologies were first developed and applied, the accounting system alone cannot come close to ensuring that significant amounts of nuclear materials are not missing. The investigation also illustrates that confidence in the security of nuclear materials should rest not on the numbers but, instead, must rely on the integrity of the nuclear safeguards system.

Fissile materials exist in every imaginable form

These materials are not like gold bricks at Fort Knox. Plutonium and uranium are highly reactive metals that oxidize rapidly, especially in humid conditions or in the presence of hydrogen. Furthermore, plutonium is constantly created and destroyed during reactor operation and transmutes into other elements over time. For weapons applications, plutonium and uranium are used in metallic form—often alloyed with other chemical elements. For reactor applications, they are used in metallic or ceramic (principally oxide) forms. To make weapons or reactor fuel elements, they are processed using industrial processes such as dissolution in acids or salts; gasification; melting and casting; powder processing; electrochemical processing; shaping, machining, welding, or pressing; and waste processing and storage. For plutonium, all such operations are conducted in specially designed laboratories to prevent exposure to airborne plutonium. It is no surprise that operating losses and inventory differences are large when tons of plutonium or HEU are processed. Moreover, large-scale processing without adequate control and accounting leads to the potential of plant operators covertly diverting small but significant quantities of these materials.

Fissile materials exist in many locations, not just in a few storage vaults

Plutonium and HEU exist in enrichment and fuel fabrication facilities, reactors, reprocessing plants, and storage facilities. The materials are typically well secured in weapons. Historically, however, security for nuclear research reactors and facilities has not been adequate. In states that reprocess spent fuel, plutonium also exists in reprocessing plants and mixed-oxide fuel fabrication plants. And of course, these materials exist in transport, all of which are not always secure.

Not only do these materials exist in many locations within one country, they exist in multiple countries. In addition to states with nuclear weapons programs, they exist in countries that have reprocessing plants or use mixed-oxide fuel. The greatest concern, however, is the use of HEU in research reactors around the world. In the United States, the Atoms for Peace program supported building such reactors in more than forty countries. The Soviets had a similar export program. The security environment in many countries was inadequate to protect fresh HEU fuel. Today, roughly 120 research reactors in forty countries still use HEU.

Fissile materials are difficult to measure and handle

Safeguard systems must be able to measure fissile materials accurately. Monitoring and accounting of plutonium is hampered because plutonium must be handled in glove boxes or other ventilated enclosures and stored in airtight containers because of its radiotoxicity. Masses for inventories are measured by weighing, destructive assay methods employing wet chemistry, and nondestructive assay methods such as calorimetry (measuring heat content that is related to isotope concentrations) or neutron- and gamma-ray–based radiation measurements. The extraordinary scientific complexity of plutonium metal presents additional challenges. Plutonium exists in seven different crystal structures with varying densities. Adding a few atomic percent gallium or aluminum to pure plutonium will change its density by as much as 25 percent, complicating mass determinations (Hecker 2001). Oxidizing plutonium metal to plutonium dioxide (typical for storage and reactor applications) drops the density of pure plutonium by nearly a factor of two.

Gamma ray detectors are used to make nondestructive measurements of isotopic composition in plutonium and uranium. Chemical analysis is often required to ascertain the precise chemical composition, which is especially important for plutonium because it changes composition with time by transmutation. These measurements and analytical capabilities are not available in many locations that house plutonium or HEU.

Military secrecy hampers safeguards and transparency

In the early years, information regarding both bomb and reactor materials was classified. The Atoms for Peace program declassified much of this information. But some details about plutonium chemistry and isotopic compositions were kept secret until the Energy Department released its plutonium study in 1994 (a similar study on HEU was never published). Russia and China still keep isotopic and chemical compositions of weapon nuclear materials secret, and most locations and amounts remain out of the public domain.

Implementation of a comprehensive safeguards system is imperative to protect weapons-usable materials worldwide.

