Preventing Nuclear Terrorism: Reducing the Danger of Highly Enriched Uranium*

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Abstract. It would be relatively easy for a terrorist group as well-organized as the September 11 attackers to make a gun-type weapon out of highly-enriched uranium (HEU). The highest hurdle for any terrorist group seeking to build such a nuclear weapon is obtaining HEU. The production of HEU most likely is beyond the technical capabilities of terrorists, but there is a clear and present danger that insecure HEU anywhere could be stolen and smuggled to terrorists with a global reach. Strengthening HEU control to prevent terrorists from gaining access to such material is therefore one of the most effective ways to prevent nuclear terrorism. In this paper, I will explore and recommend a range of approaches to reduce the danger of HEU, including increasing the security of existing HEU stocks, reducing HEU stocks, ending HEU production for military purpose, and ending the use of HEU for research and naval reactors.

1. The Risk of Use of HEU by Terrorist

The September 11 attacks show, for the al Qaeda organization, that the psychological thresholds of taking as many causalities as possible have already been crossed, demonstrating a willingness to perpetrate super-terrorism.[1] Given the horrifying consequences of a nuclear explosion, the acquisition of the capability to explode a nuclear device would be very appealing for terrorists who are bent on causing mass destruction. Indeed, Osama bin Laden has stated that acquiring nuclear weapons is a "religious duty". There is evidence that al Qaeda has been actively seeking nuclear weapons.

Although it could be very difficult for terrorists to acquire a nuclear weapon intact through smuggling or thefts from the arsenals of the nuclear powers because those weapons are generally under strict control, it would be easier for a terrorist group to obtain fissile materials--plutonium or HEU-- and to make a nuclear explosive device. While there are arguments about the ability of terrorists to use plutonium to make an implosion design with a high probability of success, there is little disagreement that a terrorist group would be able to design and produce a HEU-based gun-type weapon and that it could be expected to work without prior testing.[2] This is because the metallic uranium has a very low spontaneous neutron production level, which allows HEU to be used in the most basic and simple gun-type assembly. In contrast, because of Pu-240 contamination, plutonium has a very high spontaneous neutron production rate, making a gun-type design much less effective with plutonium because the fission chain reaction will start prematurely. Instead, plutonium must be used in the more complicated implosion-type assembly. Moreover, unlike plutonium, HEU poses no significant health hazards in the process of building such a device because of its low level of radioactivity.

Tens of thousands of people worldwide have critical knowledge necessary for the manufacture of nuclear weapons. In particular, with the break-up of the Soviet Union, proliferation risks of know-how become serious. Even without accessing a knowledgeable nuclear weapon expert from a major state, a group of

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terrorists could make a crude HEU-based gun-type assembly by gathering the available information of basic nuclear-weapons design in the open literature and even on the Internet. As Luis W. Alvarez, a prominent nuclear weapon scientist in the Manhattan Project, has emphasized, "With modern weapons-grade uranium, the background neutron rate is so low that terrorists, if they have such materials, would have a good chance of setting of 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."[3] Scientists believe that it would be relatively easy for terrorists to make a nuclear explosive out of HEU comparable to the Hiroshima bomb (approximately 15 kilotons) and the number of fatalities could be over hundred of thousands. Even a 1-kiloton "fizzle" from a badly executed terrorist bomb could cause massive casualties, and have a disastrous social, economic, and psychological impact.

