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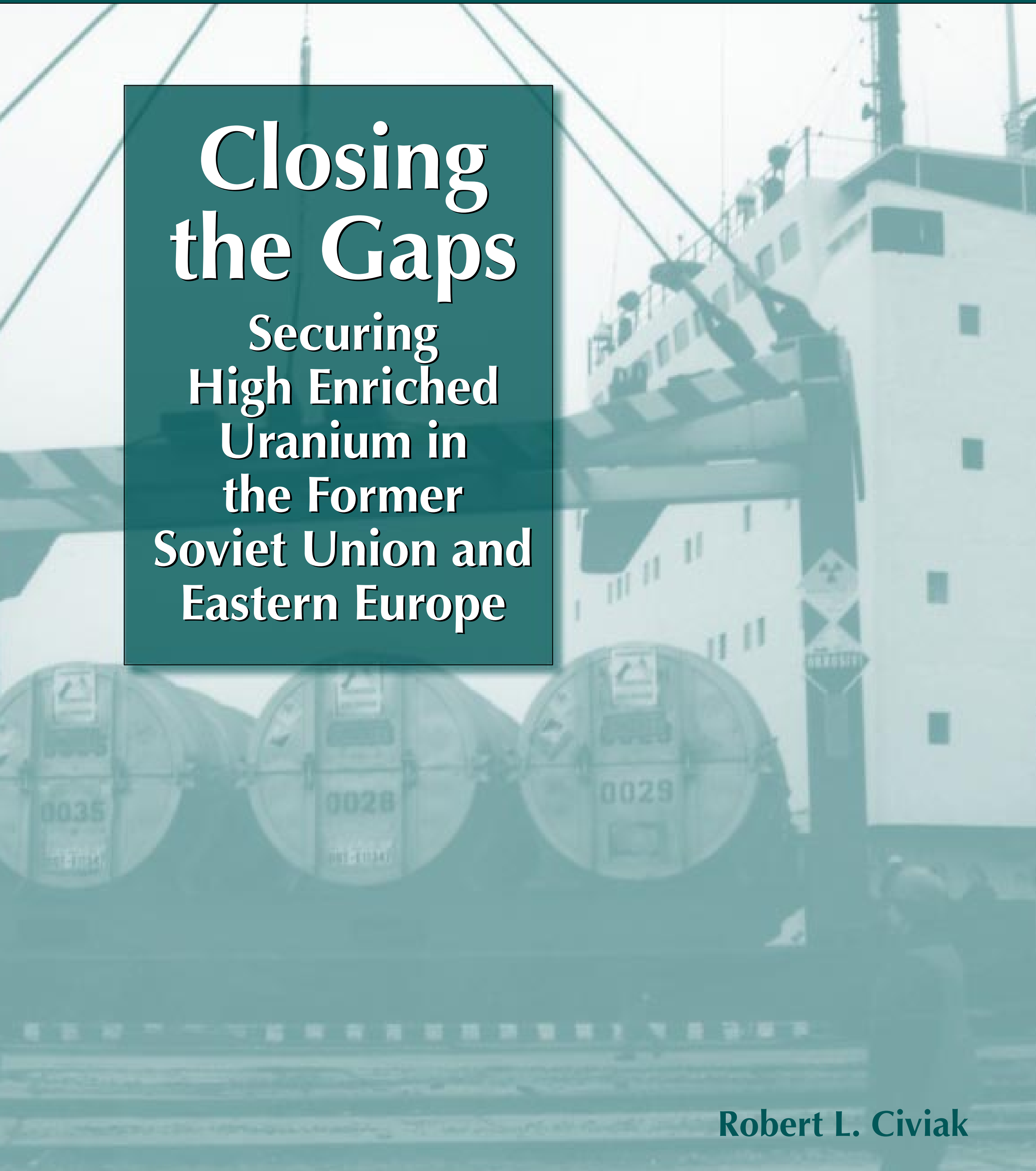

Closing the Gaps

Securing High Enriched Uranium in the Former Soviet Union and Eastern Europe

Robert L. Civiak

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About the Author

Robert Civiak has been doing research and analysis in nuclear weapons policy and related areas for more than 23 years. He received a Ph.D. in physics from the University of Pittsburgh in 1974. From 1978 through 1988, he was a Specialist in Energy Technology and Section Head in the Science Policy Research Division of the Congressional Research Service at the Library of Congress. During the spring and summer of 1988, he was a Visiting Scientist at Lawrence Livermore National Laboratory. From November 1988 through August 1999, he was a Program and Budget Examiner with the Office of Management and Budget (OMB) in the Executive Office of the President. At OMB, he was responsible for oversight of the national security activities of the Department of Energy, including DOE's nonproliferation programs. He also coordinated OMB activities regarding privatization of USEC and implementation of the Russian HEU agreement. Civiak currently resides in Lebanon, New Hampshire, where he continues to do research and policy analysis on nuclear weapons, arms control, and uranium enrichment issues as an independent consultant.

Acknowledgements

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Executive Summary

Introduction

This report presents three proposals to expand existing programs for reducing foreign stockpiles of high-enriched uranium (HEU), the material of choice for terrorists seeking nuclear weapons. Under the first proposal, the United States government would pay Russia to double the current rate at which it transforms HEU that has been removed from nuclear weapons into low-enriched uranium (LEU), which is too dilute for weapons use. The additional LEU would be stored in Russia and eventually sold for use as nuclear power plant fuel under an existing agreement which this proposal would build upon. Under the second proposal, the United States would expand its efforts and incentives for nuclear institutes in Russia to reduce—or preferably eliminate—their use and stocks of HEU. The HEU would be consolidated with larger stockpiles at other facilities and possibly be blended to LEU. Under the third proposal, the United States would provide more help to institutions in Russia and elsewhere that depend upon research reactors for their work to replace their HEU fuel with high-density LEU fuel.

Implementation of these three proposals would significantly reduce the risk that terrorists or other groups might divert HEU for use in nuclear weapons. All three are low cost options that could be started and would produce results quickly.

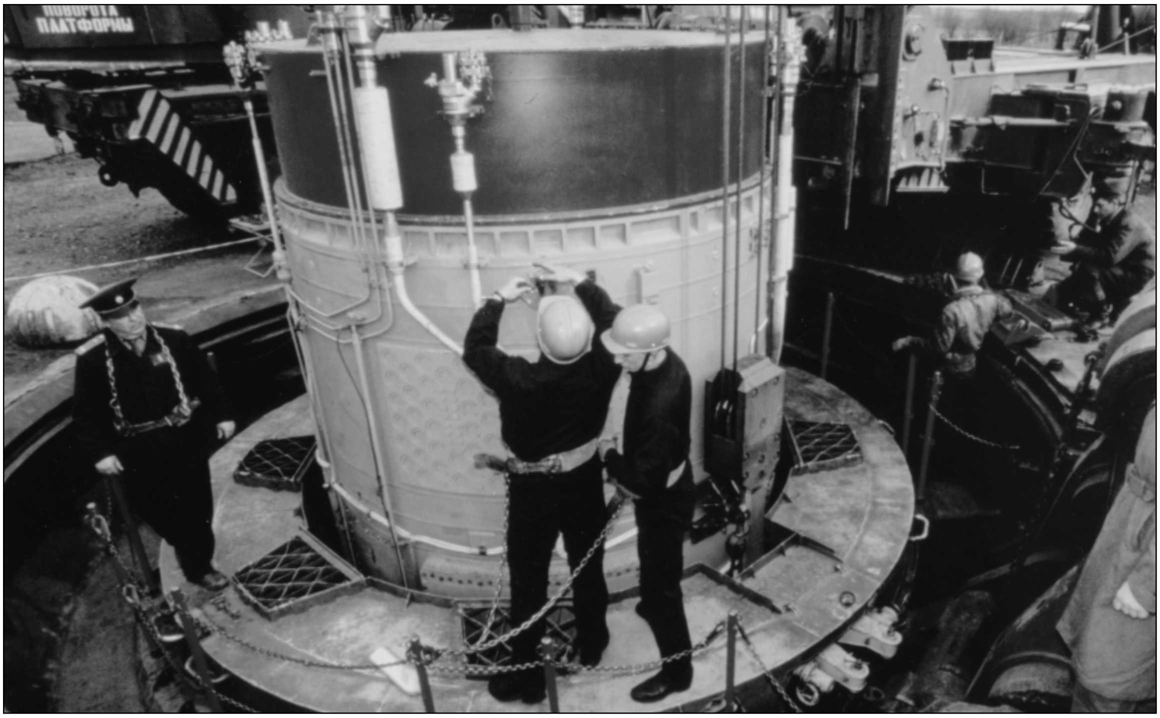
Russia and other nations of the Former Soviet Union (FSU) present a serious risk that a nuclear weapon or nuclear material could be diverted for malevolent purposes. The economic and political collapse of the Soviet Union created a formidable challenge to keeping its nuclear weapons and materials under adequate control. Individuals and groups have attempted to steal uranium or plutonium from sites in the FSU dozens of times during the past ten years, and in several incidents, a kilogram or more of weapons-usable material has been stolen or lost. In January 2001, a bipartisan task force chaired by former Senate majority leader, Howard Baker, and former White House counsel, Lloyd Cutler concluded:

> The most urgent unmet national security threat to the United States today is the danger that weapons of mass destruction or weapons-usable material in Russia could be stolen, sold to terrorists or hostile nation states, and used against American troops abroad or citizens at home.

There have been no confirmed reports of successful thefts of a complete nuclear weapon or sufficient nuclear material to make one. However, given the inadequate Soviet-era record keeping for nuclear material stocks, there is no way to know for sure that significant diversions have not already occurred. If they have not, without prompt action, it may only be a matter of time before they do.

Nuclear materials present a greater opportunity for terrorists than intact nuclear weapons, because their security is generally poorer. Soviet nuclear weapons have all been consolidated in Russia and are guarded by highly trained professional security forces. Nuclear weapons are relatively large, heavy objects that are not easily stolen. They come in discrete units that are easily counted. Contrary to the numerous thefts of nuclear materials, there are no known cases of theft or attempted theft of actual nuclear weapons.

HEU is of particular concern, because it is the material of choice for terrorists. Even though it takes at least three times as much HEU as plutonium to make a nuclear weapon, HEU can be used in rudimentary nuclear weapon designs, for which plutonium cannot be used. HEU is less radioactive and therefore less dangerous to handle than plutonium, making it easier for terrorists to transport, store, and fashion into a weapon. In addition,



USEC

A Russian army officer oversees ICBM dismantlement at a Pervomaysk, Ukraine missile base (1995).

there is six times as much HEU as plutonium in Russia, and it is located at many more sites.

Three Proposals for Expanding Efforts to Reduce HEU Stockpiles in Russia

In 1993, the United States agreed to purchase Low-Enriched Uranium (LEU) derived from 500 metric tons of HEU from dismantled Russian nuclear weapons. This agreement, commonly referred to as "the HEU deal", has proven to be one of the most successful of all US-Russian nonproliferation programs. Since 1993, about 140 metric tons of Russian weapons-origin HEU has been blended into LEU. This "blending" process involves mixing HEU with other forms of uranium in order to convert it to LEU. The benefit of this conversion is that LEU, unlike HEU, does not constitute a proliferation threat.

However, the implementation of the HEU deal is limited by the rate at which LEU can be sold without disrupting the international market for nuclear fuel. Under the current schedule, the full 500 tons of HEU will not be eliminated until 2013. Furthermore, if all Russian nuclear weapons scheduled for retirement are dismantled, there will be hundreds of tons of additional excess HEU in storage. Finally, a significant portion of Russia's HEU does not come from nuclear weapons and so is not covered under the HEU deal. This material is located at storage, research, nuclear fuel processing, and other facilities that generally have less security than storage sites for nuclear weapons and weapons-origin material.

We propose the following:

Proposal 1: Rapid Blend-Down of All Excess Russian Weapons-Origin HEU

We recommend that the Administration seek to expand the existing HEU agreement with Russia based on the following elements.

- **Speed up HEU conversion.** The United States will pay Russia its costs, plus a modest incentive payment, to blend an additional 30 metric tons per year of HEU from nuclear weapons to 19.9-percent enriched LEU using natural uranium as a blendstock.
- **Make sure the LEU does not disrupt the international market.** The 19.9-percent enriched LEU

will remain in Russia, without further blend-down, until at least 500 metric tons of HEU have been blended into LEU under the terms of the existing HEU agreement.

- **Arrange Future LEU Transactions.** The United States will agree to purchase, and Russia will agree to sell, the LEU once it has gone through an additional downblending step from 19.9-percent enriched LEU to fuel grade material. The pricing for this arrangement will be worked out separately from the framework agreement, as is done under the current HEU deal.

This proposal would double the current rate of blend-down of excess weapons-origin HEU. Such an increase would be straightforward and could be accomplished for about $40–60 million per year to cover the cost of the blending and of providing the incentives for Russia to carry it out. The financial incentives and other benefits of the proposed expanded blend-down may be sufficient for Russia to increase its total HEU downblending goals by 200-to-300 metric tons. Such an expansion of the existing HEU deal would be a significant achievement, and even greater reductions might be possible. However, larger reductions in Russia's HEU holdings would eventually impinge upon the size of its nuclear weapons stockpile or on HEU reserves that it plans to hold for potential use in nuclear weapons. As HEU reductions approach the limit of excess Russian HEU, the Russian government is unlikely to continue to down-blend its holdings without a reciprocal agreement from the United States. The US must address the issue of reciprocity if it wants to obtain the security and arms control benefits of deeper reductions in Russian HEU stockpiles.

Proposal 2: Remove HEU Stockpiles from Smaller, Less Secure Facilities

We recommend a number of measures to enhance the US Department of Energy's (DOE) efforts to encourage Russia to consolidate broadly distributed, poorly secured HEU into a few well-guarded facilities. The security of HEU would be significantly enhanced if it were removed from smaller, less secure, civilian facilities in the FSU, with a focus on the facilities that present the greatest risk of nuclear materials diversion.

Under the existing HEU deal, Russia must derive the LEU it sells to the United States from nuclear weapons. There is no question that downblending and selling this material improves its security and provides a long-term benefit for arms control. Nevertheless, stockpiles of HEU in small research facilities, with fewer resources for security, pose a greater immediate risk of diversion and should be given an even higher priority for elimination. According to the Department of Energy's 2003 budget request to Congress, "civilian sites contain approximately 35 tons of the most vulnerable, proliferation concern material. These facilities are located in densely populated areas throughout the Russian Federation and the Newly Independent States and are considered to be the most likely target for proliferants seeking weapon useable material through either abrupt theft or protracted diversion."

In 1999, the DOE and the Russian Ministry for Atomic Energy (Minatom) established the Materials Consolidation and Conversion (MCC) Project to reduce the complexity and the costs of securing Russian HEU. The approach of the MCC Project is to move HEU from smaller facilities to two large Minatom facilities with downblending capabilities, blend the HEU to 19.9-percent LEU, and store it at those facilities. The Department of Energy pays the blending facilities a fee for each kilogram of 19.9-percent LEU they produce. Unfortunately, DOE has little say in determining where the HEU to be downblended comes from—that decision is ultimately left to the Russian blending facilities. As a result, the most vulnerable facilities do not necessarily get targeted first.

The take home message is that DOE must take a more active role than the current MCC project allows for, specifically in setting priorities to work with the facilities most vulnerable to theft and in site-by-site planning to remove HEU stockpiles from those facilities. DOE should tailor specific packages of assistance to individual institutes in Russia and other nations of the FSU to provide the appropriate incentives for the removal of their HEU stockpiles. DOE should offer larger payments and additional incentives to sites that completely eliminate their HEU stockpiles.

We recommend that the Department of Energy:

- **Prepare a comprehensive list** of facilities in Russia and other states of the FSU that may be candidates for HEU reductions or removal

- **Assign an American project manager** for each facility
- **Target facilities that are the highest priority** to the US for HEU reduction and elimination
- **Designate a senior official** to negotiate tailored packages of incentives on a site-by-site basis
- **Provide an appropriate incentive** for Russia to take back spent HEU fuel from research reactors outside of Russia

Most of our recommendations are for policy changes that would cost little to implement. However, we also recommend that annual funding for DOE's Materials Consolidation and Conversion project be twice the Administration's 2003 request of $27 million. The additional funds, if maintained for three years, would be sufficient to remove all HEU from high priority facilities within that time.

