Disposition of Excess Highly Enriched Uranium

IPFM
INTERNATIONAL PANEL
ON FISSILE MATERIALS

Global Fissile Material Report 2007

Second report of the International Panel on Fissile Materials

Developing the technical basis for policy initiatives to secure and irreversibly reduce stocks of nuclear weapons and fissile materials

Cleaning up After the Cold War

2 Disposition of Excess Highly Enriched Uranium

Russia and the United States have declared excess significant portions of the huge stockpiles of highly enriched uranium (HEU) they produced for weapons during the Cold War and have initiated programs to dispose of these materials. They also are co-operating to reduce civilian use of HEU in other countries and retrieve the HEU that they exported as part of their Atoms for Peace programs.

Russia has declared 500 metric tons of HEU excess to its military needs. The United States originally declared 174.3 tons of HEU excess to military requirements and, in 2005, an additional 200 tons excess to *weapon* requirements (most of the latter material will be used as naval reactor fuel). Much more HEU will have to be declared excess, however, if the stockpiles in each country are to be reduced irreversibly below 10,000 warheads (see Chapter 1).

Most of the HEU declared excess for all military requirements will be converted to low-enriched uranium (LEU) containing 4-5 percent U-235. This is relatively easily done by dilution with depleted, natural or slightly enriched uranium. LEU cannot sustain an explosive nuclear chain reaction but is used to fuel most of the world's nuclear-power reactors and is therefore of commercial value.

This chapter describes the progress of the Russian and U.S. HEU disposition programs and how they could be expanded and accelerated. It also provides a brief update on the progress of the international programs to clean out and dispose of civilian HEU. The quantities of HEU involved are much smaller than those in the weapons programs but civilian sites are typically much less secure than military ones. Cleaning them out may therefore contribute more to reducing the overall danger of nuclear theft.

HEU to LEU

HEU contains 20 percent or more of the chain-reacting isotope U-235. Natural uranium contains only 0.7 percent. (The process of HEU production is described in the Appendix to this volume.)

In Russia, virtually all excess HEU comes from weapons and contains 90-percent U-235. The process of elimination in Russia therefore begins with the conversion of HEU weapon components into metal shavings and then the metal to oxide. The oxide is put through a solvent extraction process to remove chemical impurities and then converted to UF_6 gas, which is blended with a stream of UF_6 gas enriched to 1.5-percent U-235. The 1.5-percent enriched blend-stock is made by stripping more U-235 out of already

depleted "tails" from past enrichment operations.[66] About 30 tons of this blend-stock are required to dilute one ton of HEU (see Figure 2.1).

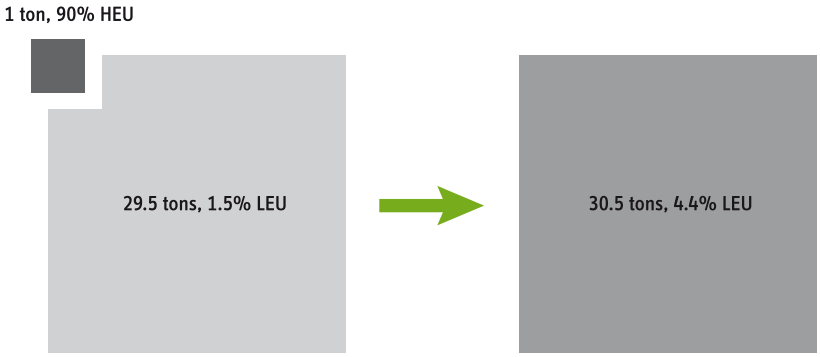

Figure 2.1. Schematic showing amount of 1.5-percent enriched blend-stock required to blend down one ton of excess 90-percent enriched Russian weapon uranium LEU for use as power-reactor fuel. Thirty tons of this LEU is sufficient to fuel a typical one-gigawatt reactor for 1.5 years.

In the United States, the excess HEU being blended down to LEU is from production scrap and reactor fuel as well as from weapons and comes in a variety of forms and enrichments. There is therefore no single U.S. blend-down process. A significant fraction of U.S. HEU is being blended down by mixing acid solutions of HEU and blend-stock together to produce LEU.

Disposition of Excess Russian HEU

Currently, Russia is carrying out two HEU disposition programs in cooperation with the United States:

- The HEU Purchase Agreement, aimed at converting excess Russian weapon HEU to LEU for export to the United States; and
- A much smaller U.S.-financed Material Consolidation and Conversion (MCC) Program, designed to remove excess HEU that is primarily civilian from Russian research institutes and blend it to LEU, to be left in Russia.