Although secrecy is necessary to protect a state's nuclear weapons program, excessive secrecy and, in particular, compartmentalization impede implementation of a rigorous safeguards system. Communication may be limited among sites that produce, use, and dispose of these materials. It can impede accounting, the establishment of systemwide inventories, and the sharing of best practices. Responsible government officials cannot assess systemic vulnerabilities due to a lack of transparency. Likewise, little information allows other nations to judge the adequacy of each others' nuclear materials security. Excessive secrecy also precludes states from sharing crucial information about the chemical and isotopic composition of fissile materials stockpiles, which makes attribution in case of theft or a detonation more difficult.

For these five reasons, simply locking up all of the materials is not a feasible course of action. Many states do not even know what "all" is. Implementation of a comprehensive safeguards system is imperative to protect weapons-usable materials worldwide.

Toward a Comprehensive Safeguards System

Each state that possesses weapons-usable fissile materials must provide for their physical protection, control, and accounting—the three pillars of a rigorous, comprehensive safeguards system. Such a system (nuclear materials protection, control, and accounting, or MPC&A) was first developed in the United States forty years ago. It became the model for the International Atomic Energy Agency (IAEA) international safeguards system. Uneven and incomplete application of domestic and international safeguards contributes to inadequate fissile materials security worldwide today.

The international nuclear safeguards system is designed to assure the international community that states party to the Nuclear Non-Proliferation Treaty (NPT) and similar agreements honor their commitments not to proliferate nuclear weapons. The traditional system attempts to verify nondiversion of declared nuclear materials; it focuses on correctness of a state's declaration. The strengthened safeguards system, which includes the Additional Protocol developed after the Gulf War, expands verification to provide credible assurance of the absence of undeclared nuclear materials; it focuses on completeness of declaration (Goldschmidt 1999).

Although international safeguards are necessary to prevent diversion of nuclear materials by a state, they are not sufficient to prevent theft of weapons-usable material by determined individuals or groups. Pellaud (1997) pointed out that IAEA safeguards agreements with more than 130 states cover some 900-plus facilities and locations but only 20,000 kilograms of HEU and 500,000 kilograms of plutonium (including fifty tons of separated plutonium) compared to the roughly 1.9 million kilograms that exist worldwide. Nuclear materials in military programs are not subject to international safeguards. The United States entered into voluntary IAEA safeguards agreements in 1977, but these exclude facilities with direct national security significance. India, Pakistan, and Israel never signed the NPT, and North Korea withdrew.

Adequate security, therefore, depends on rigorous application of domestic safeguards in addition to the international safeguards that may apply. The U.S. domestic safeguard system is designed to protect nuclear materials against external threats such as terrorists and against insider threats. The principal safeguard against external threats is physical protection. The more insidious insider threat also requires additional rigorous internal controls and accounting.

The Soviet Union focused on physical protection (guns, guards, and high fences) along with stringent personnel screening. Its nuclear materials security record was excellent because the Soviet police state with its omnipresent KGB and a system of grave consequences deterred the insider threat as well. However, with the social, political, and economic upheaval that followed the dissolution of the Soviet Union, its past practices become Russia's liability. Physical protection alone is no longer adequate.

Modern safeguard systems combine physical protection with MPC&A. Physical protection consists of measures to protect nuclear material or facilities (and their transportation) against sabotage and theft. Nuclear facilities that require physical protection include all research, development, production, and storage sites; nuclear reactors; fuel cycle facilities; and spent fuel storage and disposal facilities. These measures include guards, fences, and exclusion areas around facilities, in addition to perimeter and interior intrusion detection systems. Measures also include limited access and egress to facilities, buildings, and rooms. Technologies employed include systems such as microwave, electric field, and infrared systems on the perimeter and ultrasound, infrared, and motion detection closed circuit television on the interior. Finally, neutron, gamma ray, and metal detectors at points of egress add an important element of defense.