Proposal 3: Replace HEU Fuel in Soviet-Built Research and Test Reactors with LEU Fuel

In the third proposal, we recommend expanding existing efforts to help organizations with Soviet-designed research reactors replace HEU fuel with high-density LEU fuel. Thus, research institutes can continue to operate the nuclear reactors crucial to their work while eliminating a potential source of nuclear weapons materials.

Russia has approximately forty operational, research reactors and critical assemblies with HEU cores. There are also three such reactors in former Soviet republics and several others in operation elsewhere. Unused or slightly used fuel cores at these facilities represent attractive targets to terrorists or nations seeking to obtain HEU for nuclear weapons. Spent HEU fuel is less attractive, however, because it is radioactive and, therefore, dangerous to handle. Nevertheless, weapons-useable uranium can still be extracted from spent research reactor fuel, especially after it has had many years to cool. These uranium stocks can be eliminated as targets for proliferants if the reactors are converted from HEU fuel to non-weapons useable LEU fuel—or shut down if they are no longer needed—and if all HEU-based fresh and spent fuels at those sites are moved to larger, more secure facilities within Russia.

A US-funded program in Russia and at Argonne National Laboratories is currently developing high-density LEU fuels that are similar to HEU in their performance capabilities but can be used without the security threat that HEU poses. Under this proposal, the United States would accelerate the research program and facilitate the transition of research reactors to LEU fuel.

We recommend expanding efforts to replace HEU fuel in Soviet-built research and test reactors with LEU fuel. This will require:

- **Increasing support** for research programs to develop higher density LEU fuels
- **Providing funds for at least the initial LEU fuel cores** as an incentive for reactor operators to convert
- **Making payments to Russia** to take back Soviet-supplied spent fuel and unused fresh fuel from other countries

An increase over current appropriations of less than $20 million per year, for the next few years, could be sufficient to fund the conversion of all but one or two of the highest power Soviet-built, HEU-fueled reactors and the return of all HEU fuels to Russia within the next few years.

Implementation of all three of these proposals would significantly reduce the risk that terrorists or other groups would divert HEU for use in nuclear weapons. All three cost relatively little, and none of them pose insurmountable policy challenges that would obstruct their implementation. They are the low hanging fruit. They can be picked now while other efforts continue to address some of the more challenging long-term problems. We estimate that adopting all of our proposals would cost about $100 million per year for the first three years and $50-90 million for another five to ten years, depending on how much weapons-origin HEU is eventually downblended under the first proposal.

Introduction

This report presents three proposals to expand existing programs for reducing stock piles of high-enriched uranium (HEU) in Russia and other nations of the Former Soviet Union. Under the first proposal, the United States government would pay Russia to double the current rate at which it transforms HEU that has been removed from nuclear weapons into low-enriched uranium (LEU), which is too dilute for weapons use. The additional LEU would be stored in Russia and eventually sold for use as nuclear power plant fuel under an existing agreement which this proposal would build upon. Under the second proposal, the United States would expand its efforts and incentives for nuclear institutes in Russia to reduce—or preferably eliminate—their use and stocks of HEU. The HEU would be consolidated with larger stockpiles at other facilities and possibly be blended to LEU. Under the third proposal, the United States would provide more help to institutions in Russia and elsewhere that depend upon research reactors for their work to replace their HEU fuel with high-density LEU fuel.

Implementation of these three proposals would significantly reduce the risk that terrorists or other groups might divert HEU for use in nuclear weapons. All three are low cost options that could be started and would produce results quickly.

The Threat of Diversion of Nuclear Weapons or Weapon Material from Russia

The events of September 11, 2001 destroyed any belief that the United States is invulnerable to determined groups bent on mass destruction. Yet, as terrible as those events were, the explosion of even a small nuclear weapon in an urban area would be many times more destructive. Fortunately, the possibility that a sub-national group—even one as well funded and organized as al-Qaeda—could develop its own nuclear weapons, without outside help in obtaining the necessary nuclear material, is extremely small. There is a substantial risk, however, that such a group could clandestinely acquire a fully assembled nuclear weapon from an existing nuclear weapons state or acquire sufficient weapons-grade material to dramatically reduce the barrier to making a nuclear weapon. There have been numerous reports that the al-Qaeda organization sought to purchase nuclear weapons or material.

Thefts of HEU pose the most serious nuclear security threat of all; therefore, reducing HEU stockpiles should have the highest priority.

The vast quantity of nuclear weapons and weapon materials in Russia and other nations of the Former Soviet Union (FSU) presents the greatest risk of theft or diversion. At its peak, there may have been as many as 45,000 nuclear warheads in the Soviet stockpile.[1] Today, about 10,000 warheads are still deployed, and there may be another 10,000 warheads in reserve or awaiting dismantlement.[2] A large fraction of the rest have been dismantled, but most of their nuclear materials are still in storage. The FSU still has a vast industrial and research complex in which nuclear weapon materials are located at more than sixty sites. At least thirty-two sites have more than one-hundred kilograms (kg) of high-enriched uranium or plutonium (sufficient for several nuclear weapons), and many of them have quantities that are measured in tons (i.e., in thousands of kilograms).[3] The smaller sites, with less HEU, may actually present the highest risk, since the smaller institutions generally have fewer resources to devote to security.

The economic and political collapse of the Soviet Union has created a formidable challenge to keeping its nuclear weapons and materials under adequate control. As early as 1994, the National Academy of Sciences called the existence of surplus nuclear weapon material in the Former Soviet Union "a clear and present danger to national and international security."[4] Since then, the US government has established several programs to deal with the problem (see Appendix A). They have had some notable accomplishments, but much more remains to be done. In January 2001, a bipartisan task force chaired by former Senate majority leader, Howard Baker, and former White House counsel, Lloyd Cutler concluded:

> The most urgent unmet national security threat to the United States today is the danger that weapons of mass destruction or weapons-usable material in Russia could be stolen, sold to terrorists or hostile nation states, and used against American troops abroad or citizens at home.[5]

The danger is not merely theoretical. A recent report by the National Intelligence Council,[6] which coordinates intelligence assessments from several US government agencies, lists several cases in the past decade in which a kilogram or more of weapons-usable material has been stolen or lost, including:

- An incident in 1992, in which 1.5 kg of 90-percent enriched uranium was stolen from the Luch Production Association, in Podolsk, Russia.
- An incident in 1994, in which 3 kg of 90-percent enriched uranium was stolen in Moscow.
- A report of a theft in 1998 in Chelyabinsk Oblast, about which a Russian official stated that the amount stolen was "quite sufficient material to produce an atomic bomb". This case remains the only nuclear theft that has been so described, and the HEU has since been recovered.

In addition to actual thefts, there have been dozens of incidents during the past ten years in which individuals and groups have stolen or attempted to steal uranium or plutonium from sites in the FSU, but have been caught.[7] Given the inadequate Soviet-era record keeping for fissile material stocks, there is no way to know for sure that other significant diversions have not already occurred. If they have not, and security is not upgraded quickly, it may only be a matter of time before they do.

HEU Stockpiles—A Serious Threat, A Solvable Problem

Over the past years, there have been several appeals for a comprehensive program to address the problem of poorly secured nuclear weapons and

BOX 1. What is HEU and why does it pose a greater security threat than fully assembled nuclear weapons or plutonium?

The stockpiles of fissile materials in the Former Soviet Union present a greater opportunity for terrorists than intact nuclear weapons because fissile material security is generally poorer. Soviet nuclear weapons have all been consolidated in Russia and are guarded by highly trained professional security forces. Nuclear weapons are relatively large, heavy objects that are not easily stolen. They come in discrete units that are easily counted. Contrary to the numerous thefts of nuclear materials, there are no known cases of theft or attempted theft of actual nuclear weapons. The nuclear material of greatest concern is high-enriched uranium (HEU). HEU is defined by international convention as uranium containing 20-percent or more U-235, but the greatest security threat is posed by 90-percent-enriched weapons-grade uranium.

There is a more urgent need to reduce stockpiles of HEU than plutonium stockpiles, because HEU is the material of choice for terrorists. Once the barriers to obtaining weapons-grade HEU have been overcome, the rest of the nuclear-weapon assembly process is relatively simple. While it takes three times as much HEU as plutonium to make a nuclear weapon, HEU can be used in rudimentary nuclear weapon designs (such as gun-barrel-type weapons) in which plutonium cannot be used. HEU is less radioactive and less hazardous than plutonium, which makes it easier for terrorists to transport, store, and fabricate into a weapon. In addition, there is six times as much HEU as plutonium in Russia, and it is located at many more sites.

materials in Russia and other nations of the Former Soviet Union.[8] We support those pleas. However, the political will to fully fund an all-inclusive solution has not yet materialized. Pending the emergence of such support, this report proposes giving higher priority to the expansion of three existing approaches for reducing the number and size of HEU stockpiles in Russia and other countries.[9] Thefts of HEU pose the most serious nuclear security threat of all (see Box 1); therefore, reducing HEU stockpiles should have the highest priority. In addition, these proposals all cost relatively little. They provide readily available solutions that can be pursued now to produce significant results quickly, while other efforts continue to address some of the more challenging long-term problems.

Efforts to reduce HEU stockpiles can produce results quickly and inexpensively because:

- HEU can be easily converted into non-weapons-useable LEU by blending it with uranium of lower enrichment.
- Blended-down HEU has monetary value as fuel for nuclear power plants, and can thus be used to fund stockpile reductions.

While the downblending of HEU may involve some political challenges, these challenges pose less of an obstacle than those associated with plutonium disposition.[10]

Although intact nuclear weapons and plutonium pose a credible threat, both the US and Russia can significantly benefit from HEU stockpile reductions. The following proposals for reducing HEU stockpiles in Russia are relatively easy and inexpensive steps that have substantial payoffs for both countries in enhanced nuclear security.

USEC

Cylinders of the first shipment of warhead-derived LEU fuel arrive at USEC's Portsmouth, Ohio plant (1995).

Three Proposals to Expand Efforts to Reduce HEU Stockpiles in Russia

In 1993, the United States agreed to purchase LEU derived from 500 metric tons[11] of HEU from dismantled Russian nuclear weapons. This agreement, commonly referred to as "the HEU deal," has proven to be one of the most successful of all US-Russian nonproliferation programs. Since 1993, about 140 tons of Russian weapons-origin HEU has been blended into LEU[12] and sold for use as fuel in nuclear power plants. This transaction was facilitated by USEC Inc., the American company currently responsible for implementing the HEU deal. However, implementation of this agreement is limited by the rate at which LEU can be sold without disrupting the international market for nuclear fuel. Under the current schedule, the full 500 tons of HEU will not be eliminated until 2013. Furthermore, if all Russian nuclear weapons scheduled for retirement are eliminated, there will be hundreds of tons of additional excess HEU in storage (see Proposal 1 below).

A significant portion of Russia's HEU is not used in nuclear weapons and so is not covered under the HEU deal. This material is located at storage facilities, research institutes, nuclear fuel processing facilities, and other locations that generally have less security than storage sites for nuclear weapons and weapons-origin material.

The three proposals discussed below would all expand upon existing programs for reducing HEU stockpiles in Russia. All three are low-cost options that could be started and would produce results quickly without unduly affecting the market for nuclear fuel.

Under the first proposal, the United States government would pay Russia to blend the remaining HEU from the existing agreement, and additional quantities of excess weapons-origin HEU, to LEU as rapidly as practical. The blended LEU would be stored in Russia and sold for use as fuel for nuclear power plants at the same pace as under the current agreement.

Under the second proposal, the United States would provide incentives to civil institutions in Russia to reduce—or preferably eliminate—their use of and stocks of HEU. The HEU would be consolidated with larger, more secure stockpiles at other facilities and possibly be blended to LEU.[13]

Under the third proposal, the United States would help organizations that have Soviet-designed research reactors replace HEU fuel with high-density LEU fuel. Thus, security concerns need not interfere with the operation of research reactors that Russian institutes need for their continuing mission. A US-funded program in Russia is currently developing high-density LEU fuels that can provide similar performance to HEU fuel. Under this proposal, the United States would accelerate the research program and facilitate the transition of research reactors to LEU fuel.

The three proposals are described in detail below. An understanding of the existing HEU agreement is useful in putting these proposals into context. This agreement has been controversial and its implementation has proceeded in fits and starts. Proposals to further reduce HEU stockpiles will not be considered seriously unless the original agreement is proceeding and the new proposals do not threaten that operation. The history and status of the existing HEU deal is reviewed in Appendix B.

PROPOSAL 1

Rapid Blend-Down of All Excess Russian Weapons-Origin HEU

A Large HEU Stockpile Remains in Russia Outside of the HEU Deal

According to unofficial estimates,[14] the Russian military has about 1,000 metric tons of "weapons-grade equivalent" HEU.[15] Five-hundred tons are covered by the current HEU deal, of which 140 tons have been blended down and 360 tons are still in weapons and at storage facilities, waiting to be blended.[16] The remaining 500-ton Russian stockpile of separated HEU, which is not covered under the HEU deal,[17] is sufficient for 20,000 nuclear weapons.[18]

President Putin recently pledged to reduce Russia's deployed nuclear weapons stockpile to about 2,000 deployed strategic warheads. At an average of 25 kilograms per warhead, those 2,000 warheads would contain about 50 tons of HEU. If Russia were to retain an additional 100 ton HEU stockpile composed of tactical nuclear warheads, inactive strategic warheads, and an HEU reserve, it would still need only 150 tons of HEU. That would leave at least 350 tons of excess weapons-grade HEU remaining outside of the existing deal. Thus, while the existing HEU deal is a good start, it addresses only half of the excess weapons-grade HEU Russia may soon have from nuclear weapons disassembly (see Figure 1).

There is a pressing need to expand the existing HEU agreement, but negotiating further reductions may take some time. The Russian government may be averse to large additional, unilateral reductions in its HEU stockpile, since that could limit its ability to re-enlarge its nuclear weapons arsenal. Nevertheless, in the interests of security, the US should seek negotiations on expanding and accelerating HEU blend-down as soon as possible. At the current blending rate of 30 tons per year, the HEU remaining under the original agreement will not be eliminated until 2013. If the deal were extended at this rate, the additional excess HEU would not be blended and sold until 2025. That is much too long for this dangerous material to remain available for potential diversion.

One way to speed up the elimination of this material is to simply increase the pace of the existing HEU deal. However, any significant increase under the current arrangements would overwhelm the commercial nuclear fuel markets upon which this deal depends. Nuclear fuel prices might fall significantly, and Russia might not be able to recover the costs of blending the HEU. Increasing sales of Russian LEU could force USEC to close the only operating enrichment plant in the United States. Concern over the loss of American jobs and the national security risk of becoming more dependent on Russia for US nuclear fuel requirements could in turn undercut American support for the HEU deal. Thus, attempting to expand the existing HEU deal under its current arrangements would more likely lead to its collapse than to its expansion.

While the existing HEU deal is a good start, it addresses only half of the excess weapons-grade HEU Russia may soon have from nuclear weapons disassembly.

The solution to this problem is to increase the pace of blending excess Russian HEU into LEU while maintaining the existing level of sales. Two hurdles remain for this to work. First, a way must be found to assure US commercial interests that Russia will not prematurely bring the HEU, which it has blended into LEU, into the marketplace. Second, the cost of the blending operation must be kept low, since it will not be recovered through LEU sales for an extended period. Both of these problems can be solved if the extra HEU is blended to only 19.9-percent U-235 and is kept in Russia under Russian ownership.

Blending the HEU to 19.9-percent U-235 provides nearly the same level of security as lower levels of enrichment. By international convention, uranium enriched to less than 20-percent U-235 is classified as LEU that is not useful in making fission weapons. While this 19.9-percent LEU could be re-enriched to HEU more easily than could natural uranium or the 4.4-percent LEU, which is produced under the existing HEU deal, such enrichment is still well beyond the ability of terrorists and most governments to carry out. Even expert designers would need several hundred kilograms of 19.9-percent LEU to produce a nuclear weapon. Considerably more material would be needed for the simple "gun-barrel" weapon design that terrorists might more readily fabricate.