In addition to these two programs, Russia's Federal Atomic Energy Agency (Rosatom) is also using enriched uranium, which may be HEU, for blending with Western European reprocessed uranium to be recycled in light water reactor (LWR) fuel.[67] Each of these efforts is described below.

The HEU Purchase Agreement. In 1993, the United States and Russia reached an agreement under which Russia committed to blend down to an enrichment of 4 to 5 % over a 20-year period 500 tons of 90 percent enriched uranium recovered from dismantled warheads. The United States committed to buy the blended-down uranium for use in LWR fuel.[68] Approximately 30 tons of HEU are being blended each year and the 500-ton agreement is to be completed in 2013. As of the end of 2006, Russia had delivered to the United States LEU blended down from about 292 tons of HEU—the equivalent of almost 12,000 warheads. Figure 2.2 shows the progress of the Russian and also the U.S. blend-down program.

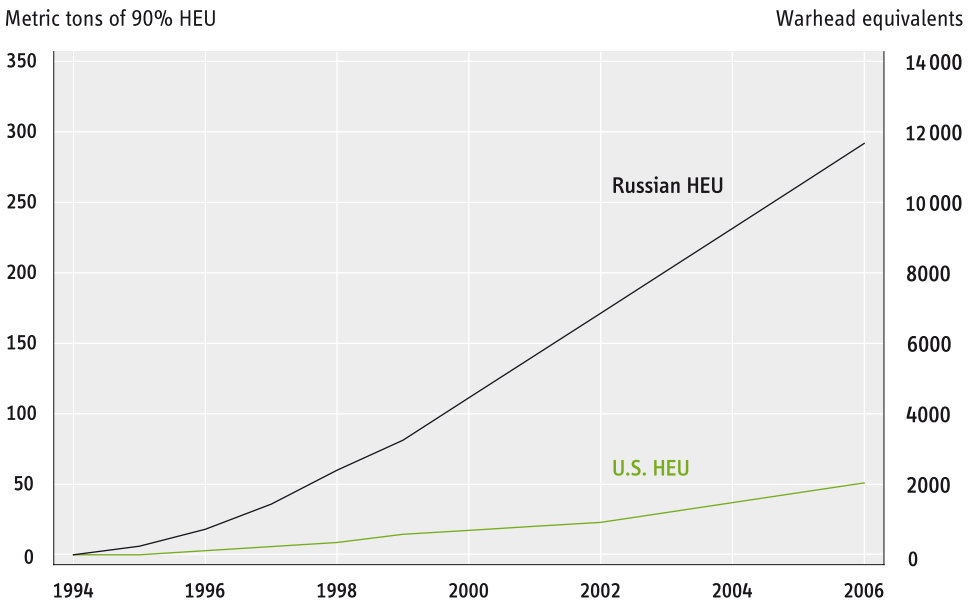

Figure 2.2. Cumulative amounts of excess HEU blended down by Russia for sale to the United States and by the United States. The Russian HEU is 90-percent enriched. The U.S. HEU is of various enrichments but represented here by tons of 90-percent HEU containing the same amount of U-235. Shown on the right-hand side are the number of warheads that could be made from this material, assuming 25 kg of HEU per warhead. The U.S. quantities are relatively small, in part because almost all U.S. excess weapon-grade uranium is being set aside for future use as naval-reactor fuel.[69]

As part of their agreement, the United States and Russia established transparency measures to be used by the United States at the Russian HEU blend-down facilities and by Russia at U.S. facilities receiving the Russian LEU for further processing. The sites involved and the material flows between them are shown in Figure 2.3.[70] U.S. inspectors make several visits each year to the facilities where the HEU metal shavings are converted to oxide. There, they can observe the whole oxidation procedure from the beginning and use gamma-ray spectrometry to confirm that the uranium is weapon-grade. The inspectors then attach tags and seals to the containers of oxide before it is shipped to the blend-down facilities.

When the containers of oxide arrive at the blend-down sites, the U.S. inspectors check the tags and seals. They can also request nondestructive analysis of the chemical composition and enrichment of containers of HEU oxide, observe the feeding of oxide into a process that chemically converts the HEU to a hexafluoride form, and perform an assay of the HEU hexafluoride withdrawn from the conversion process. The United States also has equipment continuously monitoring the enrichments and flows of UF_6 gas at the blending point. There, the 90-percent enriched HEU in one pipe and the 1.5 percent enriched blend-stock in another mix to form the LEU that flows out through a third pipe.

