

## On Nuclear Terrorism

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The terrorism attacks on Sept 11, 2001 in the U.S. shocked the world because of the enormous civilian casualties it caused. Since then, the concern over nuclear terrorism has continued to rise. People worry that terrorists will explode a nuclear device and cause even more casualties and terror. Besides exploding a nuclear device, there are two other types of action related to nuclear terrorism: distributing radioactive materials and attacking nuclear facilities. This paper analyzes the consequences of nuclear terrorism attacks and provides recommendations to reduce the risk.

### 1. Making the bomb

If a terrorist group plans to make a nuclear device by itself, it would have to overcome at least two technical problems: acquiring a significant amount of fissile materials for weapons and making the nuclear device super-critical.

There are large inventories around the world of the kind of fissile materials needed for nuclear devices: weapon-grade highly enriched uranium, weapon-grade plutonium, and reactor-grade plutonium. Reactor-grade plutonium contains too much plutonium-240 and -241 and therefore has a high rate of spontaneous neutron emission. These spontaneous neutrons prevent a simple nuclear device from releasing its full explosive yield. An advanced design could avoid the problem, but it requires some testing to improve the design. A terrorist group would not be able to conduct a test before launching an attack, so, we discount the situation in which terrorist groups using reactor-grade plutonium in a nuclear device. It is also impossible for a terrorist group to produce fissile materials for themselves. The reason is that the production of fissile materials is very visible to outsiders<sup>2</sup> and a very lengthy period of time is needed to build a production facility. The only source for a

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<sup>2</sup> Zhang, Hui and Frank N. von Hippel. "Using Commercial Imaging Satellites to Detect the Operation of Plutonium-Production Reactors and Gaseous-Diffusion Plants." *Science & Global Security* 8, no. 3 (2000).

terrorist group would be the illegal acquisition of existing weapon-grade fissile materials. The amount of weapon-grade plutonium needed for a single device is less than that needed for one made with weapon-grade uranium. According to the International Atomic Energy Agency (IAEA), 25 kilograms of weapon-grade uranium is a "significant amount," while only 8 kilograms of weapon-grade plutonium is considered a "significant amount." If an imbalance comparable to the significant amounts defined above occurs during fissile material accounting, the authority who supervises the materials would be immediately notified.

There are two ways to bring a nuclear device to super-critical: (1) a gun-type device reaches supercritical by bringing sub-critical pieces of fissile materials together; and (2) an implosive device does this by compressing the fissile material to a higher density. A gun-type device is technically less complicated than an implosive device and may not require nuclear explosive tests before its use. For example, the first U.S. gun-type design (Little Boy) did not undergo explosive testing before it was used against Japan during World War II. Weapon-grade plutonium can be used only in implosive devices while weapon-grade uranium can be used in both gun-type and implosive devices. As mentioned above, a gun-type device is technically less complicated and therefore more desirable to terrorist, making weapon-grade uranium the more dangerous material to lose.

Even if a terrorist group can obtain a significant amount of weapon-grade fissile material, it still faces some technical difficulties in triggering a full explosion. One technical difficulty is to ignite the device at the best time with a pulsed neutron source. An inappropriate ignition would make the explosive yield much lower than anticipated. For an implosive device, another difficulty would be to create a uniform and symmetrical implosive shock wave to compress the fissile core. If the shock wave has some asymmetry, the yield could also be much lower than expected or even zero.

The explosive yield of their first nuclear devices in all nuclear weapon states is about 20 kilotons. If a terrorists group could make a nuclear device by itself, its yield should be about 20 kilotons or less. The first gun-type device, Little Boy, had a weight of 4,000 kg, a diameter of 0.71 meter and a length of 3.05 meters. The first implosive device designed in the US weighed 4,900 kg and was 1.52 meters in diameter. This indicates that an early design of a nuclear device would be very heavy and large. Some countries have developed nuclear devices after the US without nuclear explosion tests. For example, Sweden designed an implosive device of 600 kilograms and South Africa produced gun-type devices weighing 900 kilograms. (See Table 1.) There is no evidence that any country produced smaller nuclear without nuclear testing. So, the Swedish and South African devices can be used as benchmarks in guessing the weights of new nuclear weapons. We believe that, the weight of a nuclear device designed and produced by a terrorist group, if it can, should be greater than the Swedish one for an implosive design or greater than

the South African one for a gun-type design. The reason is that the terrorists groups can not conduct nuclear testing before use.

A nuclear device can be made to be much smaller. As shown in Table 1, the smallest gun-type device ever deployed and known by the public is the US W33 warhead weighing 114 kg; the smallest implosive warhead is the US W54 weighing only 26.6 kg.

The Missile Technology Control Regime (MTCR) suggests denying the transfer of missiles that can bring a payload weighing 500 kg over 300 km. The assumption behind the constraint is that an emerging state cannot make a nuclear warhead weighing less than 500 kg.

Table 1: List of Some Nuclear Devices<sup>1</sup>

Device	Type	Weight	Size
US Little Boy	Gun-type	4000 kg	0.71 m 3.05 m
South Africa device	Gun-type	900 kg	0.64 m 1.83 m
US W33	Gun-type	114 kg	0.40 m in diameter 0.94 m in length
US Fat Man	Implosive	4900 kg	1.52 m in diameter
Sweden device	Implosive	600 kg	0.62 --0.80 m in diameter
US W54	Implosive	26.6 kg	cylinder of 40 cm by 60 cm
MTCR constraint		500 kg	

## 2. Scenarios of Nuclear Terrorism

If a nuclear bomb is made by a terrorist group outside the country it plans to attack, it is difficult for the terrorists to bring the bomb into the country. One possible solution is to carry the device aboard a ship and explode it on the ship near the seashore. The explosive yield of the device would be about 20 kilotons or even significantly less. This is the first scenario of nuclear terrorism.