HEU can be blended to 19.9-percent LEU at a fraction of the cost of blending HEU to 4.4-percent LEU, since a smaller amount of less expensive uranium feed stock is needed for blending to 19.9 percent. This makes such a proposition affordable. Furthermore, because of the additional expense of further blending, the existence of large stockpiles of 19.9-percent LEU is little more of a threat to commercial nuclear fuel markets than is HEU.

Proposal for Rapid Blend-Down of Additional Russian HEU

We recommend that the Administration seek to extend the existing HEU agreement with Russia based on the following elements.

- **Speed up HEU conversion.** The United States will pay Russia its costs, plus a modest incentive payment, to blend an additional 30 tons per year of HEU from nuclear weapons to 19.9-percent enriched LEU using natural uranium as a blendstock.

FIGURE 1. **US and Russian HEU Stockpiles**

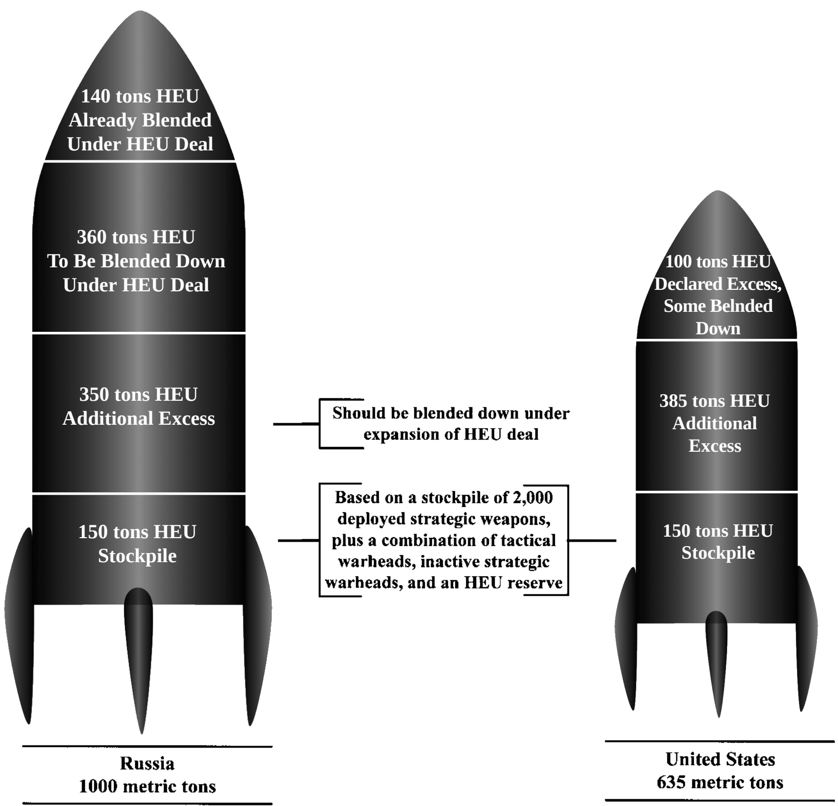
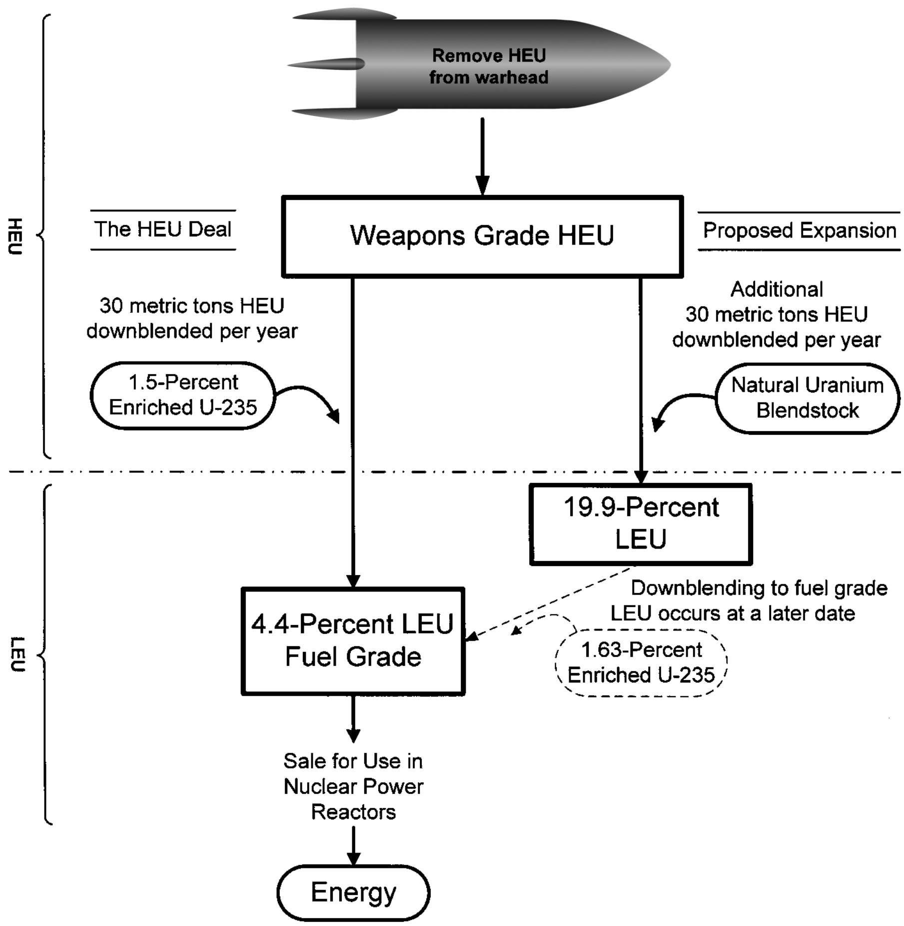


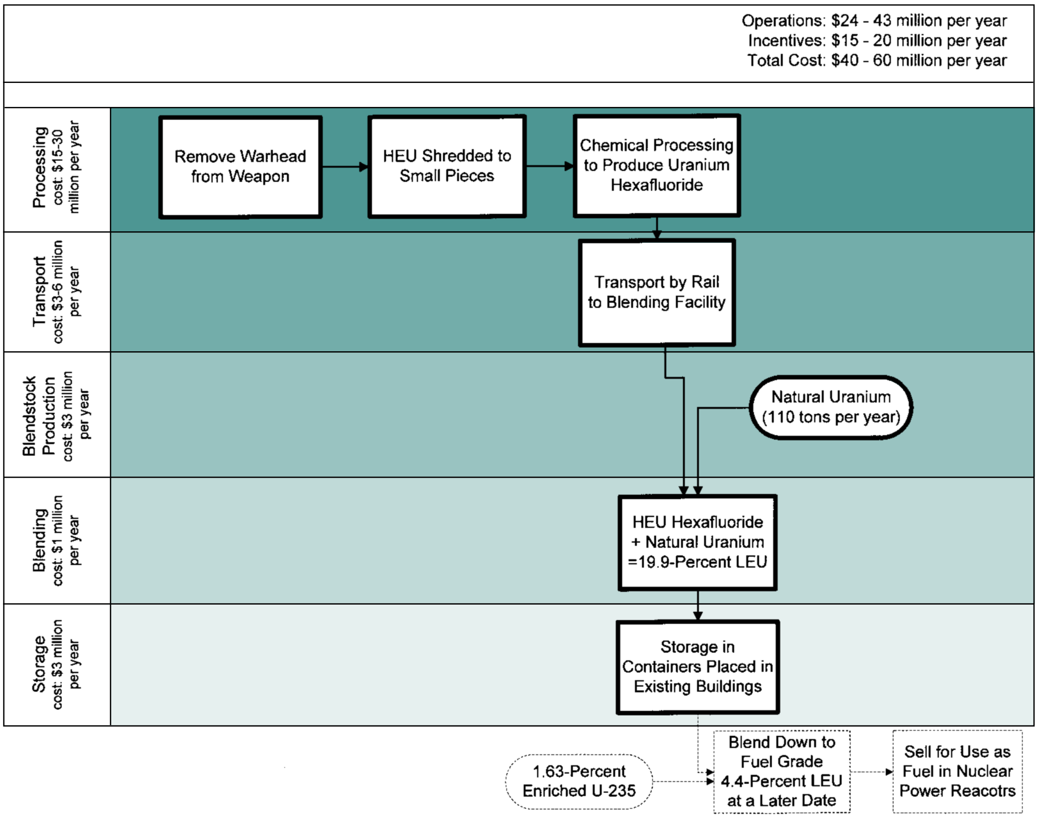
FIGURE 2. Proposal for Rapid Blend-Down of Additional Russian HEU



- **Make sure the LEU does not disrupt the international market.** The 19.9-percent enriched LEU will remain in Russia, without further blend-down, until at least 500 tons of HEU have been blended into LEU under the terms of the existing HEU agreement.
- **Arrange Future LEU Transactions.** The United States will agree to purchase, and Russia will agree to sell, the LEU once it has gone through an additional downblending step from 19.9-percent enriched LEU to fuel grade material. The pricing for this arrangement will be worked out separately from the framework agreement, as is done under the current HEU deal.

There is a security benefit to be gained in simply speeding up the blending of the 360 tons of HEU remaining under the existing deal. However, the primary US goal should be obtaining Russian agreement to expand the amount of HEU eliminated. Expanding the deal would be much more beneficial than merely speeding it up, both in reducing the risk of diversion of weapons-useable material and in limiting Russia's ability to re-enlarge its nuclear stockpile. The rapid blend-down could proceed in parallel with US-Russian negotiations to go beyond the initial 500 tons. Even with a doubling of the blend-down rate, it would take six more years to complete the initial goals set out in the original HEU deal. However, the United States should not allow Russia to view the payments it receives for rapid blend-down solely as a means for reducing the cost of blending under the existing agreement. The US

FIGURE 3. The Blend-Down Process



should make it clear to Russia from the outset that its interest lies in expanding the HEU deal, not just speeding it up (see Figure 2).

Depending on the attractiveness of the overall deal, Russia might agree to a substantial unilateral reduction of its remaining HEU stockpile. However, Russia will likely require a reciprocal reduction by the United States before it agrees to fully eliminate its excess HEU. The costs of a rapid blend-down program and the incentives for both Russia and the United States to further reduce HEU stockpiles are discussed in the following two sections.

Cost Estimate for Doubling the Blend-Down Rate of Russian HEU

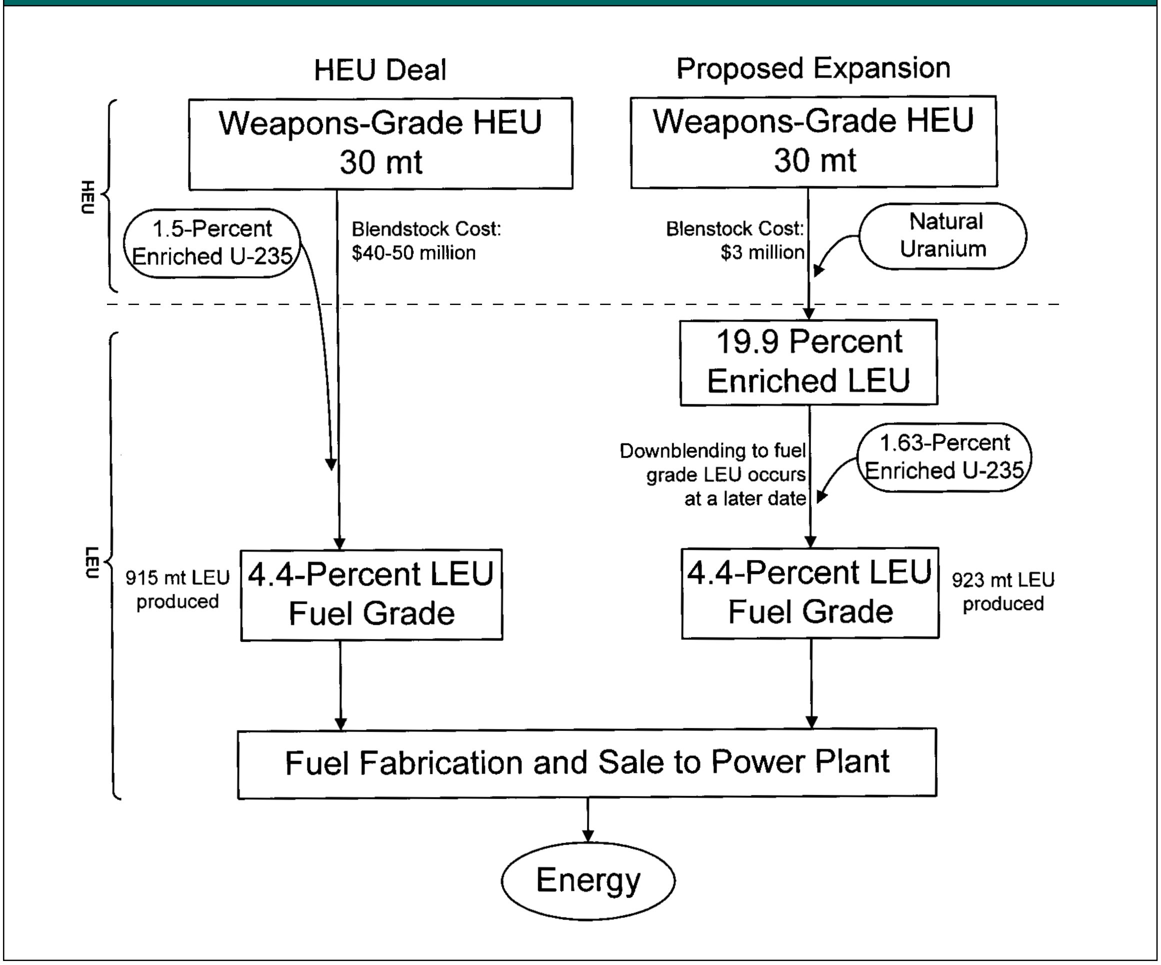
According to Russian officials, no major new facilities would be needed to double the amount of Russian HEU that gets blended down each year, increasing from 30 to 60 tons the amount of HEU eliminated annually. These officials have told the DOE and non-governmental analysts that there is sufficient capacity at existing facilities to blend 50 tons of HEU to LEU per year. DOE analysts believe Russia could increase the rate to 60 tons per year by installing new equipment costing about $1 million.[19] If these reports are accurate, operating expenses will be the primary cost component of the blending operation. Five types of activities contribute operating costs to the blending operation[20] (see Figure 3).

1. Initial processing: This involves dismantling the weapons components, shredding the HEU metal into small pieces, and putting it through a series of chemical processes to convert it to uranium hexafluoride. Uranium hexafluoride is the preferred form for blending, because it becomes an easily mixed gas at relatively low temperatures. These initial processing operations are labor intensive, and their cost is difficult to estimate. Based on incomplete information available about processing operations in Russia for the existing HEU deal, it appears that the initial processing for 30 tons of HEU would cost between $15 and $30 million per year. It is the largest cost component of the proposed blending operation.

2. Transport: The HEU must be shipped thousands of kilometers by rail, in heavily secured cars, from the facilities that do the initial processing to other facilities that carry out the blending operation. If 500 to 1,000 kg of HEU is shipped per train, and each trip costs $100,000, the annual transport costs for blending 30 tons of HEU would be $3–6 million.[21]

3. Blendstock production: To blend directly to nuclear fuel grade, Russian HEU must be mixed with a 1.5-percent enriched blendstock,[22] which could cost as much as $40–50 million per 30 tons of HEU. However, it is possible to defer this high cost by postponing the process that requires the expensive blendstock. The Russian HEU can be blended to 19.9-percent LEU using much cheaper natural uranium, at a cost of only $3 million per 30 tons HEU. Subsequent blending of the 19.9-percent enriched LEU to fuel grade LEU would still require the addition of costly blendstock. Ultimately, the total cost of blendstock production for converting weapons-grade HEU to fuel grade LEU would be roughly the same; blending to 19.9-percent in the near-term allows for significant nonproliferation achievements while deferring major costs[23] (see Figure 4).