Russian inspectors similarly have the right to regularly visit the U.S. fuel fabrication facilities where the LEU is fabricated into reactor fuel.

In aggregate, these measures give the U.S. Government confidence that the LEU arriving in the United States was in fact derived from weapon-grade metal and Russia confidence that the LEU is used for fuel.

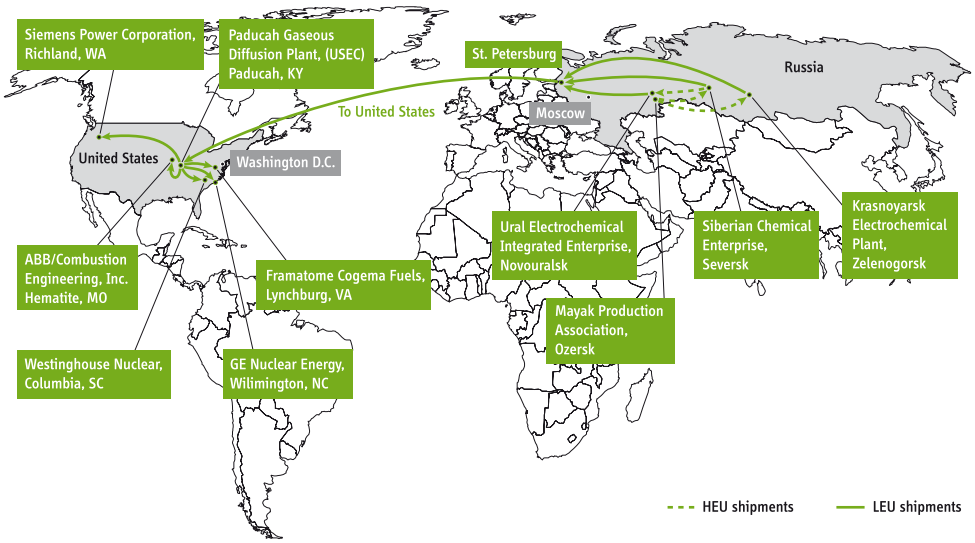

Figure 2.3. Geography of the U.S.-Russian HEU deal. Russian HEU metal from excess weapons is chopped up and oxidized at the Ozersk and Seversk facilities. It is then converted into UF_6 and blended down to LEU at Novouralsk, Seversk and Zelenogorsk. It is shipped to USEC's Paducah, Kentucky site for final adjustment of enrichment before being shipped to one of five U.S. fuel-fabrication plants. (Adapted from Status of Transparency Measures for U.S. Purchase of Russian Highly Enriched Uranium, U.S. General Accounting Office Report GAO/RCED-99-194, 1999, p. 9.)

Russia has been annually supplying the United States through the HEU deal with the equivalent of about 5.5 million SWUs of enrichment work—about 44 percent of U.S. nuclear-utility requirements.[71] The United States is currently negotiating with Russia over what access to the U.S. market Russia will have after the HEU deal ends in 2013. Rosatom hopes to have 20-25% of the U.S. enrichment market in the post-2013 period. The United States has not yet agreed, but is likely to need at least that much enrichment work from Russia.

No definite decisions have yet been announced regarding what will happen to Russia's large remaining quantities of excess weapon HEU when the 500-ton HEU Purchase Agreement is completed in 2013. Sergei Kirienko, the head of Russia's Federal Atomic Agency (Rosatom), has repeatedly made clear, however, that Russia will not continue to dispose of its HEU through USEC after 2013. The way in which the HEU Purchase Agreement is currently implemented by USEC makes it less profitable for Russia than simply selling the blended-down LEU directly on the open market.