The second scenario of nuclear terrorism is to explode a nuclear device at a population center. As explained in the last section, a nuclear bomb produced by a terrorist group would weigh a few tons and have a size of one to two meters. This

<sup>1</sup> Data drawn from, Cochran, "Nuclear Weapons Databook, Vol. I, U.S. Nuclear Forces and Capabilities"; Paul M. Cole, "Sweden Without the Bomb --The Conduct of a Nuclear-Capable Nation Without Nuclear Weapons," (RAND, Santa Monica, CA, 1994), p.31; David Albright, "South Africa's Secret Nuclear Weapons," ISIS Report, (May 1994); and Carey Sublette, "Osama, Suitcase Bombs, and Ex-Soviet Loose Nukes," <http://www.fas.org/nuke/hew/News/Lebedbomb.html>. The radius of the Sweden device is drawn from Figure A.2 of Li Bin, "Nuclear Missile Delivery Capabilities in Emerging Nuclear States," Science and Global Security, 1997, Vol. 6, p.328.

would be transportable by a truck. If the terrorist group builds the nuclear bomb in the same country it plans to attack, they could possibly transport the bomb to a population center. If the terrorists try to acquire an existing nuclear warhead, the loss would usually be immediately noticed by the authority because the accounting for nuclear devices is much simpler and stricter than the accounting of fissile materials. Therefore, the terrorist group would have very little chance of bringing the nuclear device out of the country even if they could steal it. So, the only likely chance is to explode the device within the same country the terrorists get it. Tactical nuclear weapons are in more danger of theft than strategic weapons. Compared to tactical nuclear weapons, the world's strategic weapons are under more strict control and have fewer deployment and deposit sites. Therefore, strategic weapons have much less chance of being "lost" or stolen. Most nuclear weapons are believed to have devices, such as PAL (Permissive Action Link), to prevent unauthorized initiation of detonation.<sup>1</sup> However, it is not clear if all the tactical nuclear weapons, especially those developed for quick use on the battlefield, have the same security features. If not, the loss of some tactical nuclear weapons would be a serious problem. US and Russia (the former Soviet Union) have withdrawn most of their tactical nuclear weapons from deployment, but their tactical reductions were conducted in a voluntary manner and there was no verification or transparency arrangement involved. So, the reductions cannot rule out the concern over the loss of tactical nuclear devices. A tactical device, if stolen, would pose much more danger than a device produced by a terrorist group. As seen in Table 1, an existing tactical device is much lighter, and therefore, more transportable. The terrorist group would have less difficulty bringing the device to a population center.

The third scenario in nuclear terrorism is launching an attack against nuclear facilities. This does not seem to be an effective attack unless it is done with a suicide airplane crash like those of September 11, or a truck bomb at a key part of the facility. The attack against a reactor in operation could lead the release of vaporized nuclear materials including nuclear fuels and fission products.

The fourth scenario of nuclear terrorism is to explode a bomb with radioactive materials. The bomb containing nuclear waste is always referred as a "dirty bomb." This device has very little military meaning and is a weapon purely for terrorism purposes. Nuclear waste is under less stringent control than fissile materials, so it would be easier for a terrorist group to gain access to nuclear waste. However, most nuclear waste cannot be easily used for making a "dirty bomb" because some are solidified in concrete, some are deposited in heavy containers, and some are too diluted. The radiation of the waste itself also poses a barrier to the terrorists who want to collect the nuclear waste for a "dirty bomb" if they understand and care the consequences of exposure to radiation. If there are demoralization problems in the nuclear facility staff, there would leave some chance for the terrorists to acquire a

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<sup>1</sup> Robert S. Norris et al., Nuclear Notebook: U.S. Nuclear Weapons Safety and Control Features, The Bulletin of Atomic Scientists, October 1991, Vol. 47, No. 8.

large amount of fresh nuclear waste. The terrorists could also collect unattended nuclear waste, but only a small amount at a time.

Gavin Cameron has studied the cases of the above two kinds of nuclear terrorism: reactors and radiological attacks.<sup>1</sup> He believes that many power reactors are vulnerable to airplane crashes, and even truck bombs. In his paper, he includes a list of attempted attacks against reactors which were not effective.

### 3. Consequences of Nuclear Terrorism Attack

In this section, we estimate the consequences of nuclear terrorism attack in four scenarios.

Scenario 1. A nuclear device is exploded on the surface of water by a seashore and the yield is 20 kilotons or less.

The effects of a nuclear explosion include shock waves (or referred as air blasts for an explosion in the air), thermal radiation, initial nuclear radiation, and residual nuclear radiation. The damage caused by residual nuclear radiation is usually smaller than immediate effects, so we ignore the residual nuclear radiation in assessing the damage. If a nuclear explosion happens on or below the ground surface, the thermal and initial nuclear radiation cannot go very far along the ground surface because of the deflection and absorption of the earth. So, we will also ignore the damage caused by thermal and initial nuclear radiation in this scenario. In calculating the lethal distance of a nuclear explosion, we assume that the buildings suffering attack are wood-framed.

If a nuclear device of 20 kilotons is exploded at the optimum altitude in the air, the distance from the ground zero to the farthest point of severe damage is about 7100 feet (2200 meters) and is 8500 feet (2600 meters) to the farthest point of moderate damage.<sup>2</sup> This was the case in the nuclear attacks on Nagasaki and Hiroshima. However, since the nuclear explosion happens on the surface of water by seashore in our scenario, the lethal distance should be smaller than the above figures. The damage threshold for wood-frame building is about a few psi overpressure.<sup>3</sup> For overpressure in this scale, the lethal distance of an explosion on the ground is about three fourth (3/4) of that at the optimum height. So, the average lethal distance in this scenario is about 1,800 meters. Because the surface of the sea is lower than the seashore, a significant fraction of the horizontal air blast would be resisted by the

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<sup>1</sup> Gavin Cameron, Nuclear Terrorism: Reactors & Radiological Attacks After, September 11, IAEA Meeting 2/11/01.