FIGURE 4. Two Options for Blending 30 Metric Tons of HEU to LEU



4. Blending: The actual blending is done by joining the outflow from two separate pipes containing the HEU and the blendstock, both in the form of gaseous uranium hexafluoride. The enrichment level of the product is adjusted by regulating the flow rates from the two pipes. This low-cost operation would add less than $1 million to the total cost of blending 30 tons of HEU.

5. Storage: A substantial number of specially designed containers would be needed to store the 140 tons of 19.9-percent LEU hexafluoride that would be produced each year. Storage containers for 4.4-percent LEU cost $5,000 each, and can hold 2.5 tons of LEU hexafluoride. Assuming that cylinders for storing 19.9-percent LEU hexafluoride cost about the same price, but because of criticality concerns[24] hold less material, the annual cost for purchasing containers would be about $2 million. There would be additional costs to store, monitor, and maintain the containers. If, however, they were stored in existing buildings,[25] the total cost for storage, including the cost of the purchasing, monitoring and maintaining the containers for about a decade, would come to about $3 million per year.

In sum, the annual cost for processing and blending 30 metric tons of metallic HEU weapons parts to 19.9-percent LEU hexafluoride, including storage, is estimated at $25–43 million. The price will also have to include any incentive payment that the Russian government may require to perform the blend-down. That price will be subject to negotiation, but if the incentive payment were in the range of $15–20 million[26] per year, the program could be implemented for a total cost of about $40–60 million per year.

Some preliminary steps that are needed to bring this proposal into effect, are being initiated. The Nuclear Threat Initiative (NTI)[27] has decided to fund Russian and American experts who will refine the estimates for both the operating costs and the capital upgrades that Russia would need to make in order to increase the blending rate by 30 tons per year . NTI is currently in the process of putting the teams together for those activities.

The incentive payment would be only one of several benefits that Russia could obtain from expanding the HEU blend-down program. These benefits, as well as additional benefits to the United States, are discussed in the next section.

Benefits from Expanding the HEU Blend-Down

Expanding the Russian HEU blend-down program could reduce the risk of HEU diversion for malevolent terrorist purposes. Russia would benefit from this reduced risk, as would the United States.

The rapid blend-down would benefit Russia in several other ways. The expanded blending operation would provide employment for a substantial number of Russian workers. These jobs would go primarily to workers at facilities that formerly supported the Russian nuclear weapons program. The social benefit of providing these jobs is of central concern to Russia. There would also be a significant security benefit from stabilizing the economies of cities that previously depended on nuclear weapons production. Such stabilization would further reduce the risk of diversion of fissile material and nuclear weapon-related equipment or information. Russia would also experience a savings in security costs by reducing the number of buildings and the area in which HEU is stored. It is difficult to estimate the extent of the potential security savings, but they would likely measure in the millions of dollars per year.[28]

In addition, Russia will benefit from the lower costs of future downblending operations. Since the US would cover the cost of the initial blend-down to 19.9-percent enriched LEU, Russia would only have to cover the cost of subsequent blending from 19.9-percent to 4.4-percent LEU. The primary savings would be the $15–30 million per year cost of the initial processing from weapons components into uranium hexafluoride, which will already have been carried out under US funding. As noted above, the cost of feedstock, which would be the single largest cost in subsequent blending to meet nuclear fuel specifications, would be about the same as it is now.

These benefits and a modest additional payment may provide a sufficient incentive for Russia to expand the downblending of HEU by 200–300 tons. Such an expansion of the existing HEU deal would be a significant security achievement.

Even greater reductions might be possible. However, larger reductions in Russia's HEU holdings would eventually impinge upon the size of its nuclear weapons stockpile or on reserves of

HEU that it plans to hold for potential use in nuclear weapons. As HEU reductions approach the limit of excess Russian HEU, the Russian government is unlikely to continue to downblend its holdings without a reciprocal arrangement from the United States. The United States must address the issue of reciprocity if it wants to obtain the security and arms control benefits of deeper reductions in HEU stockpiles in Russia. Reciprocity should be based on the amount of HEU remaining in the stockpiles of each nation, rather than on how much each side has eliminated. The US stands to benefit from such an agreement because Russia produced substantially more HEU during the Cold War than the United States, and would therefore have to make larger cuts in its stockpiles in order to reach equal footing with the US. An understanding based on reciprocity would be an extension of the principle of parity in deployed warheads, which has been the foundation of bilateral arms control agreements between the US and Russia for some time.

As noted above, information on the size of the Russian HEU stockpile is uncertain. Similarly, the United States government has not released information on its total inventory of HEU. According to unofficial estimates, the United States has produced about 635 tons of weapons-grade equivalent HEU.[29] The US has declared 100 tons of that HEU as excess and is blending some of it into LEU. If, as assumed above for Russia, the US were to retain only sufficient HEU for 2,000 deployed strategic warheads and a combination of tactical nuclear warheads, inactive strategic warheads, and an HEU reserve, containing twice as much HEU as the deployed stockpile, it would also need 150 tons of HEU. Therefore, the remaining 385 tons of US HEU could be considered excess.

The Bush Administration recently announced that in addition to 1,700 to 2,200 operationally deployed strategic nuclear weapons, it plans to maintain as many as 8,000 other nuclear warheads, including tactical warheads, a "responsive force," and an "inactive reserve." Furthermore, under current policy the US plans to retain all HEU from retired warheads, except what it has already declared as excess, for potential future use as fuel for US naval vessels.

A full discussion of whether the US needs these large reserves is beyond the scope of this paper. Nevertheless, the United States must decide whether its interests are best served by maintaining a stockpile of at least 10,000 nuclear weapons and additional HEU, or by supporting mutual reductions to much lower levels than exist today. In any event, the US should be willing to provide an accounting of its HEU stockpiles. Before truly deep reductions in the Russian HEU stockpile can be achieved, the United States and Russia must adopt a comprehensive transparency regime that provides each nation with some assurance of the size of the other's HEU stockpile.[30] As the numbers of nuclear weapons in US and Russian arsenals fall, such a transparency regime is necessary to provide assurance that the other side is not maintaining large stockpiles of nuclear materials that could assist in a breakout from agreed upon numbers of nuclear warheads. The achievement of such a transparency regime would provide an arms control benefit that might rival the benefit in increased security, which is currently the driving interest in reducing HEU stockpiles.

USEC

Storage casks containing the first shipment of Russian LEU to the United States (1995).

PROPOSAL 2

Remove HEU Stockpiles from Smaller, Less Secure Facilities

Small Facilities are More Vulnerable to Theft

Under the existing HEU deal, Russia must derive the LEU it sells to the United States from nuclear weapons. However, the large stocks of HEU coming from nuclear weapons do not represent the greatest risk of diversion; nuclear weapons in Russia are kept in heavily guarded facilities, and the HEU that is removed from these weapons is kept in large processing and storage facilities to which access is also tightly restricted. There is no question that blending and selling this material improves its security and provides a long-term benefit for arms control. Nevertheless, stockpiles of HEU in small research facilities, with fewer resources for security, pose a greater immediate risk of diversion and should have even higher priority for elimination. According to the US Department of Energy's 2003 budget request to Congress, "civilian sites contain approximately 35 tons of the most vulnerable, proliferation concern material. These facilities are located in densely populated areas throughout the Russian Federation and the Newly Independent States and are considered to be the most likely target for proliferants seeking weapon useable material through either abrupt theft or protracted diversion."[31]

Most of that 35 tons of HEU is located at a handful of large research institutes or processing facilities, but numerous sites have small quantities of HEU, which are still significant from a security standpoint. A recent status report on nuclear facilities in the Former Soviet Union lists twenty civilian facilities as having more than a few kilograms, but less than one metric ton of HEU.[32] Ten of those facilities are in Russia and the other ten are in Belarus, Kazakhstan, Latvia, Ukraine, and Uzbekistan. While those twenty facilities with the smallest stockpiles have less than three tons of HEU in total, that amount is still sufficient for many dozens of nuclear weapons. Removing all HEU from those facilities can provide a significant improvement in security at a modest cost.

While the US Department of Energy has upgraded the materials protection control and accounting systems at all of those twenty facilities, many of the sites do not have sufficient funds to properly operate the security systems. In order to compensate for these security inadequacies, DOE provides ongoing financial assistance for operations. According to a report by the General Accounting Office, "operational assistance is necessary because the Russian sites where DOE helped install nuclear security systems lack the financial resources, adequately trained staff, and the knowledge of procedures to operate and maintain the systems effectively."[33] Overall, DOE expects to provide about $50 million per year in operational and infrastructure assistance to Russian institutes and the Department projects that facilities will continue to need some assistance until at least 2020.[34] By eliminating stockpiles of HEU from as many facilities as possible, DOE can not only improve security, but it can reduce operations and infrastructure spending as well.

Stockpiles of HEU in small research facilities, with fewer resources for security, pose a greater immediate risk of diversion and should have even higher priority for elimination

The DOE Materials Consolidation and Conversion Project

In 1999, the US Department of Energy and the Russian Ministry for Atomic Energy (Minatom) established the Materials Consolidation and Conversion (MCC) Project to reduce the complexity and the costs of securing Russian HEU.[35] The MCC Project works toward this goal by moving HEU from smaller facilities to two large Minatom facilities with downblending capabilities, blending the HEU to 19.9-percent LEU, and storing it at those facilities.[36] The Department of Energy pays the blending facilities a fee for each kilogram of 19.9-percent LEU they produce in order to cover their costs, give them an incentive to acquire and blend the HEU, and pass on an incentive payment to the sites that give up their HEU. Even though the material is moved from one facility to another its ownership does not change, since the enriched uranium is the property of the Russian Federation. Therefore, no payment needs to be made for the market value of the material as fuel.

Russia greatly benefits from this transaction because, under the MCC Project, it retains ownership of the LEU. If market conditions become favorable, Russia may still reap the full market value of the material blended under the MCC Project in the future. This differs from the weapons-origin HEU deal, under which the US executive agent (currently USEC Inc.) ends up owning the LEU.[37]

Through 2001, about 2.4 tons of HEU was blended to LEU under the MCC Project. DOE estimates that another 1.2 tons will be blended in 2002. According to the DOE's 2003 Budget request, the MCC Project plans to fund the conversion of 29 tons of HEU to LEU and the removal of all HEU from 55 buildings by 2010. These figures came from a draft conversion plan produced by Minatom, but Minatom has not provided any site-by-site information to corroborate its estimates.[38]

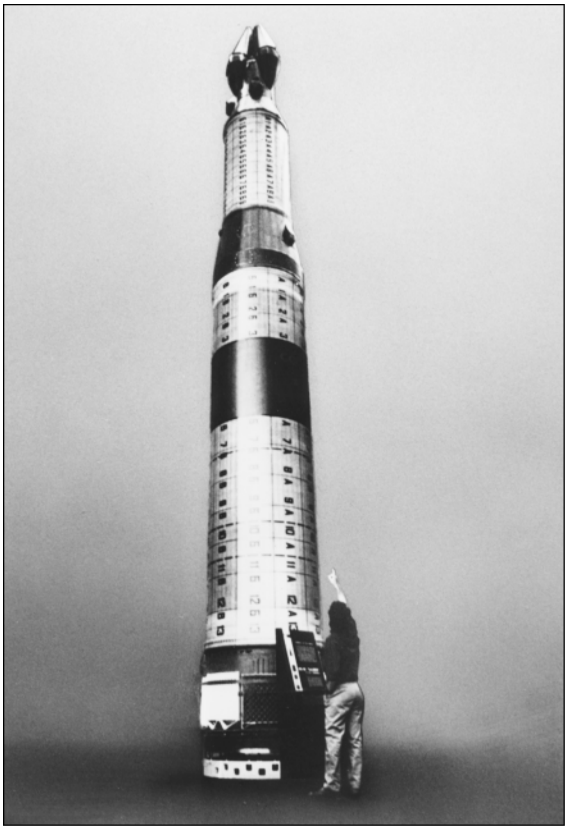
Limitations of the MCC Project

If Minatom follows through on its stated goals and successfully removes 29 tons of HEU from the most vulnerable facilities, thereby removing all HEU from 55 buildings, it will dramatically reduce the potential for diversion of HEU and simultaneously reduce the cost of security. It is not clear, however, whether that full goal can be achieved, and it is very unlikely that it will be reached by 2010. Moreover, the current program is not targeting the most vulnerable facilities first. As noted above, twenty small facilities have less than three tons of HEU in total. Removal of HEU from those facilities should have a higher priority than reducing stockpiles of HEU at larger facilities.

Removal of HEU from the smallest facilities would produce the largest improvement in security per ton of HEU downblended. However, under the current arrangement, DOE has little say in determining where the HEU to be downblended comes from. That decision is left to the discretion of the Russian blending facilities. The blending facilities have consulted with DOE in selecting the sites from which they get HEU, but the Minatom-operated blending facilities have had final control over where the HEU comes from. In some cases, DOE has not even known its place of origin. The MCC Project may be paying to draw down stockpiles of HEU from large storage facilities, where the reductions produce only a marginal improvement in security.

Minatom has told DOE that it will provide comprehensive site-by-site information after the US and Russia complete an umbrella agreement to govern the MCC Project, but progress toward such an agreement has been slow. The US government held up negotiations on the umbrella agreement for more than two years, first because of concern over Russia's nuclear cooperation with Iran, and then while the new Bush Administration reviewed all of DOE's Russian nonproliferation programs. In October 2001, the Administration gave DOE approval to submit its draft to Minatom, and negotiations on the umbrella agreement have finally begun. DOE hopes these discussions will lead to a site-specific planning document for the blending program.

Even if the current discussions produce a site-specific plan, it is likely to be limited. Minatom controls only those institutes and facilities that are or were directly involved in nuclear weapons development or nuclear power research. There are at least seven non-Minatom, civilian facilities in Russia with significant quantities of HEU. It is not clear whether Minatom has the authority to coordinate the removal of HEU from those facilities. Even if Minatom has such authority, it will still be difficult for DOE to establish priorities and tailor incentives to individual facilities by working through Minatom as an intermediary.



USEC

The HEU contained in Soviet SS-20 IRBMs is being blended down under the HEU deal. The missile above is on display at the Smithsonian Air and Space Museum, minus the HEU.

Many of the facilities of greatest concern are reluctant to give up their HEU. These facilities will require specifically tailored incentives, including non-monetary incentives, in order to cooperate with HEU consolidation efforts.[39] Non-monetary incentives may include assistance in replacing HEU fuel in research reactors with LEU fuel (the third proposal of this paper discusses the steps needed to do that) and assistance in converting research programs to new activities that are not based on HEU (for which there are several programs in DOE and other government agencies). It would also help if DOE had more flexibility in the types of monetary incentives it could offer, including the ability to provide low or no interest loans and the ability to increase the size of the incentive payment to facilities that completely eliminate their HEU stockpiles. On the other hand, some facilities have no current use for their HEU and should accept a lower payment to have it removed from their site than facilities for which the HEU has a continuing valid use. The lack of flexibility in the current program makes it difficult to match the incentives to the requirements of specific sites.

Another problem is that the current MCC Project is limited to Russian facilities. As noted above, there are significant quantities of HEU at ten non-Russian facilities in countries of the Former Soviet Union. These are mostly small facilities whose ability to maintain effective security is questionable. Concerted efforts should be made to remove material from these facilities. In at least one case, Ukrainian officials have indicated to US officials their willingness to sell about 75 kg of HEU from the Kharkiv Institute of Physics, which no longer needs the material. However, the US government has not yet made an offer to purchase this material.[40] Ideally, this HEU should go to one of the Russian blending facilities for downblending to 19.9-percent LEU, but there are alternative solutions. If the U.S. government cannot broker such an arrangement, it should bring the material to the United States for storage, blending, and perhaps sale.

The key point is that DOE must be more active in setting priorities and in site-by-site planning to remove HEU stockpiles than it is under the current MCC Project. DOE should tailor specific packages of assistance to individual institutes in Russia and other nations of the FSU to provide the appropriate incentive to remove their HEU stockpiles. DOE should offer larger payments and additional incentives to sites that completely eliminate their HEU stockpiles. Officials from the Luch blending facility told the General Accounting Office that some facilities would not transfer their HEU to Luch for blending, because they thought they could get a better deal from DOE.[41] DOE must play an active role in negotiations with these facilities to make it clear that they cannot profiteer from removing HEU, while at the same time offering to structure a multifaceted incentive package to match each institute's needs.

