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U.S.-Russian Bilateral Transparency Regime to Verify Nonproduction of HEU

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A bilateral U.S.-Russian regime to confirm that that neither country secretly produces fresh highly enriched uranium (HEU) would be an important nonproliferation and nuclear threat reduction initiative. It would close the remaining loophole in the emerging system of international controls of fissile materials and make reductions in the U.S. and Russian HEU stockpiles irreversible. An HEU nonproduction transparency regime appears feasible. Applicable monitoring technologies and procedures already exist and have been tested operationally. U.S.-Russian cooperation in the areas of HEU and plutonium disposition and other nuclear technology applications could provide Russia with a needed incentive to participate in the proposed regime.

WHY HEU NONPRODUCTION TRANSPARENCY?

The United States and Russia each have declared that they no longer produce fissile materials for weapons. The United States stopped the production of highly enriched uranium (HEU) for any purpose in 1993. It is believed that Russia also is no longer producing HEU. In fact, neither country needs to produce additional HEU for non-weapons purposes as the existing stocks are estimated to be sufficient to cover the national requirements for 150 years or more (see Appendix A: *HEU Uses and Requirements in the United States and Russia*). Each country has designated a portion of its HEU stocks to be in excess of defense requirements and is blending down excess HEU.

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Under the 1993 U.S.-Russian HEU agreement, the United States is committed to buying at least 500 t of Russia's HEU from dismantled nuclear weapons after its conversion to reactor-grade low enriched uranium (LEU) in Russia.[1] To assure that LEU is derived from HEU, the United States implements a set of transparency measures at the Russian facilities that are involved in HEU-to-LEU downblending. Downblending of excess HEU in the United States is to be monitored by the International Atomic Energy Agency (IAEA).[2]

The United States and Russia also have stopped the production of plutonium for weapons. Each country has declared 34 t of plutonium to be an excess to defense requirements. Disposition of this plutonium could possibly begin within several years. Storage and disposition of excess plutonium is expected to be monitored by the IAEA. On September 23, 1997, the United States and Russia reached the Plutonium Production Reactor Agreement (PPRA), which provides for U.S. monitoring of plutonium produced after January 1997 in the three plutonium-production reactors still in operation in the closed cities of Seversk and Zheleznogorsk. The goal of this monitoring (which is yet to begin) is to verify that newly produced plutonium is placed in storage and is not transferred to the nuclear weapons program.[3] The 1994 U.S.-Russian Plutonium Production Reactor Shutdown agreement provides for verification measures to confirm the shutdown status of the reactors that are no longer operational.

This emerging system of bilateral transparency arrangements (which in some cases are complemented by IAEA safeguards) to verify irreversible reductions in their defense stocks of HEU and plutonium has a significant loophole, however. In particular, there are currently no arrangements in place to confirm that neither country secretly produces fresh HEU for use in nuclear weapons or to compensate for HEU stockpile reductions that are taking place according to its international commitments.

Such a bilateral HEU nonproduction transparency regime could be an important building block of the post-Cold War U.S.-Russian nuclear security relationship that is based on trust and cooperation. Internationally, it would become an important step towards a global fissile material production cutoff treaty.

For the United States, perhaps the most significant incentive to negotiate with Russia a bilateral HEU nonproduction transparency regime would be to ensure that Russia does not replace HEU, which it is downblending under the 1993 U.S.-Russian HEU agreement, with newly produced HEU.[4] This would become even more important if the two countries agreed to eliminate additional stocks of Russia's HEU. A joint U.S.-Russian expert group on accelerated nuclear material disposition, established after the Bush-Putin summit in May 2002, has recently proposed to eliminate additional amounts of Russian

HEU by establishing a strategic reserve of HEU-derived LEU in the United States, and by using downblended HEU in Western reactors.

For Russia, a similar compelling specific reason does not exist. As explained below, the United States is clearly not producing HEU and Russia does not pay for the U.S. HEU downblending effort. Russia, however, could possibly become interested in HEU nonproduction transparency in exchange for a U.S. commitment to expand the 1993 HEU deal and technical cooperation in the area of nuclear fuel cycle and reactor technologies.

DESIGNING A HEU NONPRODUCTION TRANSPARENCY REGIME

Essentially all uranium in the United States has been enriched at three gaseous diffusion plants. The Oak Ridge and Portsmouth plants, both of which are no longer operative and are already partially dismantled, produced both HEU and LEU. The Paducah gaseous diffusion plant, the only remaining operating U.S. enrichment facility, has never produced HEU and is currently licensed to enrich uranium to 5% U-235. The United States has constructed a small number of experimental and pilot centrifuge facilities, all of which have been shut down. A small calutron facility at Oak Ridge produces pure non-uranium isotopes. New commercial centrifuge facilities could be brought on line in the United States around 2010.