<sup>2</sup> The data are drawn from Figure 5.140, in Samuel Glasstone et al., "The Effects of Nuclear Weapons," Third Edition, US Government Printing Office, Washington, DC, 1977. p. 219.

<sup>3</sup> Ibid., pp. 178-179.

earth and therefore declines much faster than in other direction. So, the lethal distance should be much lower than 1,800 meters. If the explosion yield is lower than 20 kilotons because of imperfect technology in making the device, that would also greatly reduce the lethal distance. For a given area, we can then calculate the casualties caused by the explosion by determining the product of the size of the lethal area and the population density.

For comparison, the casualties in the nuclear attack on Nagasaki were about 130,000. The lethal area was proportional to the square of the lethal distance and since half the area in our scenario is on the sea and half is on the bank, the lethal area for our scenario is about 23%  $[\frac{1}{2}(\frac{3}{4})^2]$  that of the attacks on Nagasaki and Hiroshima. Assuming that the attacked area has the same population density as that in Nagasaki in 1945, the casualties under the conditions of our scenario would have been about 30,000. If we consider the fact that some air blast is resisted by the seashore above the explosion, the casualties could drop even lower, to the order of that in the September 11's terrorism attack.

Scenario 2. A nuclear device is exploded at a population center. The yield is about 20 kilotons.

Although the explosive yield in this scenario is the same as in the last one, the damage in this scenario would be much bigger because the population density would be much higher. The casualties would be at the level of those in the Nagasaki and Hiroshima attacks or even larger.

Scenario 3. An operational reactor releases a significant amount of vaporized nuclear materials, including spent fuels and fission products after suffering an attack.

Nuclear materials released from an operational reactor are harmful to human beings. They could cause immediate effects in a few days, mid-term effects in a few years and long-term effects in tens of years. Immediate effects include acute radiation sickness caused by exposure to large-dose radiation, scalding by hot venting, and injuries by solid debris. Mid- and long-term effects are caused by internal radiation and is more enduring than exposure to external radiation.

For internal radiation, Iodine-131 is a major concern for three reasons. First, it is volatile and therefore easy to be released from the reactor and dispersed over a large area; second, it is highly radioactive; and third, Iodine-131 stays inside the body of human beings and concentrates in the thyroid gland. The radiation of Iodine-131 in the thyroid can cause thyroid cancer.

Strontium-90 and cesium-137 are also of major concern. They have half-lives of a few tens of years and therefore pose long-term effects. Strontium-90 and

cesium-137 can also stay in living organs and pose radiation within the human bodies.

The Chernobyl accident of April 26, 1986, released into the atmosphere a large quantity of radioactive materials and can be used as a benchmark to assess the damage in our scenario. In and after the accident, there have been some health impacts observed. About thirty people died due to immediate effects and one hundred suffered sickness caused by radiation exposure. Since the accident, a few hundred childhood cases of thyroid cancer have been recorded in the contaminated area. A few children have died due to this sickness. Long-term health effects caused by strontium-90 and cesium-137 have not yet been observed to date.<sup>1</sup>

If an attack against an operational power reactor causes a leakage of nuclear materials as happened in the Chernobyl accident, the consequences would be similar to that of the Chernobyl accident. It seems that the casualties caused by a terrorism attack against a nuclear reactor would be much smaller than that of Sept. 11's attack. However, the psychological and economical effects would still be very serious.

Scenario 4. A "dirty bomb" with radioactive material is exploded at a population center.

The effects of the explosion of a "dirty bomb" are highly dependent on the type of nuclear materials used, the form of dispersal, and the weather condition after the explosion. Therefore, it is difficult to give an exact estimate about the damage. However, the fatalities and injuries caused by a dirty bomb in different cases would be much less than those at the Chernobyl accident because the dispersing range of nuclear contamination would be much shorter. The main effects would also be psychological and economical ones.

The analyses in the above four scenarios show that the biggest damage caused by a nuclear terrorism attack on a country would be the explosion of a nuclear bomb acquired or produced within the same country. If some nuclear weapons or fissile materials get lost, it hurts the security of the country itself most. So, the countries possessing nuclear weapons or fissile materials should well protect their nuclear weapons and materials for at least their own sake. The casualties caused by an attack against nuclear facilities or the explosion of a "dirty bomb" would be much smaller than those in the Sept. 11 attack. For these two cases, the psychological effects would be the more serious concern.

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<sup>1</sup> OECD Nuclear Energy Agency, "Chernobyl Ten Years On Radiological and Health Impact, An Assessment by the NEA Committee on Radiation Protection and Public Health," November 1995. And, "Summing Up the Consequences of the Accident," International Conference: One Decade after Chernobyl, Austria Center Vienna, Austria, 8-12 April 1996.

#### 4. Where is the Achilles' Heel?

There have been some reports of fissile material thefts in the past. This is a reminder for us that some national fissile material accounting and protection systems may have some loopholes. In the Appendix made, there is a literature review on fissile material accounting and protection systems. Besides the problems indicated in the appendix, there is another general problem, that is, the accounting period is much greater than the time needed to respond a theft. The fissile material protection system provides immediate notifications to the authority if a illegal access occurs while the accounting system measure cannot do this because of the lengthy period of measurement. So the main barrier against theft is fissile material protection rather than accounting. If an insider is involved in a theft, the protection itself may not be sufficient and a near real-time accounting could play a backup role. It is technically difficult to measure the amounts of fissile materials in different shapes if a large inventory is kept. As time being, the accounting uncertainties are increasing and leaves higher risk for theft. To reduce this risk, the nuclear-weapon states should consider faster steps in disposing excess fissile materials.