Funding Issues

At the start of the FY 2002 Budget season, and even well after the September 11 terrorist attacks, it appeared there would be a large overall cut in funding for DOE's Russian nonproliferation programs. However, last minute actions in both House and Senate Energy and Water Appropriations and an emergency supplemental appropriation for anti-terrorism activities increased the funding for DOE's Materials Protection Control and Accounting (MPC&A) Program, of which the MCC Project is a part, to $293 million. That is an increase of 68 percent above 2001 and more than double the Bush Administration's original request of only $139 million.

The Administration's original request included $26 million for the MCC Project, from which it anticipated spending $19 million as incentive payments for Russian facilities to downblend two tons of HEU to LEU. The final legislation, however, gave DOE little guidance on how to spend the increased funds for MPC&A. Nonetheless, the report accompanying the House version of the Energy and Water Bill (H. Rept. 107-112) stated:

The Committee has provided a significant increase in funding for fiscal year 2002. This increase should be targeted toward projects to consolidate materials and reduce the number of buildings and facilities holding nuclear materials.

This language appears to tell DOE to provide a major portion of the increase over the budget request for MPC&A to the MCC Project. However, according to DOE's 2003 Budget request, it plans to devote to MCC only $5.3 million of the extra $154 million in 2002 congressional funding for MPC&A. That would bring 2002 funding for MCC to $31.3 million. Furthermore, DOE has reduced its 2002 target for blending under this program. The 2002 Budget request had a goal of blending 2.0 tons of HEU to LEU in 2002, but the 2003 Budget request has reduced the 2002 goal to only 1.2 tons. The lower goal is primarily due to the slow progress in negotiating an umbrella agreement with Minatom. If additional funds were available for incentive payments to Russian institutes, the downblending could proceed at a faster pace.

The Budget requests only $27 million for the MCC Project for 2003, which is a decrease of 13 percent from the amount that DOE plans to spend on MCC in 2002. DOE's blending target for 2003 is 2.9 tons, which is more than twice the 2002 target, suggesting that a portion of the 2002 funding will go to payments for future blending.

Much HEU remains at civilian facilities in the FSU. It would appear that the pace of blending this HEU to LEU could be increased if more funds were allocated to the MCC Project. However, despite the large increase in funding for MPC&A provided by Congress in 2002, the Administration has chosen to devote very little of it to the MCC Project.

Recommendations to Enhance the MCC Project

The MCC Project has made a promising start in reducing HEU stockpiles at civilian facilities in Russia. DOE and the project team should be commended for their efforts, but the scope of the project must still be expanded. The DOE approach of working with Minatom and with Minatom-controlled blending facilities to identify sources of excess HEU and candidate facilities for removal of all HEU has some advantages. It makes maximum use of Minatom's inside knowledge of, and in some instances control over, the operation of facilities with large HEU stockpiles. However, the MCC Project is not currently devoting sufficient resources to non-Minatom, civilian facilities in Russia or to facilities in other nations of the FSU that have smaller, but still dangerous, stockpiles of HEU and inadequate security programs. In addition, by working solely through Minatom, DOE does not have sufficient flexibility to tailor packages of incentives to the needs of individual facilities to persuade them to significantly reduce or eliminate their stockpiles of HEU. We make the following recommendations to augment the MCC Project.

The Department of Energy should:

- **Prepare a comprehensive list of facilities in Russia and other States of the FSU that should be candidates for HEU reductions or removal.** For each facility, DOE should seek to determine how much HEU is at the site and what it is used for. DOE should also assess how well the HEU is protected and the potential for eliminating HEU from individual buildings and from the entire site. DOE should seek cooperation from Minatom in preparing this list, but should not rely solely on its help. The list must also include non-Minatom, civilian facilities in Russia, and facilities outside of Russia. DOE's MPC&A Program is collecting some of this information, but a comprehensive inventory of candidate sites for HEU removal is long overdue and urgently needed to set consolidation priorities.

- **Assign a project manager for each facility on the list.** Each project manager should work with their facility to develop proposals for reducing its stockpiles and eliminating HEU from specific buildings or from the entire site. DOE should reassign current employees and possibly hire new staff on an emergency basis to provide sufficient project managers for all facilities of concern.

- **Target facilities that are the highest priority to the US for HEU reduction and elimination.** DOE should not allow Minatom alone to set the priorities for reducing and eliminating HEU stockpiles. The forthcoming Minatom master plan for its nuclear complex can be a useful starting point, but since it will not include non-Minatom facilities in Russia or non-Russian facilities, it should not be the sole basis of the US consolidation effort. Furthermore, Minatom's priorities for consolidation may not always conform to US priorities. Significantly more benefit can be derived from the elimination of all HEU from a building or site than from simple reductions in the amount of HEU present. Therefore, the US should offer greater incentives (including a higher direct payment) to facilities that completely eliminate HEU from buildings and sites than to those that simply blend down a portion of their inventory. The highest priority should be given to those facilities with the greatest risk of diversion. Efforts should be focused on facilities that have fresh HEU fuel for reactors that are no longer operational or other high-grade HEU that is left over from their programs. Those facilities have the least incentive to spend their resources protecting obsolete HEU stockpiles. Facilities with small, but still significant, stockpiles of HEU should be another high priority. Working first with those facilities will maximize the number of buildings and facilities from which HEU is eliminated for a given investment.

- **Designate a senior official to negotiate tailored incentive packages on a site-by-site basis** to encourage facilities in Russia and other States of the FSU to eliminate HEU from their sites. This official should have the authority to offer flexible packages that may include assistance (including direct payments and subsidized loans) from multiple DOE programs and programs in other agencies. The means of eliminating HEU from a site should also remain flexible and might include the blend-down operation of the existing MCC Project. They might also include other mechanisms, such as blending and sale by a Western agent or transfer to an appropriate large, secure storage facility in Russia or a Western country, possibly the United States.

- **Provide an appropriate incentive for Russia to take back spent HEU fuel from research reactors outside of Russia.** Spent HEU fuel from research reactors still contains appreciable amounts of weapons-usable HEU. Because fuel elements from research reactors are much smaller than those from nuclear power plants, the spent fuel is less radioactive and may provide a very attractive target for diversion. Removal of spent HEU fuel from facilities that no longer have operating reactors should be a high priority because security at such facilities is generally lax. Spent HEU fuel should also be removed from all facilities outside of Russia. For many years, it has been official Russian policy to take back spent fuel that it has supplied to other nations, but Russia has not followed that policy consistently. There is little financial incentive for Russia to recover spent HEU fuel from other nations because the transport and processing costs exceed the value of the reprocessed product. Unlike agreements that Russia has recently made with other countries, the FSU states do not pay Russia a fee for taking the spent fuel off their hands. The US government should give a high priority to recent efforts (discussed in the following section) to accelerate Russian take-back of such spent fuel. US support might at least cover Russia's cost of repatriating and managing the returned fuel.

The Administration and Congress should:

- **Increase funding for an expanded MCC Project to at least $54 million per year (twice the 2003 request).** The additional funds should be sufficient to remove all HEU from high priority facilities within three years and to cut two or more years from DOE's goal of converting 29 tons of HEU to LEU and removing all HEU from 55 buildings by 2010.

- **Provide legislation for DOE to work with Western-based agents to purchase, blend, prepare, and sell LEU derived from non-weapons HEU.** This would allow for the yearly removal of up to 2 tons of HEU from civilian facilities in Russia or other States of the FSU. This legislation is needed to exempt the material from current trade restrictions so it can be sold in the United States. Facilitating the sale of LEU derived from civil HEU can provide additional incentives for Russian blending facilities and institutions with HEU to cooperate in converting the HEU to LEU. It can also provide new opportunities for Western-based organizations to remove HEU from vulnerable facilities for downblending and sale. Care must be taken to insure that this new supply of LEU does not damage the market arrangements of the existing HEU deal. However, the market impact of LEU from an additional two tons of HEU would be small.

PROPOSAL 3

Replace HEU Fuel in Soviet-Built Research and Test Reactors with LEU Fuel

Soviet-Built Research Reactors

The Soviet Union built large numbers of research and test reactors and critical assem blies[42] in Russia, in other Soviet republics, in Eastern Europe, and elsewhere. They were installed at reactor development institutes, military research and production centers, academic research institutes, universities, and non-nuclear research and industrial facilities. Most of them used fuels containing HEU. Today, Russia has approximately 40 operational HEU fueled research and test reactors and critical assemblies (not including reactors used for defense-related activities).[43] There are three operational research reactors in former Soviet republics and several others in operation elsewhere (see Table 1).[44] Unused or slightly irradiated fuel at these facilities represents an attractive target to terrorists or nations seeking to obtain HEU for nuclear weapons. Spent HEU fuel is less attractive because fission products make it radioactive and, therefore, difficult to handle. However, spent fuel or materials extracted from it can still be used to make a nuclear weapon. Research facilities can be eliminated as targets for proliferants if they convert their reactors from HEU fuel to LEU fuel and if all remaining HEU-based fresh and spent fuels at those sites are moved to larger, more secure facilities within Russia.

The facilities of most concern are reactors with continuous power levels above one megawatt (MW). Lower-power reactors, critical assemblies, and pulse reactors typically have fuel cores that last for the lifetime of the reactor and do not need to be replaced. While the fuel is inside of the reactor, it is much less of a security risk. However, reactors with a continuous power level of more than one MW have much higher uranium requirements and may need frequent HEU fuel reloading and replacement. For example, a 5-10 MW IRT- or VVR research reactor may require up to 10 kg of 90-percent HEU per year for reloading. The 100-MW, SM-3 reactor at the Institute of Atomic Reactors in Dimitrovgrad (NIIAR) consumes an estimated 70 kg of HEU per year (see Table 1).

The relative openness of research reactors, especially those located in universities or academic research institutes, to a large number of people makes it more difficult to assure stringent security and control of fissile materials.

There is also a sizable industrial infrastructure within Russia to support the research reactor program. Movement of HEU fuel through this infrastructure provides additional opportunities for diversion, which could be eliminated if all HEU-fueled reactors were to convert to LEU fuels.

Why Fuel Conversion?

Research reactors in Russia and other former Soviet republics are now facing considerable difficulties. Approximately one-third of all facilities are over 30 years old. The reactors are aging

This section is based on a draft of a paper by Oleg Bukharin of Princeton University, titled "US-Russian Reduced Enrichment and Test Reactor (RERTR) Cooperation."

TABLE 1. **Soviet-Built Research Reactors Over One MW Power**[45]

OPERATOR	FACILITY	POWER (MW)	ENRICHMENT (%)	UTILIZATION (MWd/yr)	MAXIMUM BURNUP (%)	ANNUAL U-235 REQUIREMENT (kg/yr)
RUSSIA						
Kurchatov Institute/Moscow	IR-8	8	90	300	60	0.5
IPPE/Obninsk	BR-10 fast reactor	10	90 or Pu	1,500	8	20
NIIAR/ Dimitrovgrad	SM-3 MIR-M1 BOR-60 RBT-10/1 RBT-10/2 RBT-6 Prima	100 100 60 10 10 6 100	90 90 90 or Pu 63 63 63 na	30,000 28,000 20,000* 2,800 2,800 1,680 Under Development	43 60 50* 45 45 45	70 47 42 RBT reactors use spent fuel from SM reactors.
NIKIET- Yekaterinburg	IVV-2M	15	90	2,600	75	3.5
Institute of Nuclear Physics, TPI/Tomsk	IRT-T	6	90	1,000*	50	2.1
MIFI/ Moscow	IRT-MIFI	2.5	90	450	50	1
NIFKhI-Obninsk/ Obninsk	VVR-TS	15	30	2,400	50	4.8
PNPI/Gatchina, St.Petersburg	VVR-M PIK	18 100	90 90*	2,600 Under Construction	70 40	3.7
FORMER SOVIET UNION						
Tashkent, Uzbekistan	VVR-CM	10	Was 90, converted to 36	2,000	70	3
Institute of Nuclear Physics/Almaty, Kazakhstan	VVR-K	10	36	1,000	50*	2.1
Institute of Nuclear Physics (Kiev, Ukraine)	VVR-M	10	36	2,000	60	3.5
EASTERN EUROPE AND OTHER COUNTRIES						
Czech Republic	LWR-15	15	80	1,700	45	4
Serbia	R-A	6.5	80	†	†	3.0
Poland	MARIA	30	Was 80, converted to 36	2,800	40	7.4
Bulgaria	IRT-2000	2	36	85	50*	0.2
Hungary	VVR-SZM	10	36	875	55	1.6
Romania	VVR-S	2	36	400*	50*	0.8
North Korea	IRT-DPRK	8	36	640	50*	1.3
Libya	IVV-7	10	80	270	40	.7
Vietnam	DRR	0.5‡	36	30	0.5*	0.06

† Information not available.

* There is some uncertainty about these figures. They were estimated based on available information when there were insufficient data to provide exact figures.

‡ Although the Vietnam reactor operates at less than one MW, it is still significant from a non-proliferation standpoint.

physically and obsolete in design. For many there is inadequate funding either to continue their operation or to decommission them. In addition, there is a considerable attrition of research and technical staff due to aging and losses to commercial jobs. Funding problems make it difficult for facilities to provide adequate security for their HEU fuels.

The relative openness of research reactors, especially those located in universities or academic research institutes, to a large number of people (including scientists, technicians, and the general public) makes it more difficult to assure stringent security and control of fissile materials. Certain security measures and equipment such as armed guards, multi-layered access restrictions, and sophisticated intrusion detection systems, which are routinely employed at nuclear defense and fuel cycle facilities, are often not accepted in a research reactor setting because of political and public safety reasons. During Russia's financial meltdown in August 1998, small research facilities found themselves in particularly dire straights. Many were not able to pay for electricity to power safeguards and security systems or to support even the most basic operations of their guard forces.

There have been some particularly troubling incidents at research reactor sites. For example, in 1997, the Institute of Nuclear Physics at the Tomsk Polytechnical Institute in Russia could not account for a fresh fuel assembly, which contained 145 grams of 90-percent enriched HEU, which was intended for its IRT-T reactor.[46] This is considerably less than the 25 kilograms considered by the International Atomic Energy Agency as a "significant quantity" for the production of a nuclear weapon, but its disappearance is troublesome nonetheless.

Many Soviet-built research reactors have become permanently non-operational. Expanding the MCC Project can facilitate the task of removing HEU from those facilities, as could a revitalized program to return spent research reactor fuel to Russia as discussed below. Other facilities may be persuaded to shut down their reactors and give up their HEU if provided sufficient incentive to do so. However, some facilities will continue to do research that requires a reactor or critical assembly. Converting research reactors at those facilities from HEU to LEU fuel would eliminate the risk of HEU diversion. Such a conversion would have a number of other important nonproliferation benefits as well. It would:

- Reduce (or eliminate) the proliferation risks associated with fabrication, storage, transportation, and disposition of research reactor fuel;
- Facilitate consolidation and disposition of inventories of fresh HEU fuel that exist at some research reactor locations;
- Allow the Russian government, other host governments, and the international community to save millions of dollars needed to upgrade and maintain security at research reactor facilities; and
- Support US efforts to get Western-built research reactors to convert from HEU to LEU fuel.

US-Russian Cooperation to Reduce Enrichment of Research Reactor Fuel

The United States has been supporting reactor fuel conversion for over 20 years. The Department of Energy launched the Reduced Enrichment Research and Test Reactor Program (RERTR) in 1978. The program, which the Argonne National Laboratory (ANL) coordinates, works to develop higher-density LEU fuels and seeks to make them broadly available to research reactors. Higher densities allow the uranium to be diluted to low enrichment without increasing the physical size of the fuel elements. Approximately 40 research reactors of over one MW in the United States and abroad have begun or completed the transition to LEU fuel since the beginning of the program; this is more than half of the HEU fueled reactors in the US and other Western nations. As a result, US HEU exports declined from almost 700 kg per year in the mid-1970s to zero in 1993. Furthermore, with the exception of the FRM-II research reactor nearing completion in Germany, no HEU-fueled research reactor has been built in the Western world since the RERTR program began.