There are many alternatives to continuing the HEU deal in its current form. For example, if Russia could get trade barriers removed, it could sell blended down excess HEU on the open market.[72] Alternatively, Rosatom may wish to use blended down HEU to fuel some of the reactors it plans to build in Russia and abroad. This LEU would not need to meet Western commercial specifications and could be produced simply by blending the HEU with natural or depleted uranium. Russia is believed to be spending as much enrichment work stripping tails to produce the blend-stock used in the Russia-U.S. deal as would have been required to produce the LEU from natural uranium.[73]

Not needing to enrich blend-stock would free more Russian enrichment capacity for foreign business. It also would make it much easier for Russia to blend excess HEU at a

rate greater than 30 tons per year. Studies by Russian experts sponsored by the Nuclear Threat Initiative (NTI) indicate that the largest constraint on Russia's blend-down rate is its capacity to make the 1.5-percent enriched blend-stock.[74]

With the end of the HEU Puchase Agreement only six years away, accelerating the HEU blend-down rate would only make sense, however, if Russia increased the amount to be blended down beyond the 500 tons already committed. The United States could encourage Russia to do so by offering to let it compete for a larger share of the U.S. enrichment market if it does so.[75] The United States also could offer to ship some of its depleted uranium to Russia on condition that some agreed amount of HEU would be blended down. Although considered waste until recently, at current high uranium prices, U.S. depleted uranium could profitably be enriched by Russia's centrifuge plants. For example, if the relatively rich U.S. depleted uranium were used to produce 1.5-percent enriched blend-stock for the HEU Purchase Agreement, it would save Russia a great deal of enrichment work.[76]

Acceleration of Russia's blend-down rate could raise concerns about the potential disruption of the world enrichment market. If this became a problem—which appears unlikely, given the currently tight market—it could be mitigated if Russia stored some material it blended down until the market was ready to absorb it. The United States could encourage this by paying Russia, as a security investment, for the cost of blending to 19-percent LEU, with Russia gaining the full commercial value when the 19-percent stockpile was eventually blended down to 4-5 percent LEU and sold for power reactor fuel.

Material Consolidation and Conversion (MCC) Program. The second Russian-U.S. cooperative HEU blend-down effort is focused on excess civilian HEU in Russia's nuclear research institutes and the facilities that fabricate Russia's research-reactor fuel. Many of these facilities have large quantities of HEU (see, for example, Figure 2.4). Under this program, the Research Institute of Atomic Reactors in Dmitrovgrad (RIAR) and the Scientific Production Association Luch in Podolsk are funded by the U.S. DOE to buy excess civilian HEU and blend it down to LEU. The MCC Program is interested primarily in material enriched to more than 80-percent and containing more than 50-percent uranium by weight.

MCC Program plans call for blending 17 tons of Russian civilian HEU to LEU by the end of 2015. As of the end of fiscal year 2006, some 8.4 tons of HEU had been blended down.[77] The down-blended material is shipped to the Machine Building Plant (Russian acronym MSZ) in Elektrostal for fabrication into reactor fuel.

Blending-up west European reprocessed uranium. Nuclear utilities in Germany, Sweden, Switzerland, and the Netherlands have been sending reprocessed uranium to Russia to be mixed with Russian enriched uranium to produce LEU. This is part of an agreement in which the fuel-fabrication company, MSZ of Elektrostal, uses hardware supplied by the French company AREVA, to produce fuel containing an equivalent amount of LEU for the European utilities.[78] MSZ has already produced more than 1000 fuel assemblies containing about 500 tons of low-enriched uranium.[79]

Figure 2.4. The BFS-2 Critical Assembly at the Institute of Physics and Power Engineering (IPPE), Obninsk, Russia, has huge inventories of HEU and plutonium. These include about 700 kg of weapon-grade uranium fuel in thousands of disks that are stacked up in columns mixed with similar disks of 36-percent enriched HEU, depleted uranium and plutonium to simulate large fast-reactor cores. Since the maximum enrichment in a fast reactor core is less than 36-percent, the weapon-grade uranium is not required and could be declared excess and blended down by the MCC Program.[80]

Some sources indicate that the reprocessed uranium is being blended with HEU, originally destined for submarine and icebreaker fuel, or even ex-weapon HEU.[81] If the blending were done with 90-percent enriched HEU, roughly 35 kilograms of HEU would be required to produce each ton of LEU. For 500 tons, some 17.5 tons of HEU could have been consumed. But a responsible Russian official reports that the material comes from reprocessed naval and icebreaker spent fuel with an enrichment of 16-17%.[82] In that case, this program would not, strictly speaking, count as additional blending of HEU, which is defined as containing at least 20 percent U-235.