There is very little transparency in U.S. and Russian reductions of tactical nuclear weapons. There are still some tactical nuclear weapons intact the U.S. and Russia. It is not certain that all these tactical nuclear weapons remained have been equipped with locks that prevent illegal triggering. This should be a big concern in anti-terrorism. There is a new danger now in tactical nuclear reductions because some groups in the U.S. are pushing the government to develop nuclear penetrating warheads -- a new tactical nuclear weapon. If this proposal is accepted by the U.S. government, it would hurt tactical reductions in the U.S. and Russia. To prevent unauthorized use of existing nuclear weapons, it is important for the nuclear-weapons states to dismantle all tactical nuclear weapons when some progress is being made in strategic nuclear reductions.

## Appendix: Review of Literature on Fissile Material Accounting

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### Introduction

"Several kilograms of plutonium, or several times that amount of HEU, is enough to make a bomb. With access to sufficient quantities of these materials, most nations and even some sub-national groups would be technically capable of producing a nuclear weapon...."<sup>1</sup>

Nuclear terrorism is a real threat felt by many, and discussion about the topic has escalated after the tragedy of September 11. Much literature has been written on the topic and the general consensus is that the threat is real. However, the consensus seems to break down when we start discussing what the threats are and materials are involved. What materials are assessable and desirable to terrorist, therefore posing the greatest risk of theft? What are the safeguards in place and are they capable of stopping such activities? Are there safeguards that function as a deterrent to thieves?

### Fissile Materials

There are six types of fissile material that are of concern when talking about nuclear terrorism. The first is weapons-grade plutonium. Plutonium is considered weapons-grade if it consists of less than 7% plutonium-240 (Pu-240). This is the material of choice by nuclear weapon states (NWS) because of its extremely low weight to yield ratio. The second material of interest is weapons-grade uranium. Weapons-grade uranium is enriched to over 90% Uranium-235 (U-235). The next is highly enriched uranium, which contains more than 20% U-235. The other material that is of interest to nuclear terrorist is reactor-grade plutonium which is usually comprised of less than 19% Pu-240, and typically about 30% non-fissile material. Unirradiated mixed materials such as uranium-plutonium mixed oxide (MOX) fuel also pose a threat. The last type of material is nuclear waste which is the radioactive by-products formed by fission and other nuclear processes in a reactor and is initially contained in spent fuel.

### Fissile Materials and the Making of a Bomb

Weapons-grade plutonium is processed in military production reactors specifically designed and operated for production of low burn-up plutonium. Due to its desirability, lethality and proliferation concerns, weapons-grade plutonium is under the strictest security in every NWS.

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<sup>1</sup> US Department of Energy, Office of Arms Control and Nonproliferation, *Final Nonproliferation and Arms Control Assessment of Weapons-Usuable Fissile Material Storage and Excess Plutonium Disposition Alternatives*, DOE/NN-007 (Washington, DC: DOE, January 1997), p.vii.

However, it is not under international safeguards because of the national security concerns related to nuclear materials and forces.

Obtaining reactor-grade plutonium, on-the-other-hand, is easier in comparison because of its use in commercial reactors. The feasibility and desirability of using reactor-grade plutonium as a nuclear explosive material is debatable. The United States' Department of Energy (DOE) successfully conducted an underground test in 1962 in Nevada which used reactor-grade plutonium in the nuclear explosive in place of weapons-grade plutonium. The yield was less than 20 kilotons. This fact was declassified in July 1977. What was not declassified, however, was the isotopic composition of the plutonium used, but it has been estimated to be about 90% Pu-239.<sup>1</sup> The proliferation threat of reactor-grade plutonium has been a debate among experts and its feasibility is not commonly accepted.

The disadvantage of using reactor-grade plutonium in nuclear devices, even if it is feasible, is the increased complexity in designing, fabricating, and handling them. Building a nuclear device with reactor-grade plutonium poses many problems because of the high level of Pu-240, a highly unstable element capable of spontaneous fission. Therefore, using reactor-grade Pu to build a bomb requires a higher level of sophistication than using weapons-grade material.

The Pu-240 content even in weapons-grade plutonium is sufficiently large that very rapid assembly is necessary to prevent pre-initiation. Hence the simplest type of nuclear explosive, a "gun type," in which the optimum critical configuration is assembled more slowly than in an "implosion type" device, cannot be made with plutonium, but only with highly enriched uranium (HEU), in which spontaneous fission is rare. This makes HEU an even more attractive material than plutonium for potential proliferators with limited access to sophisticated technology.<sup>2</sup> HEU is uranium enriched to 20% or greater U-235, usually around 90%. All HEU can be used to make nuclear explosives, although very large quantities are needed for HEU enriched to 20%.

Some experts say that oxide powder could also conceivably be used by terrorist as-is to make a nuclear device if they do not want to spend the number of days required to go through the chemical operation of reducing it to power, although fuel elements of any type have to be subjected to chemical processing to separate the fissile material they may contain from diluents. This process would also require specialized equipment, a supply of appropriate reagents, well-developed techniques specific to the materials handled, and at least a few days to conduct the operations.<sup>3</sup>

If terrorists can not obtain weapon-grade uranium for their "gun-type" device and want to

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<sup>1</sup> World Nuclear Association, *Introduction of Nuclear Electricity*, August 2000, Ch. 7-3. Available at <http://www.world-nuclear.org/education/ne/ne7.htm>

<sup>2</sup> *Management and Disposition of Excess Weapons Plutonium*, Committee on International Security and Arms Control of the National Academy of Sciences, 1994.