In 1978, the Soviet Union launched its own effort to reduce the enrichment level of research reactor fuels. During the next ten years, they were able to develop higher density "cermet fuel"[47] with uranium enriched to 36-percent U-235; this meant an increase in uranium density from 1.5

to 2.5 gU/cm^3 (grams of uranium per cubic centimeter). This new higher density fuel was able to be loaded into IRT- and VVR-type reactors without changes in core configuration, but it did result in some loss of neutron flux.[48] This reduction in flux was problematic, because neutron production is the main task that research reactors are designed to carry out. During the 1980s, the Soviet Union largely stopped exporting 90-percent HEU fuel to Soviet-built research reactors in other countries and started supplying them with 36-percent HEU instead. The Soviet reduced enrichment program, however, ground to a halt in the late 1980s due to insufficient funding.

Revitalizing the Russian fuel conversion effort has become an important priority of the US RERTR Program. In December 1993, the United States and Russia signed an agreement to design and manufacture fuel enriched to 19.75-percent U-235 for Soviet-designed research reactors.[49] Under this agreement, the US RERTR Program contracts with Russian research institutes to perform RERTR-related studies. It also supports the Russian effort by providing US expertise in fuel development and design and help in analyzing how well Russian reactors would perform with new LEU fuels. In addition, the program assists reactor operators with actual conversion.

Development of LEU fuel

In the joint program's first years, the Russian institutes insisted on working on the development of higher-density (3.85 gU/cm^3), uranium-oxide cermet fuels, with which they had considerable experience, instead of US-proposed silicide fuels. In 1997, test fuel assemblies for MR-, VVR-, and IRT-type reactors were irradiated in the reactors at the Institute of Atomic Reactors in Dimitrovgrad (NIIAR), the Institute of Nuclear Physics in St. Petersburg (PNPI), and the Kurchatov Institute in Moscow, respectively. The NIIAR and Kurchatov fuel assemblies failed tests,[50] delaying the project's overall progress. However, PNPI successfully completed tests of fuel elements in 2001, which put the program in a position to convert the fuel in VVR-type reactors, such as the research reactor in Budapest. Some uncertainty remains, however, regarding the ability of Russian fuel fabricators to mass-produce new, higher-density uranium oxide fuel at a reasonable cost.

In 2000–2001, the fuel development effort took a new turn, which may make the work on uranium-oxide fuels obsolete. The Bochvar Institute in Moscow, in cooperation with the Electrostal fuel fabrication facility near Moscow, proposed using a uranium-molybdenum alloy fuel dispersed in an aluminum matrix (U-Mo fuel).[51] The U-Mo fuel is easier to manufacture and experts believe they can achieve densities of 6–7 gU/cm^3 with it. This should allow all Soviet-designed reactors outside of Russia and most reactors in Russia to convert to LEU fuel. The US RERTR Program funds the development work, which draws on both Russia's research intoU-Mo fuels and technical data from US and French efforts.[52] Irradiation of test fuel elements is scheduled to begin in mid 2002. Other Russian institutes are also working on uranium-molybdenum fuel.

Reactor conversion

So far, the joint US-Russian program has had only limited success in facilitating conversion to LEU fuel. Some elements of the Russian nuclear establishment continue to view all nuclear operations as sensitive and oppose cooperation and information sharing with the United States. In addition, Russian specialists, having observed the dissatisfaction of some reactor operators in Western Europe with RERTR arrangements and seeing the DOE's refusal to convert some of its own reactors to LEU fuel, might believe that the use of LEU fuel would entail a financial burden and a decline in the quality of reactor performance. Some are concerned that since LEU fuel has a higher neutron-absorbing U-238 content, it might produce a less intense neutron flow than its HEU counterpart. This reduced intensity would be problematic, because, as mentioned above, neutron production is the *raison d'être* for most research reactors. This fear can be conclusively alleviated only by demonstrating adequate performance in the first reactors to adopt the new fuels.

Because of the opposition from Russian operators, the RERTR Program is focusing its initial conversion work on Eastern Europe and former Soviet republics other than Russia. The initial conversions are still several years away. Assuming full cooperation of the reactor operators and availability of the new U-Mo fuel, conversion of the reactor in Tashkent, Uzbekistan, which program officials consider a pilot project, could happen as early as 2005. The program has targeted reactors in Kazakhstan, Ukraine, the Czech republic, Hungary, Poland, and Bulgaria for conversion between 2006 and 2009. The actual schedule will depend on many factors. For example, the MARIA reactor in Poland has recently made a transition to 36-percent enriched fuel and has a fresh fuel supply that will last until 2009. The reactor does not plan to convert to LEU before then.

In the meantime, the US and Russian partners are working to characterize the remaining Soviet-built research reactors, and to define procedures for management and disposition of spent high-density fuel. For example, the Kurchatov Institute has begun to study the feasibility of converting its IR-8 reactor to high density LEU fuel.[53] We hope that reactor conversion experiences in Eastern Europe and former Soviet republics will demonstrate the benefits of the new LEU fuel to reactor operators in Russia.

Moving Forward

Conversion of research reactors from HEU to LEU fuel is not possible unless there is a source of high-density LEU fuel, which is of high-quality and reasonable price, and unless the reactor

BOX 2. Russian Take-Back of HEU Fuels

For many years, it has been official Russian policy to take back spent research reactor fuel, but Russia has not followed that policy consistently. Spent HEU fuel has some value if it is reprocessed, blended, and sold, but the cost of transporting, storing, and processing the spent HEU fuel exceeds the value of the product. Russia has been unwilling to bear that cost. Since late 1999, the United States has been working with Russia and the International Atomic Energy Agency to repatriate Soviet-supplied HEU fuels from 16 nations. Most of those nations are eager to send back their spent fuel to eliminate the storage and security costs and reduce the risk of accidents or theft of the HEU fuel.

Negotiations are well under way for a program under which the United States will pay Russia to take back Soviet-supplied fuel. This effort is closely tied to efforts to convert research reactors from HEU to LEU fuels. According to a US source cited in *NuclearFuel*, “the US funding is tied to a commitment to convert to LEU.”[54] If reactor operators agree to convert, the US would pay some or all of the costs of fabricating and transporting new LEU fuel in addition to assisting with Russia’s cost to transport and manage the HEU fuel. Under this program, Russia would also take back unused fresh HEU fuel from reactors that convert and would take all HEU fuels from reactors that are no longer operating.

According to DOE’s 2003 Budget request, the US and Russia have reached “preliminary agreement” on spent fuel management costs and a pilot shipment site for return of Soviet-supplied HEU fuels to Russia. DOE hopes to complete the agreement this year. According to the Budget, in 2003 DOE plans to “initiate repatriation to Russia of 500 fresh and spent nuclear fuel assembles and participate in two fact-finding missions to evaluate fuel inventory and conditions at six potential sites”.

The first test bed for the program is likely to be the Tashkent reactor in Uzbekistan, which is currently using 36 percent-enriched HEU fuel. However, according to the *“NuclearFuel”* article cited above, the Tashkent reactor reportedly has both fresh and spent fuel of 80 to 90 percent enrichment in storage, the removal of which should be a high priority. Another high priority for the United States is removal of about 50 kg of fresh, 80 percent-enriched, HEU fuel and additional amounts of spent and lightly irradiated fuel from an inoperable reactor at the Vinca Institute of Nuclear Sciences, near Belgrade, Serbia.

Russian takeback of Soviet-supplied HEU fuel can have a significant impact on reducing the proliferation danger of HEU stockpiles. It should receive the strongest possible support from the United States, including sufficient funding and attention from high-level policy officials.

operators are willing to make the transition. The recent change of RERTR's focus from uranium-oxide to U-Mo LEU fuel will hopefully put the program on track towards solving the fuel availability problem. However, conversion of the SM-3 reactor in Dimitrovgrad and some other high-power reactors in Russia may require additional efforts to change structural materials in their fuel and possibly develop even denser fuel.[55]

Convincing all reactor operators to convert to LEU fuel will remain a challenging task and will require focused and sustained efforts on the part of Russia and the United States.

Incentives for reactor operators

Most reactor operators are likely to make the transition to LEU fuel if that are provided with a package of incentives, including:

- Provision of a guaranteed supply of free LEU fuel for a reasonable period of time;
- Assistance in removing the backlog of spent fuel to another location; and
- Payment for and disposition of any un-irradiated HEU fuel.

The first incentive would likely involve payment by the United States to a fuel fabricator (presumably in Russia) for at least the first LEU fuel core. The United States might also cover fuel qualification and other conversion-related expenses. The second and third elements of the package would involve negotiating with and paying Minatom a reasonable price for packaging and moving fuel to Russia, and for subsequent fuel storage and disposition in Russia. (See Box 2).

While conversion to less than 20-percent enriched LEU is the ultimate goal, the US should provide incentives to research reactors to move to 36-percent enriched fuel, as a first step, if no suitable LEU fuel is available. The VVR-CM reactor in Tashkent has made such a transition, thereby greatly reducing the overall risk of nuclear proliferation from Uzbekistan. The reflected critical mass[56] of 36-percent enriched uranium is about 150 kg—six times that of 90-percent enriched HEU. That means about six times as much material is needed to make a nuclear weapon from the lower enriched HEU. For comparison, the reflected critical mass of 19.9-percent enriched LEU is over 400 kg.

Strengthening the US RERTR Program

In recent years, the RERTR Program has received little support from DOE's top management. The program is under-funded at $5 million per year. In addition, DOE has not drawn on the potential for synergy between the RERTR Program, the MCC Project, and efforts to encourage Russian take-back of Soviet-supplied HEU fuels. Conversion of research reactors to LEU fuel would help eliminate or reduce the resistance of some institutes to giving up their HEU stocks out of fear that they would be unable to continue nuclear research.

The level of funding for reactor conversion has been grossly insufficient. Since 1996, much of the RERTR work in Russia has been financed though a one-time $1.5 million grant from the US Department of State's Nonproliferation and Disarmament Fund. These resources are insufficient and, as a result, potentially valuable work is going unfunded. In principle, the DOE could use funds from the RERTR program to support work in Russia, but the RERTR Program's budget has been declining, and it is not sufficient to fund both the US and Russian development efforts.[57]

A broad effort to convert Russian-origin research reactors, which goes beyond current research, development, and demonstration projects, would require additional funding. Ballpark estimates suggest a cost of $1 million per reactor to convert to the new fuels, including the cost of the first LEU core, but not including the cost of other incentives. An increase over current appropriations of less than $20 million per year, for the next few years, would be sufficient to fund the conversion of nearly all Soviet-built, HEU-fueled reactors and the return of all HEU fuels to Russia within by 2010. No funding for these purposes is likely to be available from Russia or other former Soviet countries. It is up to the United States to fund these programs, in order to significantly reduce the potential for diversion of HEU.

Conclusion

The danger that nuclear weapons or weapons-usable material in Russia or other nations of the Former Soviet Union could be stolen, sold to terrorists or hostile nations, and used against Americans or our allies remains an urgent threat to the security of the United States. The US government supports several programs to reduce this danger. These efforts have made considerable progress, but much more remains to be done.

We have presented three proposals to expand existing programs for reducing stockpiles of HEU in Russia and other nations of the Former Soviet Union. We recommend that the United States adopt these proposals to:

- Rapidly blend down all excess Russian weapons-origin HEU;
- Remove HEU stockpiles from smaller, less secure facilities in the FSU; and
- Replace HEU fuel in Soviet-built research and test reactors with LEU fuel.

We recommend that the current rate of blending down excess weapons-origin HEU be doubled. Such an increase would be straightforward and could be accomplished for about $40-60 million per year to cover the cost of the blending and to provide the incentive for Russia to adopt it.

We recommend a number of measures to enhance the Department of Energy's efforts to remove HEU from smaller, less secure facilities in the FSU and to focus those efforts on the facilities that present the greatest risk. Most of our recommendations are for policy changes that would cost little to implement. However, we also recommend that annual funding for DOE's Materials Consolidation and Conversion project be twice the Administration's 2003 request of $27 million. The additional funds could be sufficient both to remove all HEU from high priority facilities within three years and to cut two or more years from the time needed to fulfill DOE's longer term goals.

The US government supports several programs to reduce this danger. These efforts have made considerable progress, but much more remains to be done.

We recommend expanding efforts to replace HEU fuel in Soviet-built research and test reactors with LEU fuel. That will require continued support for research programs to develop and test higher density LEU fuels; payment for at least the first LEU fuel core for reactors whose operators agree to convert; and payments to Russia to take back Soviet-supplied spent fuel and unused fresh fuel in other countries. An increase of less than $20 million per year over current appropriations, for the next few years, would be sufficient to fund the conversion of virtually all Soviet-built, HEU-fueled reactors and the return of all HEU fuels to Russia within the next few years.

Implementation of these three proposals would significantly reduce the risk that terrorists or other groups might divert HEU for use in nuclear weapons. All three are low cost, and none of them pose insurmountable policy challenges that would obstruct their implementation. They are the low hanging fruit. They can be picked now, while other efforts continue to address some of the more challenging long-term problems.

APPENDIX A

Overview of US Efforts to Control the Spread of Russian Nuclear Weapons, Materials, and Expertise

The United States government currently conducts about twenty programs, costing upwards of half a billion dollars a year, that aim to control the spread of Russian nuclear weapons, materials, and expertise.[58] The first was the Cooperative Threat Reduction Program in the Department of Defense (DOD), which began in 1992 as the "Nunn-Lugar" program. As part of that program, DOD has taken the lead in efforts including the dismantlement of nuclear weapons delivery systems, construction of a secure storage facility for fissile materials from dismantled nuclear weapons, and cooperating with the Russian Ministry of Defense. The Department of State manages programs to address "brain drain" problems in Russia and other countries of the FSU. It also has the lead role in negotiating government-to-government agreements such as an agreement that governs joint activities for the disposition of plutonium. The Department of Energy (DOE) is the lead agency for efforts to secure, monitor and reduce nuclear material stockpiles in the FSU, reduce the size of the Russian weapons complex, and redirect weapons experts to civilian employment. Related programs are conducted by the US Customs Service, the Nuclear Regulatory Commission, and other agencies.

The results of these programs have been impressive. Hundreds of ICBMs (intercontinental ballistic missiles) and other delivery systems have been destroyed, and thousands of nuclear weapons have been dismantled. Nuclear warheads and delivery systems in Ukraine, Belarus, and Kazakhstan have all been returned to Russia or destroyed. Warheads at over 500 sites in the FSU have been consolidated to fewer than 80 sites,[59] all within Russia, and they are tightly guarded. All major sites with weapons-usable fissile material in the FSU, with the exception of four nuclear warhead assembly and dismantlement plants in Russia, are cooperating with DOE's Materials Protection, Control and Accounting (MPC&A) Program.[60] Under this program, DOE funds upgrades to security systems at sites holding stockpiles of fissile materials. Work on these security upgrades has begun at nearly every site and has been completed at many of them. In the brain drain area, several US and international programs have provided grants and assistance that engage in civilian endeavors more than 40,000 FSU scientists and engineers with weapons-of-mass-destruction-related expertise.

Much more remains to be done. In early 2000, experts at the Harvard Project on Managing the Atom estimated that only 20 percent of the work needed to achieve effective and sustainable security of nuclear weapons and materials in the FSU had been completed, and only 10 percent of the defense conversion work needed to achieve a smaller nuclear complex had been done.[61] The Department of Energy estimates that it will not complete installation of security systems at all sites under the MPC&A program until 2011.[62] Less than 30 percent of the weapons-origin HEU, which Russia has declared as excess, has been downblended into LEU, and disposition of the first gram of excess weapons-origin plutonium is still several years away.

US efforts must overcome several barriers to fully address the threat of diversion. The most fundamental obstacles involve differences between the priorities of the US and those of Russia. While the primary US interest in the Russian nuclear complex is nonproliferation, Russia's primary interests are to maintain a functioning, albeit smaller, nuclear arsenal, develop its civil nuclear industry, and provide employment for the vast number of workers previously supported by the weapons program.