MPC&A are designed to offer accurate nuclear materials inventory information, control nuclear materials to deter and prevent loss or misuse, provide timely and localized detection of unauthorized removal of materials, and ensure in near real time that all nuclear materials are accounted for and that theft or diversion has not occurred. Proper material control limits the handling of nuclear materials only to authorized and properly identified personnel and ensures that two people are present during nuclear material transactions. It helps track nuclear material from one site to another, from facility to facility, and from room to room. It ensures that there are a limited number of entries and exits, and alarms alert authorities to potential theft or diversion. It identifies nuclear material for tracking purposes.

Modern material accounting also employs statistical and computer-based measures to maintain knowledge of quantities of nuclear material present in each area of a facility. It relies on inventories and material balances to verify the presence of material or to detect a loss. In the United States, the Nuclear Materials Management and Safeguards System (NMMSS) implemented in 1976 contains current and historical data on inventories and transactions involving source and special nuclear materials within the United States and on all exports and imports. It tracks all transactions, including domestic and foreign transfers, operating losses, inventory differences, and burn up (transmutation and fission). Reconciliation of facility books with NMMSS also ensures that control indicators are furnished to those who perform oversight responsibilities and that anomalies are identified.

I provide this level of detail to demonstrate the complexity of securing nuclear materials. Effective MPC&A systems must be integrated with operational and safety practices. In the United States, it remains a challenge to provide adequate protection against changing terrorist threats. In view of the DOE plutonium report, it is not possible to guarantee that kilogram quantities of plutonium are not missing. We must rely on the integrity of the MPC&A system and its application for our confidence that such materials are not outside of state control. In U.S. facilities, operators must account for every gram of these materials in virtual real time. To declare any of it as an "inventory difference" or "waste" requires rigorous justification and verification.

It is imperative that each state with nuclear facilities implement its own rigorous, comprehensive safeguards system to prevent theft or diversion of weapons-usable materials. Although both countries have made progress in recent years, Russia and China have much work to do to achieve a modern safeguards system. Little is known about Pakistan and India. States that currently employ such systems and the IAEA should expand significantly their efforts to provide technical assistance to these nations. The G-8 should reprioritize its nuclear security financial assistance to help states develop their own rigorous MPC&A systems. These efforts will also help states meet their counterterrorism obligations under UN Security Council Resolution 1540. In addition, the international safeguards system should be strengthened by universal adoption of the Additional Protocol and greater access for IAEA inspectors, along with stricter enforcement by the UN Security Council.

Each state must also develop a complete registry of weapons-usable plutonium and HEU along the lines of the DOE plutonium study. The IAEA already has registry requirements for states that hold safeguarded materials, but as pointed out above, that constitutes only a fraction of the total worldwide. Such registry studies (both public and classified) will help identify historical anomalies and potential vulnerabilities in nuclear material inventories.

Other Vulnerabilities

Since rigorous safeguard systems have not been in place since the advent of nuclear materials, and since many countries still fall short today, nuclear materials could already be in the wrong hands or at least outside state-controlled systems. Fortunately, there are few known incidents of theft to date. The IAEA (2006) illicit nuclear trafficking database shows 196 incidents involving nuclear materials from 1993 to 2004. Only eighteen involved fissile materials, three with kilogram quantities of HEU and three with gram quantities of plutonium.

Each state should enhance its internal detection and tracking capabilities for illicit trafficking of nuclear materials and enhance its border and port security. These efforts should be aided by international efforts such as the DOE Second Line of Defense program, which has helped to install radiation detectors (and train personnel) at airports, seaports, and border crossings in Russia and other states. It is imperative that each state identify past weaknesses and anomalies in fissile material inventories.

Efforts to interdict potential shipments of nuclear materials such as the Proliferation Security Initiative should be strengthened. Increased intelligence sharing is important. Cooperative sting operations may flush out material outside state-controlled systems. Enhanced emergency response capabilities will help manage the consequences of an attack and potentially help disable suspected terrorist devices. Finally, forensics and attribution will be important, both for response and for preventing repeat attacks.