<sup>3</sup> Mark, Taylor, Eyster, Maraman, Weschsler, *Can Terrorists Build Nuclear Weapons*, Nuclear Control Institute, Washington, DC. Available at <http://www.nci.org/k-m/makeab.htm>

achieve rapid turnaround time (a day or so after obtaining the material), the amount of fissile material necessary would tend to be very large - possibly twenty times the so-called formula quantities identified in federal regulations for the protection of nuclear materials (5 kg of U-235). This would then increase the weight of the completed device to probably more than a ton.<sup>1</sup> The second option of converting the materials to metal would require less fissile material to be used but more time would be needed and quite specialized equipment and techniques.

In all cases, successful execution would require the efforts of a team having knowledge and skills additional to those usually associated with a group engaged in hijacking a transport or conducting a raid on a plant. It is exceedingly unlikely that any single individual could equip himself to proceed confidently. Therefore, a subnational group with a number of specialists would be the most likely and feasibly terrorists. The time it would take a group to get ready would depend on a number of factors, such as the form and nature of the material acquired and the form in which the terrorists proposed to use it, but it is likely that the whole team would require a considerable number of weeks or more -probably months, prior to acquisition. The time intervals for the completion of a nuclear weapon might range from a number of hours, on the supposition that enriched uranium oxide powder could be used as-is, to a number of days in the event that uranium oxide powder or highly enriched (unirradiated) uranium reactor fuel elements were to be converted to uranium metal.

Taking into account the issues and limitations involved in the use of these various fissile materials, it can be inferred that the most desirable material for terrorist groups would be HEU. As explored in this section, technical limitations pose one of the strongest hurdles for terrorist who wish to build nuclear weapons. However, even if a terrorist group possessed the technical capability to manufacture a nuclear device, there is still the hurdle of bypassing international safeguards which watch over the materials and work to detect and halt clandestine activity.

### **International Safeguards**

As stated earlier, there are currently no international safeguards of weapons-grade materials. However, international safeguards are widely used for non-weapons grade materials such as reactor-grade plutonium and waste that could be useful to proliferators. Current safeguards include the International Atomic Energy Association (IAEA) which was established under the agreement of the NPT with the newest protocols of INFCIRC/540. The application of NPT safeguards is built upon cooperation between the agency and the state. All signatories and some who are not are under IAEA safeguards.<sup>2</sup> International safeguards consist of monitoring and accounting measures designed to prevent NNWS from diverting nuclear material from peaceful nuclear activities to weapon programs. Safeguards activities are aimed predominantly at verifying “declared” nuclear material and items. In the past, the capability of the IAEA to detect undeclared nuclear activities was limited.

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<sup>1</sup> *ibid*

<sup>2</sup> See Appendix-A

However, reaction to the Iraqi discovery of an extensive nuclear weapon program which had largely gone undetected until 1991 following the Gulf War, helped create four significant changes to international safeguards. The first was the direct and continuous engagement of the UN in the pursuit of non-proliferation objectives. In particular, the UN Security Council gave legitimacy and authority to intrusive actions which the IAEA did not have the power to perform before. The second was the intensification of intelligence gathering and sharing by states and its use to guide diplomacy and verification. The third was the strengthening of technology controls, especially through the incorporation of dual-use technologies in the list attached to the Nuclear Suppliers Guidelines. Last of all, IAEA launched the "Program 93+2" which aimed to enhance the effectiveness of the NPT safeguards by increasing the availability of information about the nuclear materials, equipment and facilities possessed by NNWS parties to the NPT, by broadening access to their sites, and by improving detection techniques. The new measures increased the IAEA's abilities to detect warhead development and manufacturing programs as well as detect the production and separation of fissile materials. However, it remains to be seen how successful they can be implemented.

Other inspection agencies include Euratom which is responsible for fifteen member states of the European Union. Euratom supplies safeguards to all civil nuclear material in the member states, regardless of state's status under the NPT. Military materials in Britain and France are not subject to Euratom safeguards.

Another international agency was established under a bilateral agreement between Brazil and Argentina called the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC). It was formed in 1990 and is responsible for inspecting all nuclear facilities and verifications of the material declarations of each country and conducts routine inspections at nuclear facilities. The two countries also signed the Quadripartite Agreement, drawn up between Argentina, Brazil, ABACC and the IAEA which allows IAEA inspectors to draw independent conclusions.

For weapons-grade material in NWS which are not under the NPT and international safeguards, each country has implemented their own policies and safeguards. However, the policies of each country are not transparent. Russia and China still keep their weapons-material production under a veil of secrecy and few facts are known about their material production, storage, or safeguarding measures.

### **US Safeguards**

In contrast, the United States has, in recent years, offered more transparency to its plutonium production, acquisition, and utilization. Created under the Atomic Energy Act of 1954, the Nuclear Materials Management & Safeguards System (NMMSS) is the US government's information system containing current and historic data on the possession, use and shipment of nuclear materials. This centralized data base contains information collected from government and commercial nuclear facilities and provides output reports to those facilities

and other interested parties, primarily US government offices. The US Department of Energy (DOE) and the US Nuclear Regulatory Commission (NRC), materials control and accountability staffs use NMMSS information in carrying out nuclear materials safeguards responsibilities. Fundamental safeguards uses of NMMSS data are identifying shipper-receiver differences and inventory differences. Currently, data from 1,130 commercial and government facilities in the US is collected and maintained in the system. It also maintains accounting data on US peaceful use exports and imports that have occurred since 1950. The NMMSS also generates reports for IAEA and foreign countries on the inventories, material balances and transactions that the US has agreed to provide.<sup>1</sup>

Inventory and material balance data are reported according to established periodic schedules to NMMSS.<sup>2</sup> The DOE and the NRC maintain the same reporting requirements for the nuclear materials. However, the DOE requires more material types to be reported than does the NRC. Both of the governmental bodies require the reporting of source and special nuclear material.<sup>3</sup> For the materials that are of concern to our report, plutonium and enriched uranium, facilities are required to report to the NMMSS during transactions and material balance, the weight of the material to the nearest whole gram, except in the case of Pu-238 which requires reporting to the tenth of a gram. This is similar to DOE's inventory reporting requirements.