The core of Russia's enrichment complex constitute large gaseous centrifuge plants located in Novouralsk, Seversk, Zelenogorsk, and Angarsk. In addition, half a dozen or so small centrifuge and calutron facilities are associated with R&D institutes and centrifuge production facilities and are used for centrifuge R&D and/or enrichment of non-uranium isotopes.

Eventually, under a Fissile Materials Cutoff Treaty, all enrichment facilities in the United States and Russia would have to come under IAEA safeguards. In the interim, however, it might be more practical to negotiate a simplified transparency regime. The goal of such a regime would be detection of large-scale HEU production (for example, 100 kg HEU per year, which is enough to make five or so nuclear weapons) while protecting commercial information about facility operations and production output and sensitive technical information such as centrifuge design data.

Implementation of a transparency regime would begin with a political declaration of nonproduction of HEU and an exchange of data on all operating and shutdown enrichment facilities, including their general design, capacity, and dates of operation. Data exchange would be followed by familiarization site visits.

A data exchange would allow the two countries to remove from monitoring lists calutrons, experimental centrifuge cascades, and other smaller facilities that are not capable of producing threshold amounts of HEU. The regime would then focus on larger enrichment facilities, including the operating and shutdown gaseous-diffusion plants (mostly in the United States), inactive centrifuge enrichment facilities (again, mostly in the United States), the operating centrifuge enrichment plants in Russia, and the proposed centrifuge plants in the United States.

Monitoring arrangements for the gaseous diffusion plants in the United States would be fairly straightforward. The inactive status of the Oak Ridge and Portsmouth gaseous diffusion plants could be easily confirmed by overhead surveillance of cooling towers and facility operations, or by observing infrared signatures of the cascade buildings. Overhead surveillance could be complemented by short-notice site visits to confirm that process equipment is cold or remains dismantled.[5]

The Paducah plant was not designed for HEU operations, and the use of its equipment to produce HEU would be a nuclear criticality safety risk.[6] Short-notice on-site visits to Paducah to verify that no changes in processing equipment have taken place would probably be sufficient for the purposes of a nonproduction regime.

Transparency measures to confirm the shutdown status of the U.S. and Russian centrifuge facilities that are inactive would also be relatively simple. Possible approaches could include the installation of tamper-indicating devices on power-supply equipment and other critical elements of process equipment, or the use of sensors to detect vibrations that are associated with enrichment operations or elevated temperatures at feed and product withdrawal stations. Remote monitoring could also be an effective tool. Remote monitoring technologies, which are currently under development in U.S. and Russian national laboratories, rely on the use of tamper-indicating devices, motion sensors, and motion-activated surveillance cameras with sensor output accessible via internet.

Any new enrichment facilities in the United States would likely be made available for IAEA safeguards. Indeed, the now shutdown Gas Centrifuge Enrichment Plant at Portsmouth, which briefly operated in the mid-1980s, was at that time judged as not needed for national security missions and was offered to the IAEA for safeguards. Also, in 1993, the U.S. Government announced the Nonproliferation and Export Control Policy, which provided for IAEA safeguards on all fissile materials excess to defense needs.[7]

The most challenging problem and the key element of an HEU nonproduction regime would be the monitoring of the operating centrifuge enrichment facilities in Russia. The challenges of and possible technical approaches to monitoring a large centrifuge facility are briefly discussed below.

MONITORING LARGE CENTRIFUGE ENRICHMENT FACILITIES

High separation capacities of individual centrifuges, small in-process material inventories, and modular plant design make the task of safeguarding a centrifuge enrichment plant difficult (see Appendix B: *Safeguards Vulnerabilities of Centrifuge Enrichment Technology*). The IAEA and Euratom, however, have accumulated considerable experience in safeguarding centrifuge plants in Western Europe and the Far East. In fact, the IAEA already has some experience (unfortunately limited) in safeguarding Russian-designed centrifuge plants. According to the Tripartite agreement negotiated between Russia, China, and the IAEA, the Agency implements safeguards at the Russia-built Shaan-xi enrichment plant in China. As of 2001, the IAEA, however, was lacking the funds to design the enrichment and flow monitor to be installed on the product and tail pipes. (The Russia-supplied new enrichment plant at Lanzhou was not under safeguards because of the lack of funds and resources.)

IAEA safeguards at operating centrifuge facilities in Western Europe, Japan, and China incorporate such safeguards elements as verification of material flows and balance; limited containment and surveillance; limited frequency unannounced access (LFUA) inspections; and continuous enrichment monitoring (see Appendix C: *IAEA Safeguards at Enrichment Plants*). Some of these measures could be judged inappropriate for a bilateral nonproduction regime. For example, reviews of material flows, material balance documents, and production logs to detect reduction in facility's output is a particularly important element of IAEA safeguards in countering possible diversion scenarios. Checks on material flows and balances, however, could be unacceptable under the proposed nonproduction transparency regime because they would reveal production output levels and other important proprietary business information about facility operations. Some other measures employed by the IAEA at enrichment facilities elsewhere, such as monthly sampling of all UF6 feed, product, and tailings cylinders, could also be judged intrusive.