Over the longer term, we must also guard against "mining" of low-grade materials, such as nuclear waste, spent fuel, and lost or abandoned materials. We must also pay much greater attention to safeguarding alternate nuclear materials such as neptunium and americium, which have been produced in multiple-ton quantities and may eventually become a terrorist bomb threat (Albright 2005). We must safeguard any process or nuclear material that is easier to obtain and less costly than building an enrichment plant or a reactor. In addition, the commercial nuclear industry must redouble its safeguards efforts as nuclear power expands worldwide.

Why have terrorists not yet crossed the nuclear threshold? Perhaps it is the lack of access to weapons-usable fissile material. But nuclear attacks may also present an unacceptable level of risk and uncertainty to terrorists—not only risk of injury or death in preparing the mission, but potential failure of the mission. For example, even nuclear-capable states still experience criticality accidents that kill nuclear workers because of misjudgments in material handling. And terrorists are much more certain of success using chemical explosives, with which they have much greater familiarity.

Materials for dirty bombs include roughly a dozen radioisotopes that are ubiquitous in international use as radiation sources for medicine, industry, and agriculture—and readily available to determined terrorists.

Terrorists have also not yet crossed the radiological dispersal bomb (dirty bomb) threshold. A dirty bomb will disperse radioactive materials but not cause a nuclear detonation and mushroom cloud. Materials for dirty bombs include roughly a dozen radioisotopes that are ubiquitous in international use as radiation sources for medicine, industry, and agriculture—and readily available to determined terrorists. A dirty bomb would not kill many people, but it would cause enormous psychological trauma and economic disruption (Ferguson et al. 2004). Regardless of whether or not terrorists are just about to cross the nuclear bomb threshold, we must assume that some of them eventually will. The best preventive measure is to keep the weapons-usable material out of their hands.

Today's Greatest Threats

To deal with today's urgent threats, it is important to consider specifically tailored solutions in addition to the generic recommendations made above. To that end, this section briefly describes what I see as the greatest threats in the current security environment. These six threats represent the highest probability of theft or diversion of several tens of kilograms of weapons-usable plutonium or HEU and these materials getting into the hands of terrorists. Once armed with such materials, terrorists will be able to build an improvised nuclear explosive device and detonate it virtually anywhere in the world.

1. Pakistan heads the list. It has all technical prerequisites: HEU and plutonium; enrichment, reactor, and reprocessing facilities; a complete infrastructure for nuclear technologies and nuclear weapons; largely unknown, but questionable, nuclear materials security; and missiles and other delivery systems. It views itself as threatened by a nuclear India. It has a history of political instability; the presence of fundamental Islamic terrorists in the country and in the region; uncertain loyalties of civilian (including scientific) and military officials; and it is home to A. Q. Khan, the world's most notorious nuclear black marketer. Helping Pakistan secure its nuclear materials during these challenging times is made difficult by the precarious position of its leadership and the anti-American sentiments of much of its populace. Yet such cooperation is imperative.
2. North Korea is a threat because it has withdrawn from the NPT and has separated roughly forty to fifty kilograms of plutonium (Hecker 2004). Although it is unlikely that this material will be stolen, we cannot dismiss the possibility that plutonium (especially if more is accumulated) may be exported to terrorist groups. This is most likely to occur when North Korea perceives the existence of the regime or its nation as terminally threatened. I believe that the North Korean nuclear threat is solvable, but the slow pace of the six-party talks demonstrates how difficult that is. Preventing the export of plutonium must be highest priority.
3. HEU-fueled research reactors around the world are still operating in about forty countries, many with inadequate safeguards. Fresh fuel for these reactors takes little processing to convert to weapons-usable HEU. These reactors have constituted a grave terrorist threat for three decades. Much has been done to close reactors or retrofit them with low-enriched uranium. The DOE Global Threat Reduction Initiative has increased the pace of these efforts during the past two years. So long as any HEU exists in inadequately safeguarded facilities, however, it presents an unacceptable risk. The solution is an accelerated U.S.-Russian led effort to take back all HEU, backed by G-8 financing.
4. The Russian nuclear complex was most vulnerable in the early and mid-1990s. We are fortunate that nothing really terrible happened in the Russian nuclear complex. Credit goes to the loyalty of Russian nuclear workers and to the Nunn-Lugar Cooperative Threat Reduction program. Over the past five years, the Russian government has enhanced physical security at its sites and reduced economic hardship for its nuclear stewards. But the Russian complex remains excessively large, and the amount of weapons-usable materials is staggering. Unfortunately, cooperative efforts have yielded significant improvements in control and accounting in only a limited number of facilities. To my knowledge, Russia has neither a baseline inventory of fissile materials produced nor a reconciliation of what exists today with what has been produced and used. There is apparently no incentive to pursue one. Enhanced physical protection and reemergence of strong security services provide only temporary protection. It is time for Russia to make the commitment to and investment in a comprehensive, modern MPC&A system for all of its facilities. The United States can help, but only if Russia takes the lead.
5. Kazakhstan returned Soviet nuclear weapons to Russia under the Nunn-Lugar program, but it did not return all weapons-usable material. Project Sapphire brought nearly six hundred kilograms of HEU from Kazakhstan to the United States in 1994, but there are still HEU-fueled reactors and additional quantities of HEU in Kazakhstan (Albright 2005). It inherited a Soviet BN-350 fast reactor along with several tons of lightly irradiated plutonium. It also inherited the huge former Soviet nuclear test site at Semipalatinsk. U.S.-Kazakh cooperation has enhanced security of reactor installations and the BN-350 fuel. The security of the test site, however, has declined dramatically since the days of Soviet ownership, raising concerns about vulnerable materials that may have been left behind by