The biggest obstacle to manufacturing a gun-type weapon is the acquisition of the necessary amount of HEU. The amount of HEU needed to make a bomb will depend on the degree of enrichment and the design of the explosive device itself. IAEA specifies 25kg HEU as a "significant quantity". It is possible to assemble a supercritical mass of 50-100kg of WgU with a simple "gun-type" design .The Hiroshima bomb contained about 50 kilograms of highly purified U-235. The production of HEU is most likely beyond the technical capabilities of terrorists, but there is a clear and present danger that insecure HEU anywhere could be stolen and smuggled to terrorists. Smuggling such an amount of weapons grade uranium into the target city would likely be no more difficult than smuggling a similar amount of cocaine or heroin.[4]

One major concern is the possibility of a theft of WgU from the huge stockpiles of weapon-grade uranium that have already been produced. Estimates of past HEU production range from 1400 to 2100 tons (see table 1)[5] – enough for 30-40,000 terrorist nuclear weapons. Moreover, some 20 tons of civilian HEU– enough for over a thousand nuclear weapons – exist at over 130 operational and numbers of shutdown civilian research facilities in more than 40 countries. The danger of theft of nuclear material continues to be a concern. There have been a number of cases of real theft of kilogram quantities of weapons-usable nuclear material. Based on the IAEA database, from May 1993 to July 2001, 18 incidents involving seizure of stolen weapon-usable material including 9 incidents for HEU have been confirmed.[6] For example, in March 1994, police seized 2.97kg HEU (90%, in the form of defective UO2 powder) near St. Petersburg that had been stolen by an employee at a nuclear fuel fabrication plant in Elektrostal, near Moscow. In December 1994, in Prague, Czech Republic, police seized nearly 2.73kg HEU (88%) and arrested suspects who had been trying to find buyers for the material.

Table1: Estimated World HEU Stocks (metric tons, 90% U235 equivalent)

Military (1994)	
Russia	735-1365
USA	580-710
France	20-30
China	15-25
UK	6-10
Pakistan (end 1999)	0.6-0.8
S. Africa	0.4 (stocks converted to civil use)
Subtotal	**1360-2140**
Civilian HEU (research-reactor fuel)	**~20**

2. Securing HEU Stocks

Securing HEU stocks worldwide should be the most urgent task to prevent theft and smuggling of such materials. Today the security problem of fissile material is more urgent in the former Soviet Union. A number of factors-- including workers' low pay, widespread theft and corruption, and inadequate resources for building, maintaining, and operating effective nuclear security and accounting systems--are undermining nuclear security in the former Soviet Union. Since 1994, the U.S. has been helping the former Soviet Union to upgrade fissile materials protection, control and accounting (MPC&A). The U.S. DOE spends $223.5 million on this effort during FY 2003. By 2003, U.S. had budgeted about $1.4 billion to upgrade MPC&A systems in the former Soviet Union.[7] However, by the end of fiscal year (FY) 2002, after eight years of effort, only about 37% of the estimated 600 metric tons of fissile material that Russia has outside of its nuclear weapons had even "rapid upgrades" of its security and only 17% had comprehensive upgrades installed. [8]After September 11, President Bush and President Putin pledged to give "urgent attention" to security for nuclear materials at their summit in November 2001. The actual rate, however, at which security and accounting upgrades are being implemented remains very slow. During the fiscal year after the September 11 attacks, rapid upgrades were completed for only an additional 9% of Russia's potentially vulnerable nuclear material, and comprehensive upgrades for 2%. As some experts have proposed, the U.S. should take immediate steps in a partnership with Russia to accelerate and strengthen nuclear security and accounting upgrades in Russia.[9]

The problem of insecure nuclear material is not only limited to the former Soviet Union. There are lots of facilities containing HEU (for military or civilian) located in tens of countries, with security arrangements varying widely and no binding global security standards in place. Even in the U.S., which has among the toughest physical protection regulations in the world, recently US Army and Navy commando teams have demonstrated that they were still able to penetrate the security systems at a number of U.S. nuclear facilities and seize and carry off significant quantities of weapon-usable nuclear materials.[10] Many are concerned that the security systems for nuclear material in many countries would not be able to defeat such a threat as a well-planned insider theft or an attack by a significant number of well-armed and well-trained outsiders. However, after September 11, the slow pace for improving security and accounting systems worldwide is no match to the threat. To secure and account for all the world's HEU, much more must be done. Every country with HEU facilities should review and upgrade its basis used for designing physical protection for these HEU facilities to ensure that it reflect the threat as perceived after September11. Another important tool for reducing the risk of nuclear theft is to establish a "global cleanout" program to remove the nuclear material from the world's most vulnerable nuclear sites as rapidly as possible. In this regard, "Project Vinca" provides a good example, in which 48kg of 80%HEU were removed from Belgrade from a vulnerable site in Yugoslavia to safer storage in Russia on Aug. 22, 2002.[11]