Disposition of Excess U.S. HEU

The U.S. HEU disposition program is not as far advanced as Russia's. This is in part because the pace of dismantlement of U.S. nuclear weapons and weapon components has been so slow. According to DOE, some of the HEU declared excess will not be available for down-blending until 2050.[83] Most of the material being blended down is less than weapon-grade because the U.S. Navy has requisitioned virtually all excess weapon-grade uranium for use as naval fuel (see Chapter 1). The proposed disposition paths for the various batches of excess U.S. HEU are shown in Table 2.1.

The blend-down of two batches of HEU to LEU for USEC to sell for power-reactor fuel has been completed.[84] HEU also is being blended down to 19.75-percent enriched LEU for research reactor fuel. As of the end of 2006, some 2.6 metric tons of HEU had been down-blended for this purpose. These campaigns account for more than 70 percent of the U.S. HEU that had been blended down.

Because of contamination with artificial uranium isotopes, a substantial fraction of the remaining U.S. excess HEU cannot easily be processed into LEU that meets U.S. commercial specifications.[85] DOE therefore negotiated an agreement with the government-owned Tennessee Valley Authority (TVA) to use in its reactors off-specification LEU blended from some 40.3 tons of HEU. This HEU is in a wide range of forms: solutions, oxides, fabricated fuel, uranium fluorides, uranium-aluminum ingots, and metal disks. It is being dissolved and down-blended at the H-Canyon reprocessing facility at the Savannah River Site (SRS) in South Carolina and at Nuclear Fuel Services (NFS) in Erwin, Tennessee. As of late 2006, 23 tons of this "off-spec" HEU had been blended down.[86]

Destination	Quantity [tons U]	Average Enrichment	Disposition Period	Completed as of end 2006
Blend-down to LEU for USEC	14	75%	1995–1998	14
	47	43.7%	1998–2006	47
Blend-down to off-spec. LEU for TVA	40	60.7 %	2002–2016	23
Blend-down to LEU for research reactor fuel	10	33.4 %	2002-2016	2.6
Blend-down to LEU for reliable fuel supply	17	71.4 %	2007–2010	0
Blend-down to LEU, unallocated	23	Not available	2010–2020	0
	20	77%	2007–2030	0
	32	93%	2007–2050	0
	8	Not available	2010–2019	0
HEU fuel for research and space reactors	20	93%	n.a.	0
Disposition as waste or blend-down to be decided	23	Not available	TBD	0
Total	254			87

Table 2.1. Disposition plans and accomplishments for U.S. HEU declared excess to military needs.[87]

In total, as of mid-2007, 87 tons of U.S. excess HEU containing 45.8 tons of U-235 had been blended to LEU (see Table 2.1).[88]

In July 2007 DOE issued a contract for blending down 17.4 tons of excess HEU that the United States had pledged to use to establish a U.S.-controlled reserve of LEU for foreign countries that do not enrich their own LEU if their suppliers fail to deliver.[89] The plan is to complete blending down 9.3 tons by March 2009.[90]

For the remaining excess U.S. HEU, 75 tons is designated for down-blending to LEU for commercial use.[91] The pace of blending of this material is expected to be slow. For fiscal year 2010 and beyond, DOE only plans to blend about 3 tons of HEU per year.[92] At 25 kg average per warhead, this corresponds to the equivalent of about 120 warheads per year, which is close to the estimated rate of dismantlement of excess U.S. warheads in recent years. Given the planned increase in this dismantlement rate to perhaps 300 warheads per year (see Chapter 5), the blend-down rate also could increase.

The United States has invited the IAEA to monitor a portion of the U.S. HEU disposition effort. In a "verification experiment," the IAEA confirmed the down-blending of 3.5 tons of HEU at a USEC facility in Portsmouth, Ohio, and monitored blend-down of 46.6 tons of HEU at BWX Technologies. There does not appear to be any international monitoring in place at Nuclear Fuel Services or at the DOE's Savannah River or Y-12 sites, however, where the remainder of the U.S. HEU blend-down is being carried out. There is also no bilateral monitoring with Russia comparable to that associated with the HEU Purchase Agreement.

Disposition of Civilian HEU in other Countries

There are about 20 tons of civilian HEU in countries other than the United States and Russia, of which about half is in non-weapon states.[93] Much of it is excess to any current or likely future fuel needs. All but a few percent of this material was supplied by either the United States or Russia, and both the United States and Russia are now engaged in

active programs to take some of this material back or otherwise arrange appropriate disposition for it.[94] The U.S. program is managed by the DOE's Global Threat Reduction Initiative (GTRI).