the Soviets. In addition, the apparent decision to keep the spent BN-350 fuel in Kazakhstan creates significant risks if the Kazakh regime were to take on Iranian-style leadership.

6. Iran is last on this short list because it apparently does not yet have weapons-usable materials. It is clearly determined to get them, however, and when it does, it will move to second place. The only apparent solution in Iran is to prevent it from making weapons-usable material. It is imperative that Russia and China support current European and U.S. efforts to prevent the completion of enrichment capabilities and the development of other worrisome nuclear technologies.

This short list illustrates the extreme urgency of the threat posed by loose fissile material. But it also emphasizes the need for tailored nonproliferation strategies. Others may propose a different list with different priorities; indeed, my long list also includes China, India, and Israel, as well as the additional incremental risk from increased commercial nuclear power, nuclear wastes, and the alternate nuclear materials mentioned above.

I agree with the 2005 Gleneagles communiqué, which concludes that "the proliferation of weapons of mass destruction (WMD) and their delivery means, together with international terrorism, remain the pre-eminent threats to international peace and security." But the key element, keeping weapons-usable materials out of terrorists' hands, is much more difficult than is generally appreciated. A greater sense of urgency is required—not only on part of the United States but on the part of states that have more benign views of the risks of nuclear terrorism and believe that nuclear proliferation is an American problem. Quite the contrary, loose fissile material must be the top security priority of every nation.

Note

1. The "missing" 11,900 kilograms were explained as follows: 3,400 kg expended in wartime and tests, 2,800 kg declared as inventory differences, 3,400 kg as waste (normal operating losses), 1,200 kg as fission and transmutation, 400 kg as decay and other removals; 100 kg in U.S. civilian industry, 700 kg exported to foreign countries, and a 100 kg rounding difference along with classified transactions. Inventory differences are defined as the difference between the quantities of material in accounting records compared to those determined in physical inventories. They were previously identified as "material unaccounted for," which included operating losses. Today, the operating losses are counted separately, and inventory differences result primarily from statistical measurement uncertainties; recording, reporting, and rounding errors; uncertainties of the amount of material held up in the processing plant; measurement uncertainties because of wide variations of material that contain fissile materials (material matrix) during processing; uncertainties associated with waste; and unmeasured materials associated with accidental spills or releases of materials. Waste (normal operating losses) is defined as intentional removals from the inventory as waste because they are technically or economically unrecoverable. Examples include discharges to cribs, tanks, settling ponds, or disposal facilities (burial sites).

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