The international community should further enhance the international cooperative effort to upgrade security and accounting for all the world's nuclear material as rapidly as practicable. While the U.S. is currently focusing on upgrading Russian's nuclear security systems, it should also consider a cooperative effort to improving China's MPC&A system as well. The US and China conducted a Lab-to-Lab Collaborative Program from 1995 to 1998, which was designed to help create a "safeguards culture" in China by demonstrating the advantages of a modern MPC&A system. However, the program ceased in the aftermath of the 1999 Cox Committee Report and allegations of Chinese espionage at U.S. nuclear weapons laboratories. Since September 11, the cooperation between the US and China on fighting against terrorism should provide an opportunity to restart the Lab-to-Lab program on MPC&A. [12]

3. Ending Production of HEU

At the end of the Cold War, the United States, Russia, Britain, France, and China stopped HEU production. Currently, only Pakistan is believed to be producing HEU, and North Korea has recently admitted to having an HEU program. Pakistan is estimated to be producing at a rate of 0.1-0.2 tons/yr. As of the end of 1999, it is estimated that Pakistan possessed 580 - 800 kilograms of weapon-grade HEU.[13] While Pakistan is believed to maintain tight control over its nuclear assets, considerable international concern has been expressed about the security of nuclear material and facilities in Pakistan.

Ending production of HEU would reduce the threat of nuclear theft. A universal fissile material cutoff treaty (FMCT) has long been seen as a key building block in nuclear disarmament and nonproliferation. However, negotiations on the FMCT have been at an impasse since 1993. The 2000 NPT review conference called for FMCT negotiations to start immediately and to be completed in five years. China's participation in an FMCT will be critical to its success, however. China is believed to have stopped the production of HEU and plutonium for weapons, and China has consistently supported the FMCT negotiations. However, recently China has grown concerned about U.S. missile defense, which would definitely neutralize China's strategic nuclear deterrence, and possibly allow the U.S. to intervene in Chinese affairs, such as undermining efforts at reunification with Taiwan. To retain its nuclear deterrent capability, China's direct response to the U.S. missile defense could be to build up more warheads, which would then use up its existing fissile martial stockpile. China might then well keep an option to restart production of fissile materials. Consequently, because of its concerns about U.S. missile defense, which would lead to weaponization of outer space and stimulate a costly and destabilizing arms race, recently China clearly expressed that the Prevention of an Arms Race in Outer Space (PAROS) is a realistic and urgent issue. China firmly holds that the CD should start concurrently negotiating both FMCT and PAROS. However, the U.S. opposes any negotiations on the outer space issue while pressing for the immediate negotiation of an FMCT. This disagreement between China and the US over FMCT and PAROS negotiations has already prevented the CD from continuing any arms control negotiations.

Given the urgent threat of nuclear terrorism and the relatively remote threat of ICBM attacks on the U.S. from other countries, the major nuclear powers should take some measures to break the current standstill of FMCT negotiation.[14] For instance, the U.S. should allow the CD to start to negotiate a treaty on the prevention of an arms race in outer space, which would prohibit the testing, deployment and use of any weapon systems and their components in outer space. The U.S. and Russia should reduce their huge nuclear arsenals in a verifiable and irreversible manner through legally-binding instruments.