Additional barriers to cooperation include: secrecy and limited access to facilities; mistrust between the US and Russian governments; deeply ingrained differences regarding the value of separated plutonium as a nuclear fuel; continuing Soviet-style bureaucracy, poor coordination among new and changing government ministries and regional power centers in Russia; continuing US-style bureaucracy and interagency disagreements in the United States (including continuing bureaucratic wrangles over arrangements for travel of US experts to Russia to implement the programs); rampant corruption and inadequate legal and banking systems in Russia; and difficulties in redirecting the economics of formerly closed Russian nuclear cities in a stagnating economy, when defense conversion has proven challenging even in a dynamic growing economy.

Despite all this, lack of sufficient funding for some programs is perhaps the most significant barrier that must be overcome. In January 2001, a bi-partisan task force headed by Howard Baker and Lloyd Cutler called for spending $30 billion over the next 8–10 years (an average of more than $3 billion per year) in order to properly execute the Russian nonproliferation programs funded by the Department of Energy.[63] However, even with a last minute addition from the $40 billion anti-terrorism package passed by Congress in the wake of September 11, DOE expects to spend only $495 million for Russian nonproliferation programs in 2002 and has requested only $516 million for 2003.[64]

APPENDIX B
The Existing HEU Agreement

The existing HEU agreement, often referred to as "the HEU deal,"[65] is a complex arrangement that has proceeded in fits and starts. Despite numerous problems, the HEU deal has resulted in the elimination of a substantial amount of Russian HEU. As of December 31, 2001 more than 140 tons of Russian weapons-origin HEU had been blended into LEU and delivered to USEC Inc. (the US executive agent for this agreement) for sale as fuel in nuclear power plants.[66] That is nearly 27 percent more than the original 1994 implementing contract called for by that date.[67] It is enough HEU for more than 5,500 nuclear weapons.

One must understand the fragile nature of the existing HEU agreement to appreciate both the constraints upon and the opportunities for expanding efforts to reduce Russian HEU stockpiles. The first priority is to do no harm to the existing deal. Given the substantial benefits and tenuous nature of the existing agreement, the US government is unlikely to consider opportunities for further reductions in the Russian HEU stockpile, unless it is confident that they will not damage the existing deal. Within that constraint, however, there is substantial opportunity to do more.

From the beginning, the major hurdle that framers of the agreement strove to overcome was how to accommodate large quantities of Russian LEU into the market, without causing enormous disruptions to market prices or substantial layoffs in the domestic uranium and enrichment industries. Such concerns were the reason the rate of the blending and sale operation was set at 30 metric tons of HEU per year. Policymakers believed that amount of Russian LEU, equal to about 50–60 percent of the annual requirements of US nuclear power plants, was the maximum that could be absorbed. Since there were substantial excess supplies of natural uranium and a global overcapacity for uranium enrichment, sizable US production cutbacks were necessary, and continue to be necessary, to absorb that material into the market.

When the HEU deal was first established, the US enrichment industry was entirely owned by the government. Until 1993, it was part of the Department of Energy. In that year, a semi-independent, government-owned corporation, "the US Enrichment Corporation (USEC)" was established. USEC had to reduce production levels in its enrichment facilities to absorb the enrichment component (see Box 3) of the Russian LEU. This resulted in a hidden cost to the government, since its plants were less efficient when operated at the lower production level. The initial price paid to Russia under the deal was considerably less than the price at which the government was selling enrichment, so no actual federal appropriations were needed. Accommodating the enrichment

BOX 3. Two Components of Enriched Uranium

Naturally occurring uranium must be enriched to produce LEU. Therefore, LEU can be thought of as consisting of a natural uranium component and an enrichment component. Historically, nuclear power plant operators have met their uranium and enrichment needs through separate purchases. LEU produced by downblending HEU intrinsically contains both components, but the amounts of each can be established. While the two components are physically intertwined, trade in LEU is still usually based on separate sale of its contained uranium and enrichment.

portion of the HEU deal merely resulted in lower earnings for the government-owned USEC.

The situation was quite different for the uranium component of the LEU. There was no US government uranium producer, and most of the uranium used by nuclear power plants in the United States came from foreign producers. Furthermore, as a result of an earlier finding by the US International Trade Commission that the Soviet Union was guilty of dumping uranium in the United States at below the cost of production, US import and consumption of Russian uranium was severely restricted. The initial implementing contract for the HEU deal called for USEC to pay for the uranium content of the LEU it received from Russia only after USEC was able to resell it for use in nuclear fuel. It quickly became apparent, however, that it would be many years before the uranium was sold and Russia was paid. Since payment for the uranium content represented about one-third of the funds that the Russian government expected from the deal, it repeatedly threatened to stop all LEU deliveries until Russia was compensated for the uranium. Russia did suspend deliveries for a brief time in 1997.

In response, the US government agreed to pay $157 million for the uranium that Russia had delivered in 1995 and 1996 and to amend the agreement to give Russia an amount of natural uranium equal to the uranium content in the LEU it delivered under the HEU deal beginning in 1997. This turned the US-Russian HEU agreement for the purchase of LEU into an agreement for the purchase of enrichment only. LEU deliveries resumed for a while, but in late 1998, Russia suspended deliveries again, because it was still unable to sell the uranium that it got back and was not allowed to import it for its own use. At the time, the export of the natural uranium to Russia was prohibited, so the material was sitting, unused at USEC's facilities. This second crisis for the HEU deal was resolved in March 1999, when the US government paid Russia another $325 million for the uranium content of the 1997 and 1998 LEU deliveries under the agreement. In addition, three Western mining and fuel services companies (owned primarily by non-US interests) signed a long term contract with the Russian government giving them the option to purchase a substantial portion of future uranium deliveries under the HEU deal. Arrangements were also worked out for unsold uranium to be returned to Russia for its own use.

The agreements of March 1999 appeared to resolve the longstanding problem of Russia not receiving payment for the uranium portion of LEU deliveries under the HEU agreement. However, Russia is still not earning what it originally expected from the uranium. Early on, the Russian government set a floor price of $29 per kg below which it would not sell this uranium. However, during the 1990s, world uranium prices fell considerably, in part because of the extra uranium supply created by the HEU deal. Therefore, Russia sold very little of the uranium from the agreement. The price of uranium has recently recovered to slightly above Russia's $29 per kg floor price, and in November 2001 the Western parties to the 1999 agreement converted their options contracts to commitments to purchase a substantial portion of the Russian uranium from the HEU deal. However, Russia's revenue from the uranium component of the LEU is still lower than it originally anticipated. Russia's inability to receive an attractive return on the uranium content of the LEU continues to hamper the smooth operation of the HEU agreement.

Meanwhile, difficulties also arose with the enrichment portion of the deal. As this report went to press, no deliveries of LEU under the agreement had occurred in 2002 or been scheduled, because of a dispute over pricing. The original HEU agreement called for annual negotiations between the US and Russian executive agents regarding the price for both the uranium and the enrichment content of the LEU. As discussed above, payment for the uranium content is no longer part of the deal. In 1997, USEC and Tenex (the Russian executive agent for the agreement) signed a contract that set the enrichment price through the end of 2001. Under that contract, the price that USEC paid for the enrichment increased with inflation. Since 1997, however, the world enrichment price has fallen. Thus, in 2001 USEC paid Russia a wholesale price for enrichment that was nearly the same as the retail price USEC received by reselling it. This put severe financial pressure on USEC, since Russian enrichment represented about half of USEC's sales. There was now little or no profit margin on the Russian enrichment that it could apply to offset its fixed overhead costs. What really made that situation

BOX 4. Does the United States Need A Domestic Source of Uranium Enrichment?

The United States imports about two-thirds of its petroleum, 90 percent of its uranium, most of its steel, and nearly all of some types of computer memory chips. Why then is it so important to maintain a domestic source of uranium enrichment? The argument for maintaining such a source is that the enrichment industry is more highly concentrated than any of the other industries mentioned. There are only three enrichment producers (two in Europe and one in Russia) of any size outside the United States. Without any enrichment from the United States, the other three might barely meet world demand.

Short of maintaining a large and expensive strategic reserve of enriched uranium (which could be acquired by downblending HEU from dismantled US nuclear weapons), the United States would be vulnerable to a halt in deliveries from any one of the foreign enrichment producers. A substantial portion of the nation's electricity production from nuclear energy would be at risk.

a problem, however, is that in July 1998, the US government sold USEC to the private sector. Now, instead of being a hidden cost to the government, the economic penalty of constraining domestic enrichment production to accommodate Russian LEU under the HEU agreement is being borne by a private company with a fiduciary responsibility to earn a profit for its shareholders. With USEC operating as a private company, it is more difficult for the government to channel taxpayer funds to subsidize the HEU deal as it has done in the past.

In an effort to improve its profitability, in June 2001 USEC closed one of its two enrichment plants, leaving its remaining plant in Paducah, Kentucky, as the sole domestic source of enrichment services. The Paducah plant is still operating at well below its full capacity. This reduced production level (constrained to accommodate Russian LEU into the US market) does not allow USEC to fully offset its fixed costs with sales of enrichment from Paducah. To fully offset these costs and earn a profit, USEC needs a markup between the price it pays Tenex for the enrichment from the HEU deal and the price at which it resells that enrichment. Tenex, on the other hand, views that markup as a markdown from the price it would receive if it could sell the enrichment component directly to US utilities. The larger the markup/markdown, the more Tenex believes it is being unfairly treated. The US government does not allow Tenex to sell its enrichment directly to utilities in part because of a history of Soviet dumping of uranium and enrichment on the US market at below cost. In addition, direct sales from Tenex to US utilities would leave USEC unable to cover its fixed costs, which in turn might lead USEC to stop production at Paducah and exit the uranium enrichment business altogether.

Ordinarily, the profitability of a private company would not be of concern to the US government. However, in this case, a failing USEC might be forced to shut down the last operating enrichment plant in the United States. Russian and European enrichment operators would probably be able to make up for the loss of production from Paducah. However, that would leave the US nuclear power industry, which accounts for more than 20 percent of electricity production in this nation, vulnerable to a cutoff in deliveries from Russia or either of the other two producers.

The squeeze on domestic enrichment production has been caused by the large amounts of enrichment introduced into the US market by the HEU deal. That squeeze is a necessary consequence of continuing the HEU deal, which is of vital national security interest to the United States. However, the government must seek a balance between the national security benefits of the HEU deal and the viability of the domestic enrichment industry. If USEC were to shut down the Paducah plant, it would take at least five years for USEC or another entity to build a new enrichment production plant in the United States, presumably using centrifuge technology. If necessary, the government could take over operation of Paducah from USEC, or it could restart production in the Portsmouth enrichment plant, which is being maintained on standby. In such a situation, however, the government would have to directly provide the funding needed to continue operating the plants at a capacity below that needed to break even.

After lengthy negotiations, as this report went to press, USEC and Tenex had concluded a tentative agreement to establish an enrichment price for 2002 and beyond. That agreement was awaiting approval by the US and Russian governments. The tentative agreement strikes a delicate balance. While USEC and Tenex obviously have opposing interests regarding the pricing of the enrichment, it was in both of their interests to conclude an agreement and have it approved by their governments. Tenex would like an agreement to avoid lengthening the delay in deliveries, which has interrupted the flow of revenue from the HEU deal. USEC would like an agreement because a more lengthy delay in deliveries could lead the US government to reassign the executive agency for the HEU deal to another organization. In that case, USEC would suffer doubly from the HEU deal in that its production would be constrained to accommodate the enrichment imports from Russia and it would have a new domestic competitor.

The latest suspension of deliveries under the HEU deal underlines its tenuous nature. The continued operation of the agreement depends upon a fine balance of commercial interests in uranium and enrichment. Since the HEU deal is the foundation of efforts to control Russian nuclear materials, any proposal to further reduce stockpiles of HEU in Russia must not threaten that balance. The first proposal in this paper is designed to complement the HEU deal and to build upon its foundation, without causing it to crumble. Implementation of that proposal will produce a substantial new supply of LEU. However, the proposal is structured to insure that the new material is not introduced into the market until all the LEU from the initial HEU deal is sold. The second and third proposals will have little impact on commercial markets or the existing HEU deal, because they target relatively small amounts of HEU.

NOTES

[1] Nuclear Notebook, Global Nuclear Stockpiles: 1945–1997, *Bulletin of the Atomic Scientists*, vol. 53, no. 6, November/December 1997.

[2] NRDC Nuclear Notebook, Russian Nuclear Forces, 2001, *Bulletin of the Atomic Scientists*, vol. 57, no. 3, May/June 2001.

[3] Jon Wolfsthal, Christina-Astrid Chuen, and Emily Daughtry, eds., *Nuclear Status Report: Nuclear Weapons, Fissile Material, and Export Controls in the Former Soviet Union*, Monterey Institute of International Studies, Monterey, CA and Carnegie Endowment for International Peace, Washington, DC, Number 6, June 2001. <www.ceip.org/files/publications/StatusReport.asp?from=pubtitle>

[4] National Academy of Sciences, Committee on International Security and Arms Control, *Management and Disposition of Excess Weapons Plutonium*, National Academy Press, Washington, DC, 1994.

[5] US Department of Energy, Secretary of Energy Advisory Board, *A Report Card on the Department of Energy's Nonproliferation Programs with Russia*, Howard Baker and Lloyd Cutler Co-Chairs, Russia Task Force, January 10, 2001. <www.hr.doe.gov/seab/rusrpt.pdf>

[6] National Intelligence Council, *Annual Report to Congress on the Safety and Security of Russian Nuclear Facilities and Military Forces*, Feb. 2002. <www.cia.gov/nic/pubs/other_products/icarussiansecurity.htm>

[7] The Nuclear Threat Initiative maintains a searchable database of all reported incidents of nuclear trafficking at <www.nti.org/db/nistraff/index.html>.

[8] The most prominent efforts include:

A Report Card on the Department of Energy's Nonproliferation Programs with Russia, Op. cit.

Managing the Nuclear Materials Threat: A Report of the CSIS Nuclear Materials Management Project, Project chair, Sam Nunn; Project director, Robert E. Ebel, January 2000.

Matthew Bunn, *The Next Wave: Urgently Needed New Steps to Control Warheads and Fissile Materials,* A joint publication of Harvard University's Project on Managing the Atom and the Non-Proliferation Project of the Carnegie Endowment for International Peace, April 20, 2000. <http://ksgnotes1.harvard.edu/BCSIA/Library.nsf/atom>

[9] Although all Soviet nuclear weapons and more than 99 percent of the HEU is now in Russia, the problem extends beyond Russia to other nations of the Former Soviet Union.

[10] The word *disposition* is a technical term that is broader than the word *disposal*. It is used here and elsewhere to refer to disposal and other means for long-term management of fissile materials, including their use as fuel in nuclear reactors.

[11] A metric ton equals 1,000 kilograms, which is equal to 2,205 pounds.

[12] USEC Inc., Megatons to Megawatts fact sheet. <www.usec.com/v2001_02/HTML/megatons_fact.asp>

[13] The concepts behind proposals one and two first appeared in: Matthew Bunn, *The Next Wave: Urgently Needed New Steps to Control Warheads and Fissile Materials, Op. cit.*

[14] The Russian government has not released information on its total inventory of HEU.

[15] The term *weapons-grade equivalent* refers to HEU with the same amount of U-235 that would be in a specified quantity of 93-percent enriched uranium. In this case, it represents more than the specified 500 tons of material, since an unknown portion of it is enriched to less than 93-percent. If, for example, the average enrichment level is 80-percent U-235, the 500 tons of weapons-grade equivalent HEU would represent about 580 tons of total HEU.

[16] An additional 100-200 tons of non-weapons-grade, but weapons-usable, HEU is contained in naval and other reactor fuels.

[17] David Albright and Kevin O'Neill, eds., *The Challenges of Fissile Material Control*, Institute for Science and International Security (ISIS), Washington, DC, 1999.

[18] This assumes a nominal figure of 25 kg of weapons-grade HEU per nuclear weapon.

[19] Matthew Bunn, private communication.

[20] The analysis of operating costs is based on an unpublished paper prepared by Matthew Bunn of the Harvard Project on Managing the Atom. *The Cost of Rapid Blend-Down of Russian HEU*, July 11, 2001.

[21] Russia should be encouraged to rearrange the contracts between its facilities to minimize the long-distance transport of HEU required by its blend-down operation.

[22] This addresses the issue of the undesirably high concentration of U-234 in weapons-grade uranium.