The safeguards for US weapons-usable fissile material in the DOE's inventory subject to the "stored weapons standard" (the highest standard) include materials 1) in the DOE's ultimate material disposition program, 2) excess but not yet designated for disposition, and 3) to be retained for national defense. The DOE grades weapons-useable fissile material by attractiveness to someone wanting to make a nuclear weapon. It does so using categories such as quantity, enrichment, radioactivity, and chemical form for the plutonium or HEU. Such grading is also part of international standards. In comparison to the international standards for physical safeguards, the US exceeds those of the IAEA for weapons-usable fissile materials.<sup>4</sup>

However, studies have shown that accounting problems are a major problem for the DOE. The DOE Office of the Inspector General reviewed internal controls over fissile materials at seven sites and found accounting problems at three of those sites. It has been found that the DOE was unable to measure scrap, waste materials, and holdup, significantly hindering DOE's ability to accurately account for nuclear materials. Sites often had to make estimates

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<sup>1</sup> Nuclear Material Management Systems website, available at <http://www.nmmss.com/NMMSST1.nsf/>

<sup>2</sup> Nuclear materials tracked by NMMSS include source nuclear materials: normal uranium, depleted uranium, thorium; special nuclear materials: Enriched Uranium, Plutonium, Plutonium-238, Plutonium-242, Uranium-233, Uranium in cascades; other nuclear materials: Americium-241, Americium-243, Berkelium, Californium-252, Curium, Deuterium, Lithium-6, Neptunium-237, Tritium.

<sup>3</sup> The US Nuclear Regulatory Commission defines special nuclear material to mean: "Plutonium, uranium-233, uranium enriched in the isotope U233 or in the isotope U235, and any other material the Commission, pursuant to the provisions of section 51 of the Atomic Energy Act of 1954, as amended, determines be special nuclear material, but does not include source material; or any material artificially enriched by any of the foregoing, but does not include source material."

Available at <http://www.nrc.gov/reading-rm/doc-collections/cfr/part074/part074>

<sup>4</sup> George Bunn, *US Standards for Protecting Weapons-useable Fissile Material Compared to International Standards*, The Nonproliferation Review, Fall 1998.

based on historical experience or observations, varying the accuracy of such estimates from reasonably good to poor.<sup>1</sup> The DOE also encountered measuring problems during the late 1980s through the 1990s. The end of the Cold War resulted in a significant (around 30%) increase in the DOE's fissile material inventory as a weapons were returned from stockpile and DOE accepted fissile materials from other countries. The changing needs resulted in production stand-downs and large quantities of fissile materials were left in forms that could not be readily measured. Although the DOE implemented the measurement assessment project (MAP) to deal with these problems, "the overall progress to address identified fissile material assurance weaknesses has been slow."<sup>2</sup>

Some of the problems in DOE are continued and recurring weaknesses in physical inventories. It is documented that significant differences between verification measurement results and the inventory values are not resulting in new inventory values. The approaches to statistical sampling during physical inventories is not sufficient to provide confidence that fissile materials are accounted for. In many cases, the site sampling methods are not adequate to address common situations, such as items that are selected but that cannot be safely moved or measured. Such weaknesses can result in questionable or invalid inventory statements. Some physical inventory sampling plans are incomplete or do not include sufficient information.

Current inventory differences suggest that thousands of kilograms of material documented in departmental records are not accounted for. The inventory differences involve thousands of kilograms of special nuclear material.<sup>3</sup> In many cases, the inventory differences have been attributed to holdup, operational losses, such as accidental spills, environmental releases, human errors, rounding errors, and disparities between old book values and new measurement values.<sup>4</sup>

## **Russian Safeguards**

In Russia, the Ministry of Atomic Energy (Minatom) has control of most fissile materials besides those contained in Russia's nuclear weapons. Minatom's system of safeguards is functionally similar to that of the DOE - to deter, prevent, detect, and respond to unauthorized possession, use, or sabotage of weapons-usable materials. Its components include a systems of physical protection, material control measures, and material accounting. However, there are substantive differences between Minatom and DOE in how specific safeguards programs are implemented. Its system is far less technically sophisticated with its most deficient component being its system of material control and accounting (MC&A).<sup>5</sup> The system is primarily used for the purposes of material planning and financial accounting and is

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<sup>1</sup> *Follow-up Review of Fissile Material Assurance in DOE Complex*, DOE, July 1998. Available at <http://www.oa.doe.gov/reports/reports.html>

<sup>2</sup> Ibid.

<sup>3</sup> see Table 2

<sup>4</sup> *Increasing Fissile Inventory Assurance Within the US Department of Energy*, DOE Office of the Deputy Assistant Secretary for Security Evaluations, January 1995.