4. Disposing of Excess HEU Stocks

Another important measure to reduce the risk of theft of HEU is to accelerate the disposal of excess stocks of HEU. In 1994, the U.S. contracted with Russia to buy 500 tons of WgU from excess Soviet nuclear warheads after Russia had blended it down to the LEU used to fuel power reactors. As of the end of 2002, 171 tons of HEU had been blended and delivered to the United States.[15] However, at the current rate of blend-down of 30 tons of WgU/yr, set mainly by commercial considerations (in order not to disrupt the world market for LEU) instead of security concerns, this HEU Purchase Agreement will not be fulfilled until 2013. This long timeline does not match the much greater urgency in preventing the risk of nuclear terrorism. Moreover, beyond this 500-ton HEU deal, Russian still retains about 500 ton WgU in its stockpile sufficient for 20,000 nuclear weapons. In addition to 50 tons WgU for its planned strategic arsenal (about 2,000 deployed strategic warheads as President Putin recently pledged to), even if Russia plans to retain an additional 100 ton HEU stockpile for several thousand tactical nuclear warheads and an HEU reserve of tens of tons as fuel for military and research reactors, it would still leave at least 350 tons of excess WgU remaining outside of the existing deal.[16] Thus, it is necessary and urgent to expand the existing HEU agreement. At their May 2002

summit, President Bush and President Putin agreed to establish a working group on "expanded disposition" of HEU and plutonium.[17] As some analysts proposed, the blend-down rate should be accelerated by paying Russia to blend down additional Russian WgU to just below 20% U-235 and store it for later sale when the market is ready.[18]

In 1995, the U.S. declared 174 tons of HEU excess (about 100 tons 90% U235 equivalent). LEU from 153 tons of the HEU is slated to be used as commercial reactor fuel, while LEU from 21 tons of the HEU will be disposed of as waste. By late 2002, about 30 tons of U.S. HEU had been downblended to LEU.[19] However, the U.S. should declare more excess HEU. As an example, the roughly 7,600 nuclear weapons operational today in U.S. could contain about 150 tons of HEU. It is estimated that the U.S. has a stockpile of about 650 tons of WgU. Thus about 500 tons of HEU would be potentially surplus. The additional planned reduction of the strategic arsenal will further increase the stock of excess HEU. Most of U.S. WgU that is excess for weapons needs, however, is being kept in storage for future use in naval-reactor fuel. This stockpile is large enough to support its naval-reactors for "many decades," and sufficient to make on the order of ten thousand warheads as well. Such a huge stock of HEU in the U.S. would eventually discourage Russia to reduce its HEU stockpile to a lower level than it might otherwise.

Real disarmament is impossible to achieve without destroying the accumulated huge stocks of WgU. The stockpiles of HEU still reserved for military use could be returned to weapons at will. To ensure the irreversibility of nuclear disarmament, prevent nuclear proliferation, and reduce the risk of theft, the U.S. and Russia should declare a significant fraction of their HEU stockpiles excess and make more significant commitments to irreversible reduction of their fissile material stockpiles including fissile material from warheads withdrawn under deep cut agreements. Finally, even with the conclusion of their current reduction agreement to reduce the deployed strategic nuclear arsenal to around 2,000 warheads over the next 10 years, the U.S. and Russia would still keep a huge total inventory of nuclear weapons. Thus, the U.S. and Russia should take the lead and commit to further substantial reductions of their respective nuclear arsenals. The reduced nuclear warheads and explosives should be dismantled and disposed in a verifiable way, and not be used again as weapons in any form.

5. Converting HEU-fueled Reactor to LEU

Conversion of research reactors. Approximately 20 tons of HEU (enough for a thousand nuclear weapons) are in civilian stockpiles worldwide, primarily as fuel for civilian research reactors.[20] Currently, there are over 130 civilian research reactors operating with HEU in more than 40 countries,[21] which require about 1 MT of WgU per year. Among which there are about 50 HEU-fueled research reactors with a power level of at least 1MW. In most cases the HEU is WgU. There are also a large number of officially shut-down, but not decommissioned research reactors.