[23] If the enrichment were to be carried out now, about 120 tons per year of 1.5-percent enriched LEU would be needed to downblend 30 tons per year of HEU to 19.9-percent LEU. It would cost $10-20 million for Russian enrichment facilities to produce the necessary blendstock, but they are likely to charge more, since that amount of enrichment would be valued as high as $40–50 million for sale on the commercial market. If the addition of the costly blendstock were pushed back to a later date, the initial blending to 19.9 percent LEU would only cost $3 million per year. This would cover the costs of the annual supply of 110 tons natural uranium necessary to blend 30 tons per year of HEU to 19.9 percent LEU. In the future, blending of the 19.9-percent LEU to fuel grade LEU would have to be performed with 1.63-percent enriched blendstock for the product to meet the specifications for nuclear fuel. This more highly enriched blendstock would be more costly to produce than the 1.5-percent blendstock that Russia uses for its current blending operations, thereby increasing Russia's future blending costs. On the other hand, using 1.63-percent enriched blendstock would ultimately result in the production of a larger quantity of 4.4-percent LEU for sale. Those two effects would roughly cancel each other, making both options cost the same in the long term.

24 Criticality concerns involve making sure that the 19.9-percent LEU is not stored in such a way that it reaches critical mass and undergoes a nuclear chain reaction, thereby triggering a meltdown.

25 Once the HEU has been blended down to LEU, it can be stored in standard buildings because it no longer constitutes a proliferation threat. The very purpose of conducting blend-down operations is to alter the uranium so that rigorous storage requirements are no longer necessary. USEC, Inc. keeps its LEU storage containers outdoors.

26 This estimate is based on an approximately 50-percent mark-up from the $25–43 million in projected operations costs.

27 The Nuclear Threat Initiative (NTI) is a charitable organization that is working to reduce the risk of weapons of mass destruction use and to prevent their proliferation. It is funded primarily by Ted Turner and directed by Sam Nunn.

28 Security expenditures at a typical, modestly sized HEU processing facility in the United States would be about $4–5 million per year. While security costs for similar facilities in Russia may be slightly lower, potential savings from consolidating HEU stockpiles would be on the same order of magnitude. DOE's expects to spend $50 million per year on operational and infrastructure assistance to Russian institutes in order to ensure security. The estimated security savings of millions of dollars per year will presumably constitute some fraction of these expenditures.

29 *The Challenges of Fissile Material Control, Op. cit.*

30 Steve Fetter, A Comprehensive Transparency Regime for Warheads and Fissile Materials,. *Arms Control Today,* January/February 1999 <www.armscontrol.org/act/1999_01-02/sfjf99.asp>

31 US Department of Energy, FY 2003 Congressional Budget Request, Defense Nuclear Nonproliferation/International Material Protection Control and Accounting/Material Consolidation and Conversion and Civilian Sites.

32 *Nuclear Status Report, Op. cit.*

33 US General Accounting Office, *Nuclear Nonproliferation: Security of Russia's Nuclear Material Improving; Further Enhancements Needed,* February 2001, GAO-01-312, p. 17.

34 *Ibid*, p. 23.

35 Thomas Wander, *et al*, Material Consolidation and Conversion: the Model & Pilot Projects", Presented at the 42nd annual meeting of the Institute of Nuclear Materials Management, Indian Wells, CA, July 15–19, 2001.

36 The facilities are the Scientific Industrial Association "Luch," in Podolsk, Russia and the Research Institute of Atomic Reactors (RIAR) in Dimitrovgrad, Russia.

37 The difference in final LEU ownership under the HEU deal and the MCC Project is reflected by the cost differences associated with each program. Under the HEU deal, the US pays Russia on average twice as much as it does under MCC for each metric ton of HEU that is downblended. The HEU deal payments are based on the value that the material has for use as nuclear fuel, while the MCC payments are structured to cover downblending expenses and provide a financial incentive for Russian facilities to cooperate with the program.

38 The lack of site-by-site information makes it difficult to verify whether the 29 tons in question will be removed piecemeal from many small facilities or wholesale from a few larger facilities. The former approach must be taken if the blend-down of 29 metric tons of HEU is to result in the removal of all HEU from 55 buildings.

39 *The Next Wave*. *Op. cit.*, p. 78.

40 Matthew Bunn, private communication.

41 GAO-01-312, *Op. cit.*, p. 27.

42 A critical assembly is a mock up of a nuclear reactor core. It is capable of reaching criticality but cannot generate any power because it does not have the necessary cooling arrangement to remove fission heat. Researchers use these reactors to study the physics of reactor cores.

43 As of 1998, there were 113 research reactors and subcritical and critical assembly facilities in Russia. Of those, 61 were in operation, 46 were not in operation, and six were under construction. For a list of research reactor facilities see: T.Cochran, S.Norris and O.Bukharin, *Making the Russian Bomb: from Stalin to Yeltsin*, Westview Press, Boulder, CO, pp. 198–201.

44 The higher-power reactors (up to 100 MWt) are primarily used for research on nuclear materials and reactor equipment and are located in large reactor-technology development centers. Reactors with power levels of between 1 and 20 MWt are used for basic research with neutron beams and for isotope production. Low-power reactors (below 1 MWt) and critical assemblies are used for activation analysis, training, and research on reactor core configurations.

45 Information on Soviet-built research reactors is derived from multiple sources, including:

The Radiation Legacy of the Soviet Nuclear Complex: An Analytical Overview, N.Egorov *et al.*, eds. IASSA, Earthscan Publications Ltd, London, 2000, pp. 130–141.

The International Nuclear Safety Center (INSC) web site <www.insc.anl.gov/index.html>

U-235 requirements are calculated from reactor utilization and fuel burn-up data (from INSC). It is assumed that 1.05 grams of U-235 are required to produce one megawatt-day (MWd) of power.

46 Information, *Yaderny Kontrol*, No. 36, December 1997, p. 8.

47 Cermet fuel is made from uranium dioxide power dispersed in an aluminum matrix.

48 The conversion to 36-percent enriched fuel resulted in an estimated loss of 11–50 percent in thermal neutron flux and 0.1–7 percent in fast neutron flux. See: Mark Hibbs, US will Help Russia Develop LEU Fuel for Research Reactors, *Nuclear Fuel*, December 6, 1993.

49 US Will Help Russia Develop LEU Fuel for Research Reactors, *Op. cit.*

50 The fuel released radioactive fission products into the reactor's coolant.

51 The proposed U-Mo alloy would be seven to nine percent molybdenum, with the rest being 19.75-percent enriched uranium.

52 Argonne National Labs and its international RERTR partners are working to develop U-Mo alloy fuels with six to ten percent molybdenum. Initial irradiation tests of such fuel with uranium densities up to 8–9 gU/cm^3 were successful. Experts believe that fuel with uranium densities of 6 gU/cm^3 will be qualified by mid-2005. Denser fuel (8–9 gU/cm^3) is expected to be developed and qualified by mid-2007. See: A.Travelli, Progress on the RERTR Program in 2001, International Conference on Research Reactor Fuel Management, Ghent, Belgium, March 17–20, 2002.

53 Armando Travelli, *The RERTR Program: A Status Report*, Presented at the International Meeting on Reduced Enrichment for Research and Test Reactors, October 18–23, 1998, San Paulo, Brazil.

54 Russia, US Nearing Agreement on Plan for Russian Takeback of HEU Fuel, *Platts NuclearFuel*, vol 27, no. 2, Jan 21, 2002, p.1.

55 The fuel cores used in most of these reactors contain steel and copper. Replacement of these materials with aluminum could obviate the need for higher uranium densities.

56 The reflected critical mass is the amount of reflective-metal-encased uranium that is necessary to create a nuclear fission chain-reaction.

57 With adequate funding and strong political support, the RERTR program could be used to phase out the use of HEU fuel at pulse-power reactors, barge-mounted naval reactors designed to produce electricity and fresh water, and other facilities.

58 For more detailed summaries of existing programs see: *Nuclear Status Report* or *The Next Wave, Op. cit.*

59 *The Next Wave*, *Op. cit.*, p. 20.

60 DOE and Minatom have recently signed a new access agreement that broadens DOE's access to the entire Minatom complex. However, it remains to be seen whether the new access agreement will lead to effective cooperation at the four nuclear warhead assembly and dismantlement plants.

61 *The Next Wave*, *Op. cit.*, p. 30.

62 GAO-01-312, *Op. cit.*, p. 20.

63 *A Report Card on the Department of Energy's Nonproliferation Programs with Russia*, *Op. cit.*

64 US Department of Energy, FY 2003 Congressional Budget Request, *Budget Highlights*, p. 29. The DOE figures have been adjusted to remove funding for that portion of the Fissile Materials Disposition Program that is for disposition of fissile materials that were produced by the United States.

65 Its official name is, "The Agreement between the Government of the United States of America and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted from Nuclear Weapons." It was signed February 18, 1993.

66 USEC Inc., Megatons to Megawatts fact sheet. <www.usec.com/v2001_02/HTML/megatons_fact.asp>

67 The initial implementing contract, signed on January 14, 1994, called for the Russian executive agent to deliver to the US agent LEU derived from 10 tons of HEU, on an annual basis from 1995 through 1999. The contract also called for the Russian agent to deliver LEU derived from 30 tons of HEU on an annual basis from 2000 until the total of 500 tons was reached. See: GAO-01-312, *Op. cit.*, p. 6.

Acronyms and Abbreviations

ANL	Argonne National Laboratory
DOE	Department of Energy
FSU	Former Soviet Union
gU/cm³	Grams Uranium per Cubic Centimeter
HEU	High-Enriched Uranium
ICBM	Intercontinental Ballistic Missile
IRT	Thermal Research Reactor (Russian Acronym)
kg	Kilogram
LEU	Low-Enriched Uranium
MCC	Materials Consolidation and Conversion
Minatom	Russian Ministry for Atomic Energy
MPC&A	Materials Protection Control and Accounting
mt	Metric Tons
MW	Megawatts
NIIAR	Institute of Atomic Reactors (Russian Acronym)
NTI	Nuclear Threat Initiative
PNPI	Institute of Nuclear Physics in St. Petersburg (Russian Acronym)
RERTR	Reduced Enrichment of Research and Test Reactors
U-Mo	Uranium-Molybdenum
U-235	Uranium-235
VVR	Water-Water Reactor (Russian Acronym)

Glossary

Blendstock: uranium that is mixed with more highly enriched uranium in a downblending operation.

Breakout: rapid change in strategic posture or a rapid reversal of a formal or informal agreement about nuclear weapons status. For example, a rapid increase in the number or U.S. nuclear missiles would be a breakout from the START I treaty.

Cermet: a type of fuel used in nuclear reactors that is made from uranium-dioxide power dispersed almost homogeneously in an aluminum matrix or framework. Also referred to as dispersion fuel.

Critical assembly: simulation of a nuclear reactor core, a reactor that cannot generate any power because it does not have a high enough concentration of fissile material to maintain a self-sustaining nuclear chain reaction. Researchers use these reactors to study the neutron-physics of reactor cores but do not use them to generate power because they do not have cooling arrangements to carry away the heat released by fission.

Depleted uranium tails: a waste product of the uranium enrichment process. The typical concentration of U-235 in depleted uranium tails is at most one-half its concentration in natural uranium.

Deployed: on a launch vehicle such as a missile or bomber (refers to a warhead).

Disposition: disposal and other means of long-term fissile materials management, including their use as fuel in nuclear reactors. The term has a broader meaning than the word *disposal*.

Enrichment: a process in which the concentration of uranium-235 is increased in a sample of uranium.

Fissile material: material capable of sustaining a fast-neutron chain reaction. This chain reaction is a series of events in which atomic nuclei are split in two and release neutrons in the process. These neutrons, in turn, cause other nuclei to split and release more neutrons, thereby perpetuating the reaction. Fissile material can be used in the fission core of a nuclear reactor or in a nuclear explosive.

Fission: the disintegration of a heavy atomic nucleus into two or more lighter fragments. Nuclear energy is released in the process.

Feed stock: Uranium that is fed into an enrichment plant to produce uranium that is more enriched—i.e. composed of a higher percentage of U-235.

Gun-barrel weapons: a simple way of creating a nuclear explosion in which two pieces of high enriched uranium are brought together, causing a mass to become supercritical and a nuclear fission chain reaction to occur. Because of its simplicity, scientists and policy makers fear that this type of device may be used by terrorists if they obtain sufficient fissile material.

High-density LEU fuel: uranium fuel that is low-enriched in U-235, but has a high overall density of uranium. This type of fuel has the potential to serve as a safe substitute for HEU in nuclear reactors because its low degree of enrichment means that it cannot be used to make a nuclear weapon. At the same time, its U-235 concentration is high enough to allow the reactor to "go critical", meaning it can maintain a self-sustaining nuclear chain reaction.

HEU (high-enriched uranium): Uranium that has been enriched to greater than 20-percent U-235.

HEU deal: the 1993 agreement between Russia and the US to blend Russian weapons-origin HEU down to LEU for sale through a US agent.

Inactive: not ready for launch.

Irradiation test: a test of uranium fuel cores that determines if they are safe to use—i.e. they do not release fission products into the coolant—usually water. A suitable reactor core should contain its radioactive fission products; otherwise large amounts of contaminated, radioactive coolant are generated.

Isotopes: members of a chemical-element family with the same number of protons in its nucleus, but a different number of neutrons, so that while they have the same chemical attributes, they often display different physical attributes. For example, U-235, which can maintain a nuclear chain-reaction, and U-238, which can not, are different isotopes of uranium.

kg (kilogram): one thousand grams, roughly equal to 2.2 pounds.

LEU (low-enriched uranium): by definition, uranium that is less than 20 percent enriched in U-235. There are two ways to get LEU: (1) High enriched uranium is blended with naturally occurring uranium in order to reduce the concentration of U-235, a process often referred to as downblending. (2) Naturally occurring uranium is processed at an enrichment plant to produce uranium that is only moderately enriched.

Low-power reactors: reactors that generate steady power at a very low level.

MW (megawatt): 1 million watts. A watt is a measure of energy flow per unit time. For example, nuclear power generators in the U.S. typically produce 1,000 megawatts of electricity.

Metric ton: a measure of mass. 1 metric ton equals 1000 kilograms or 2,205 pounds.

Neutron: a particle that is found in the nucleus of an atom and has zero charge and approximately the same mass as a proton. They are used to sustain fission chain reactions.

Neutron flux: the flow of neutrons across some surface.

Pulsed reactors: reactors that deliver bursts of neutrons.

Radioactive: containing unstable atoms. In order to regain their stability, these atoms give off, or emit, one or more of three kinds of radiation: alpha, beta or gamma rays. Depending on the intensity and duration of exposure, these radioactive rays can pose health risks either by causing tissue damage or by increasing the risk of cancer. Therefore, highly radioactive materials such as spent fuel cores are difficult to handle without risking one's health or even one's life.

Silicide: a compound of silicon and uranium used in one type of high-density LEU fuel.

Strategic nuclear warheads: nuclear weapons mounted on long-range missiles or bombers.

Tactical nuclear warheads: nuclear weapons for shorter range missiles, aircraft, artillery or land mines.

Tenex: Russian government owned company that is currently serving as the Russian executive agent for the HEU deal.

Thermal Research Reactor: (Russian acronym—IRT) nuclear reactors that use neutrons in the thermal energy range.

U-Mo fuel: uranium-molybdenum alloy fuel, a type of high-density LEU fuel that is currently under development. It has been proposed as an alternative fuel that could be used to convert Soviet-designed research reactors.

U-235 (uranium-235): the chain-reacting isotope of uranium.

Uranium-dioxide: a molecule composed of one uranium atom and two oxygen atoms. This substance is used in the fuel of nuclear-power reactors.

Uranium-hexafluoride: a molecule containing one atom of uranium and six fluorine atoms. Uranium hexafluoride is the form of uranium used in the blending process. It is the preferred form for down-blending, because it becomes a gas at relatively low temperatures.

USEC Inc: a formerly government owned but now private company that is currently serving as the U.S. executive agent for the HEU deal with Russia.

Water-Water Reactor: (Russian acronym—VVR) nuclear reactors in which water is used both to slow the neutrons in the chain reaction and to remove the fission heat.

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