<sup>5</sup> Oleg Bukharin, , *US-Russian Cooperation in the Area of Nuclear Safeguards*, *The Nonproliferation Review*, Fall 1994.

based on the principle of personal responsibility where a designated accounting worker receives nuclear material and assumes personal responsibility for it. After the material has been processed, it is transferred to another accounting worker who then assumes full responsibility. The discrepancy of the amounts of material before and after the operation is considered process loss and, under Minatom regulations, must not exceed centrally specified limits. However, because of the lack of equipment, material containers that do not allow measurements, or for other reasons, material transactions are conducted without actual measurements. Generally, measurements are rare and most of them are carried out as a part of quality control program, not as a strict accounting system. The effectiveness of the MC&A system is also limited by the lack of regulations and by a variety of accounting formats.

The economic crisis in Russia has also degraded the technical and research and development base of the nuclear complex and its safeguards system. There has been a shortage of containers and adequate storage facilities for fissile materials. Production facilities have eliminated material-control related jobs. Meanwhile, the demand on the existing system of safeguards has increased as a result of fissile materials left over from the dismantlement of nuclear warheads.

FSU states are thought to possess roughly 1350 tons of weapons-usable nuclear material of which some 700 tons is in nuclear weapons, and 650 is in a variety of forms ranging from metal weapons components to impure scrap. These materials are stored in over 50 sites, estimated nearly 400 buildings containing kilogram quantities. Accurate measured inventories of all nuclear material on hand have still not been carried out at most facilities, and there is still no accurate and up-to-date national inventory known.

The greatest threat stems from an experienced and corrupt insider. A survey for Gostomnadzor, the Russian nuclear regulatory agency, showed that every nuclear theft from the Russian facilities it regulated during 1990-95 involved an insider (although outsiders were often involved) and none were detected by the existing Russian safeguards and protection systems then in effect.<sup>1</sup> Security for nuclear materials in weapons in Russia is substantially better than for the "loose" materials. However, the top leadership of the 12<sup>th</sup> Main Directorate have testified to the Russian Duma that funding for nuclear weapons security is grossly inadequate.

Russia is aware of their deficiencies, as is the US. Russian Minister of Atomic Energy Evgeniy Adamov said that "the weakening of our ability to manage nuclear material has been immeasurable." In 1996, the US Director of CIA testified that weapons-usable nuclear materials "are more accessible now than at any other time in history - due primarily to the dissolution of the former Soviet Union and the region's worsening economic conditions," and that none of the facilities handling plutonium or HEU in the FSU states had "adequate

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<sup>1</sup> George Bunn and Fritz Steinhausler, *Guarding Nuclear Reactors and Material from Terrorists and Thieves*, Arms Control Today, October 2001.

safeguards or security measures." For this reason, the US and Russia has established a number of programs to help strengthen its safeguard system. In November 1991, US Congress enacted the Soveity Nuclear Threat Reduction Act (known commonly as the Nunn-Lugar program), which formed an interagency group on safe secure dismantlement of nuclear weapons.

In 1996, the Trilateral Initiative was launched between the IAEA, Russia, and the DOE to develop a new IAEA verification system for weapon-origin material designated by the US and the RF as released from their defense programs.<sup>1</sup> The US also intends to submit to IAEA verification other fissile material designated by it as no longer required for defense purposes. IAEA verification under the initiative is intended to promote international confidence that fissile material made subject by either of the two States to the IAEA verification remains irreversibly removed from nuclear weapons programs. An essential requirement of the verification system and the methods to be applied is that they must allow the IAEA to draw credible and independent conclusions to assure that the objectives of verification are met. A number of workshops and meetings have been held since its launch in 1996, but no verification agreement has yet been agreed upon and implemented.

There are many difficulties and uncertainties surrounding the measurement of FSU's plutonium inventory. The figures that the US have are based on estimates of the size of its arsenals, calculations based on assumptions about its reactors, and the krypton-85 measurement method. There have been no announcement of historical production of weapons-grade Pu or inventories at its different sites. The records that are present are believed to be incomplete of inventories at sites and data on production losses and waste disposal are particularly unlikely. It is also feared that historical records may also be untrustworthy because it was common practice to misrepresent annual production in order to justify enterprise incomes from the state.<sup>2</sup>

Some documented thefts from states in the FSU include: 1.5 kilos of weapon-grade HEU from the "Luch" production association in Podolsk, Russia, in 1992; 1.8 kilos of 36% enriched HEU from the Andreeva Guba naval base near Russia's Norwegian border in July 1993; 4.5 kilos of material enriched to +19% U-235 from the Sevmorput naval shipyard near Murmansk in November 1993; over 360 grams of Pu seized in Munich on a plane from Moscow in August 1994; and 2.73 kilos of weapons-grade HEU seized in Prague in December 1994. In 1998, conspirators tried to steal 8.5 kilos of radioactive material as suitable "production of components of nuclear weapons" from a major MINATOM facility in Chelyabin processing plant in Ozersk and the disassembly facility at Trekhgornyy. 1993, 2 kilos of 90% enriched HEU has still not been accounted for when scientists fled the Sukhumi research center in the Abkhazia region of Georgia due to civil war.<sup>3</sup>

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<sup>1</sup> IAEA, *IAEA Verification of Weapon-Origin Fissile Material in the Russian Federation and the United States*, September 2001. Available at <http://www.iaea.or.at/worldatom/images/nix.gif>.

<sup>2</sup> Albright, Berkhout, and Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies* (SIPRI, Oxford University Press, N.Y., 1997), p. 51.