Many research reactors could be the targets for theft of HEU contained in the fresh fuel. Unlike military weapons establishments, many research reactors are typically located at universities and other civilian locations with much lower security. The spent HEU fuel also poses a proliferation and terrorism threat. When WgU fuel is "spent", e.g. 50% burnup, it is still about 70% enriched and the critical masses of such HEU would be about 20 kg.[22] Also, many research reactor fuels have been cooling for many years and are therefore not sufficiently radioactive to be self-protecting against theft. These fuel elements are relatively easy to handle and transport. Indeed, Iraq tried to make a bomb with HEU from spent research reactor fuel in 1991. Moreover, there is a risk associated with the HEU at large number of civilian sites including on-site storage of fresh and irradiated HEU, fuel fabrication, and transport.

Due to concern about the potential use of civilian HEU to make nuclear explosives, in 1978 the U.S. DOE launched a Reduced Enrichment Research and Training Reactor (RERTR) program. One main objective of

such program is converting reactors. As of the end of 2001, 20 foreign and 11 U.S. reactors had been converted and 7 foreign reactors were in the process of conversion.[23] As a consequence, the civilian commerce and use of HEU has dropped significantly. In addition, LEU fuels were planned for a number of new research reactors worldwide, including the new China Advanced Research Reactor (60 MW) in China.[24] However, the FRM-II reactor in Germany and the PIK reactor in Russia were still being designed with HEU fuel which could damage the effort of RERTR program. Most of the remaining HEU-fueled facilities are located in Russia and the United States. Progress in fuel development has been one essential key to the success of the RERTR program. When the RERTR program began, uranium densities in research-reactor fuels were 1-2g/cc. Advance fuel available today is 4.8g/cc. There is only a very limited number of HEU-fueled reactors today that cannot use currently qualified LEU fuel without performance loss. The program has put fuels under development with a density of 8-9 g/cc and has established that uranium alloyed with 6% molybdenum with a density of 16 g/cc has excellent properties under irradiation. This fuel would enable LEU operation of all existing and future research reactors in combination with unprecedented performance. Meanwhile, Russia restarted its RERTR program in cooperation with the U.S. RERTR program in 1993 .The progress achieved within the Russian RERTR program, both for the traditional tube-type elements and for the new "universal" LEU U-Mo pin-type elements, promises to enable soon the conversion of most Russian-designed research and test reactors. However, the insufficient funding of the program has impeded the program's full and timely implementation.[25] The international community, and especially the U.S. and Russia, should take measures to speed the effort for conversion of research reactors.

Moreover, given the risk of spent WgU fuel, a spent-HEU-fuel take-back policy without impeding the effort for converting reactors should be a high priority. In 1996, the U.S. DOE initiated U.S. Foreign Research Reactor Spent Nuclear Fuel Acceptance Program, which allows, until May 2009, the return of spent research reactor fuel elements of U.S. origin irradiated before May 13, 2006. The Congress linked take back to the conversion of reactors to LEU by promulgating a policy that banned U.S. export of HEU fuel unless the reactor operator commits to convert to LEU fuel as soon as it is available and the U.S. is working on the development of such fuel. In an effort to remove potential bomb material from the most vulnerable sites around the world, Russian future policy on take-back of Soviet-supplied HEU could be crucial. If Russia simply takes back those materials without any reactor conversion commitment, the effort for converting reactors would be undermined seriously. The U.S. and Russia are currently negotiating U.S. financial support for a similar Russian spent-fuel take-back program. U.S. funding would be conditioned on the reactor operator's commitment to convert to LEU fuel. [26]

Conversion of naval reactors. Currently, there are about 170 nuclear-powered vessels at sea, including about 150 submarines.[27] All these nuclear-powered vessels are in the five nuclear weapon states, mostly in the U.S. and Russia (~135). The total annual demand of HEU for naval reactors has currently dropped to about 3.5 tons after the end of the Cold War, but it is more material than currently required by research reactors (about 1 MT/yr). Currently, the U.S. and U.K. use WgU (93–97%) to fuel their nuclear-powered subs and surface ships, Russia uses HEU (21–45%) for its subs and up to 90% for its icebreakers. France uses both LEU and WGU for its existing subs, but future designs will use LEU (12%). Chinese naval reactors reportedly use LEU fuel enriched to five percent.