As part of the Bush-Putin nuclear security initiative launched at the Bratislava summit in early 2005, Russia and the United States hope to remove or otherwise dispose of all of the estimated 2.2 tons of Russian-origin HEU outside of Russia. As of the end of 2006, some 0.5 tons of HEU, including 60 kilograms in irradiated fuel, had been returned to Russia under this program. Under current plans, all of the HEU currently outside of reactor cores is to be removed or blended down by the end of 2010. The remainder is to be removed by the end of 2015, after it has been discharged from reactors and cooled enough for transport.[95] Once in Russia, the fresh HEU is blended down to LEU at the Luch and Dmitrovgrad facilities. The irradiated fuel is reprocessed and its HEU blended down to LEU in the Mayak facility.

Some Russian-origin material in Kazakhstan, the Ukraine, and Belarus is likely to be blended down in those countries. In a program largely financed by the private Nuclear Threat Initiative, Kazakhstan has already blended down 2.9 tons of unused HEU fuel (enriched to 22-26%) that had been destined for the BN-350 fast-neutron reactor.[96]

An estimated 17.5 tons of U.S.-origin HEU that was shipped abroad had not been returned as of the beginning of the U.S. take-back program in 1996.[97] Of this, some 5.2 tons—roughly one-third—was in fuel eligible for take-back (currently aluminum-based and TRIGA reactor fuels and target material from isotope production). DOE estimates that, after irradiation, this eligible material now contains 3.6 tons of HEU.[98]

Several countries are not planning to take advantage of the take-back offer, however. As of mid-2007, 1.14 tons HEU had been returned and DOE expected the return of only an additional 110 kg by the end of the program.[99]

When returned to the United States, aluminum-based fuel is sent to the DOE's Savannah River Site where DOE currently plans to reprocess it in the H-Canyon.[100] TRIGA fuels are being shipped to the Idaho National Laboratory and will probably be placed in a geological radioactive waste repository.

The remaining 12.3 tons of the original HEU not currently eligible for the U.S. take-back program is mostly in Europe, Canada, or Japan. Small but significant quantities are in many other countries, however. A modest fraction of this material has already been reprocessed abroad, and more is slated for reprocessing in the future. For much of the rest, however, no definite disposition path has been identified.

GTRI therefore has launched an effort known as the "Emerging Threats and Gap Materials" program designed to dispose of potentially vulnerable material not covered by other efforts. This material includes HEU that is neither of U.S. or Russian origin. The new program removed its first 83 kilograms of HEU during fiscal year 2006, (fresh, unirradiated HEU from Belgium, Canada and the Netherlands).[101]

The GTRI hopes to remove a total of 1.4 tons of material in this program by the end of 2013. Several disposition paths are being pursued. Unirradiated HEU is to be added to the stocks of excess U.S. HEU at the DOE's Y-12 facility in Tennessee, from where it is to be sent to Nuclear Fuel Services or Savannah River for blending. Some spent HEU fuel is to be reprocessed at La Hague, France. In addition, DOE is currently considering whether additional HEU and plutonium can be imported into the United States.[102]

Even if successful, however, all these programs will leave many tons of HEU at research reactors and associated sites outside the United States and Russia.

Conclusion

HEU is being eliminated on a large scale by blending down to LEU for commercial use. The primary Russian HEU down-blending program will end in 2013, however. The scale of the U.S. effort has been limited by the U.S. Navy's requisition of almost all excess weapon-grade uranium for its fuel stockpile. And the rate of the U.S. blend down now appears to be limited—at least in part—by the leisurely pace of U.S. warhead dismantlement. The efforts in both countries need to be expanded and accelerated.

Russia and the United States therefore should immediately begin discussions on blending large additional quantities of excess weapon HEU to LEU. Given the current high price of natural uranium—which is anticipated to last at least a decade—both countries could realize billions of dollars.

This approach would contribute to deep and irreversible nuclear arms reductions, strengthen international political support for the nonproliferation regime, and reduce the costs and risks of guarding HEU.

Reductions in excess stocks of civilian HEU should be pursued with equal urgency. If the United States, Russia, and other countries work together to ensure that unneeded civilian HEU is consolidated in secure locations and blended down, the number of civilian sites with enough HEU to make a bomb could be reduced dramatically within a few years. In the longer term the goal should be to eliminate the use and presence of HEU at all civilian facilities.