<sup>3</sup> Matthew Bunn, *The Next Wave: Urgently Needed New Steps to Control Warheads and Fissile Material* (Washington, DC: Carnegie Endowment for International Peace and Harvard Project on Managing the Atom, April 2000) Available at <http://ksgnotes1.Harvard.edu/BCSIA/Library.nsf/pubs/Nextwave>

The U.S. Department of Energy (DOE) estimates that there may be enough weapons-usable nuclear materials to produce 40,000 nuclear weapons at facilities in 8 countries that were once a part of the Soviet Union. The Soviet Union secured most of these facilities by placing them in closed cities or by using with gates and armed guards. But, according to DOE, budget cuts and political upheavals have undercut this system. Many facilities lacked fences, monitors, alarms, and comprehensive accounting systems to keep track of materials. Reports indicate that even those facilities with security and monitoring systems often disconnected them to save money on electric bills and to reduce false alarms. They also have been unable to pay the guards and officers charged with maintaining security at the facilities.<sup>1</sup>

There have been numerous reports of nuclear materials from facilities in the former Soviet Union appearing on the black market in Europe. In most cases, the materials lacked the purity to be used to manufacture nuclear weapons. However, in several of the reported cases, the materials could have been useful to a nation seeking to develop nuclear weapons. In May 1999, the National Research Council, an arm of the U.S. National Academy of Sciences, issued a report stating that security at Russia's nuclear materials facilities was worse than previously reported.

#### **Other NWS Safeguards and Fissile Material Inventory**

The British government has made no announcements about the quantities of plutonium produced for nuclear weapons. No material has been published about the accounting for military nuclear materials in the UK. It is not known how precisely the British government can identify the quantities and locations of the plutonium in its military inventories. Unlike the US, FSU, and the PRC, all the civil nuclear materials held by the UK have been under international (Euratom) safeguards since the early 1980's and identical standards are now applied to civil and military nuclear materials in the UK.

Similarly, no information has been made public on the accounting for military materials in France. It is believed that, like the FSU, France had restricted its accounting at military facilities to records of inputs and outputs.<sup>2</sup> And unlike the UK, the approaches followed in regard to civil and military activities were not identical.

The size of China's plutonium inventory are based upon estimates which are very tentative because so little is know about China's nuclear weapons arsenal and production processes. No materials are available about how weapon materials are accounted for in China.

Regarding HEU, the United States stopped production of HEU for nuclear weapons in 1964. It suspended production of HEU for any purpose in November 1991. However, with the end of the cold war and arms reductions, large excess stocks of HEU from dismantled weapons

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<sup>1</sup> Amy F. Woolf, *Nuclear Weapons in Russia: Safety, Security, and Control Issues*, CRS Issue Brief, updated December 5, 2001.

<sup>2</sup> Albright, et al. p. 75.

have appeared. As for Russia, although little is known about its historical enrichment production, HEU production for military and civilian purposes was ceased in the early 1990s. The UK obtained weapon-grade uranium from its own enrichment facility at Capenhurst and from the US. Until as late as the end of 2001, the UK had an agreement with the US to acquire HEU from the US. Little is known about the amount produced at Capenhurst and questions remain about the quantity acquired from the US. France has stopped making HEU for nuclear weapons, although the exact date is unclear. As for China, it is reported that the country has stopped producing weapon-grade uranium for weapons in 1987. Although worldwide production of HEU has plateaued, significant changes are taking place in the forms in which they are held as weapons are decommissioned which could become problematic if proper and adequate accounting and safeguard measures are employed to keep track of those materials.

## **CONCLUSION**

Nuclear terrorism will and should always be a threat not to be taken lightly. What seems unlikely should still not be ignored. As the September 11 attacks have shown to the world, acts of terrorism are unpredictable and can be devastating. We should not underestimate the abilities of terrorists groups. However, we must also not allow ourselves to be stunted by our fear. Threats must be assessed objectively and changes made according to the needs.

Although nuclear weapons are a desirable possession for terrorist groups due to its destructiveness and therefore, threat value, systemic and scientific hurdles stand squarely in the way of terrorists going nuclear. Weapon-grade materials (Pu with <7% Pu-240 or U at 90+% U-235) are the most desirable materials for making the smallest and most effective weapon. However, due to international nonproliferation concerns, weapon-grade materials are under the strictest government and physical military safeguards in all countries. Theft of the amount needed to make a crude nuclear weapon (it is discounted that terrorists groups can build the smaller, more sophisticated weapons which use less material because of the level of technical skill is hard to achieve even at a state level) is unlikely without causing international awareness.

Materials that might be easier to obtain because of their accessibility in commercial facilities and less stringent physical and systematic safeguards such as MOX fuel or reactor-grade Pu create other problems for terrorists which are also not easily overcome. Due to the high level of impurities, crude nuclear weapons made with such materials require much higher amounts than the internationally accepted standard amount just to reach critical mass. And while these materials are under less stringent safeguards, the sheer amount necessary to build such a weapon makes it unlikely that even the least stringent nation would not notice. The use of such impure materials also require a higher level of sophistication in bomb design than one built with weapon-grade material. Regardless of the terrorists' sophistication, little is known about nuclear weapons made with MOX fuel or reactor-grade Pu and without prior thorough testing, the likelihood of an unsuccessful detonation is extremely high. However, any thorough testing or preparation that takes more than a couple of days threatens the

clandestine nature of its operations.

Despite these hurdles which the terrorist would have to face if it chose to go nuclear, it is not to say that terrorist groups would not try and possibly succeed. One of the biggest threats to fissile material safety is Russia. Since the end of the Cold War, Russia has seen a steady decline in its ability to safeguard and keep track of its fissile materials. The enormous military complex that once made it a superpower is now threatened under the grave economic situation in the country. Faced with unstable paychecks and a meager salary, workers are tempted by the fissile material black market that caters to terrorists groups. Although US and international efforts have been put in place to help Russia deal with some of these problems, the funding is not enough and the quality of Russian safeguards are highly questionable. This makes Russia the point of most concern when talking about theft of fissile materials.