There have been some thefts of Russian HEU naval fuel. While such danger has been reduced recently by the U.S.-Russian cooperative MPC&A program, conversion of the world's nuclear navies to LEU is important to nuclear nonproliferation, nuclear disarmament, and to reduce the opportunities for terrorists to acquire HEU. First, ending the production and use of HEU for naval will fix the loophole of existing NPT safeguards. Paragraph 14 of INFCIRC/153, the NPT model safeguards agreement, allows states to withdraw nuclear material from international safeguards for non-explosive military purposes, including HEU for use in military reactor fuel. It would be very difficult to verify that the HEU for naval were not being diverted to make nuclear weapons. Although only five nuclear weapon state currently have nuclear-powered vessels,

over the years several non-nuclear weapon states (including Canada and Brazil) have indicated an interest in also acquiring nuclear submarines. The potential proliferation impact of nuclear submarines has been an issue of great concern for decades and various approaches to deal with it have been proposed.[28] Second, allowing production and use of HEU for non-explosive military purposes would leave another loophole for FMCT treaty. As currently envisioned, the FMCT would permit the continued production of HEU for use in naval reactors. Thus, countries could produce or acquire HEU and remove it from international safeguards under pretext that it was to be used in naval reactor fuel. However, they could then use that material to make nuclear weapon. It would be impossible to verify in a timely manner that none of this HEU was going to weapons use. Finally, as long as HEU is used as a naval reactor fuel, large stocks of the material will be reserved for such a use, as the U.S. does now. Such large stockpiles of fissile materials could create a potential for "breakout" from arms reduction obligations.

It is necessary to take an effort for converting naval reactors or designing future reactors with LEU. At least China's and some of France's nuclear submarines already use LEU. During the transition to LEU fuel, the U.S., Russia and British naval reactors designed to use HEU could be fueled from excess nuclear weapons. The U.S. should provide leadership by seriously investigating the potential for using new LEU fuels for naval reactors. In fact, in 1994, the U.S.Congress asked the Navy for a study of the feasibility of fueling U.S. naval reactors with LEU. However, the Director of the Office of Naval Propulsion responded that "the use of LEU for cores in the U.S. nuclear powered warships offers no technical advantage to the Navy."[29] Some independent discussions and analysis, however, demonstrated the potential of such a conversion.[30] Another focus should be on converting Russian ice-breaker reactors to LEU. Russia currently operates seven nuclear-powered icebreakers and cargo ships. These vessels are powered by KLT-40 reactors. This reactor type uses 90% HEU, requires refueling every 3–5 years, and has a thermal power of 135 MWt. Preliminary calculations indicate that the Russian ice-breaker KLT-40 reactors can be fueled with LEU without decreasing the lifetime of the core.[31]

6. Summary

It would be relatively easy for a terrorist group to make a gun-type weapon out of highly-enriched uranium. The highest hurdle for any terrorist group seeking to build such a nuclear weapon is obtaining HEU. However, there are large amounts of HEU in many locations worldwide, which poses a high risk of theft. To prevent nuclear terrorism, and to strengthen efforts on nuclear nonproliferation and disarmament, it is urgent that the world to moves as rapidly as possible to increase the security of HEU stocks, to end production of HEU, to dispose of excess stocks of HEU, and to eliminate the use of HEU in both civilian and military reactors.

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