In contrast, an application of continuous enrichment monitors appears promising and could be a central element of a monitoring regime. Installed on a product pipe, near product withdrawal stations outside of LFUA areas, an enrichment monitor would measure the enrichment of uranium continuously and autonomously. The monitor could be placed inside a tamper-proof enclosure. To protect sensitive information it could utilize an information barrier and provide output to inspectors in the Yes/No (HEU/LEU) fashion. The device could be connected to an inspection office via E-mail.

The United States and Russia have already implemented a similar system at the blend-down facilities in Russia as a part of the HEU transparency arrangement. The Blend-Down Monitoring System (BDMS) is used to verify uranium enrichment and UF6 flow at the blending point for the HEU, blend-stock, and LEU product component. It is based on the activation of the fissile stream by neutrons and subsequent downstream detection of the delayed radiation produced by fission products.

An important question would be whether Russia agrees to grant U.S. personnel access to production cascade halls and centrifuge R&D cascades for a limited number of unannounced inspections. Such inspections would be important for countering hypothetical batch recycle and cascade reconfiguration diversion scenarios and would involve checks of process equipment for additional piping and unusual valve setting (e.g., to verify cascade isolation and to determine the number of stages); and observation of cascade areas for unauthorized equipment (portable feed/withdrawal stations, UF6 containers) or activities in the process area. The use of remote monitoring technologies to confirm the status of key valve equipment and work areas could also be helpful.

Inspections with the use of portable NDA equipment to check process equipment (e.g., gas headers, UF6 cold traps, and product withdrawal stations) for signs of HEU presence (high-fluxes of 186-keV gamma rays) could also be a potentially attractive technique. The European experience suggests, however, that the use of portable NDA equipment could be complicated if pipe dimensions, process gas pressure and pipe wall deposits are not suitable. Because of these reasons, of all Urenco plants, portable NDA monitors are in routine use only at the E22 Capenhurst plant in Great Britain.[8] In the case of Russia, the use of portable NDA equipment would also have to account for possible traces of HEU from past production activities. In addition, all Russian facilities (with the exception of the Angarsk plant) would be processing large amounts of HEU (including in the form of UF6, and scrap and waste) under the 1993 HEU blend-down agreement and, possibly, Russia's HEU downblending efforts to supply LEU to its own reactors.

HEU nonproduction monitoring could be conducted at a modest cost as an add-on to the HEU-LEU monitoring effort already under way in Russia. The United States already maintains a permanent U.S. monitoring office in Novouralsk; and another such permanent presence office is being established in Seversk. Additional visits would be required to install and maintain continuous enrichment monitors at the Zelenogorsk and Angarsk centrifuge enrichment facilities and to conduct unannounced inspections at these locations.

CONCLUSIONS

An HEU nonproduction transparency regime would be an important nonproliferation and nuclear threat reduction initiative. It would close the remaining loophole in the emerging system of U.S.-Russian and international controls of fissile materials and make reductions in the U.S. and Russian HEU stockpiles irreversible.

Achieving an HEU nonproduction transparency regime will not be easy, however. The Russian uranium enrichment industry has traditionally been highly secretive and the level of secrecy in the nuclear complex has recently increased. (To a large extent, secrecy measures in the uranium enrichment complex are intended to protect commercial secrets and sensitive centrifuge technologies.) At least initially, a new regime would also have to deal with the asymmetry of the U.S. and Russian enrichment technologies and infrastructures (which would subject Russia to a significantly greater and more intrusive inspection effort). Finally, inspections at operating enrichment facilities would require additional funding and could impact production operations.

Nevertheless, an HEU nonproduction regime appears feasible. Applicable monitoring technologies and procedures already exist and have been tested operationally by the IAEA and under the 1993 HEU agreement. U.S.-Russian cooperation in the areas of HEU and plutonium disposition, spent fuel storage, and other nuclear technology applications could provide Russia with a needed incentive to participate in the proposed HEU nonproduction regime.

NOTES AND REFERENCES

1. Additional amounts of Russian HEU are downblended under the Material Consolidation and Conversion initiative, which is a part of the U.S.-Russian nuclear material protection, control, and accounting program, as well as under the Russian-German effort to fabricate nuclear power reactor fuel using reprocessed uranium and HEU.

2. In the United States, disposition of HEU began in 1999 at the BXW Technologies Inc. plant in Lynchburg, VA; 50 t HEU are expected to be eliminated by 2006. William Wallack "BWXT Expects to Complete Downblending of 50 Metric Tons of HEU by Mid-2005," *Nuclear Fuel* (November 27, 2000).

3. Monitoring provisions call for confirmation of declared mass-quantities of produced plutonium and its declared weapon-grade isotopic composition. Because the isotopic composition of weapon-useable plutonium in Russia is classified, monitoring is expected to involve radiation measurements and the use of information barrier technologies. Plutonium will be considered of weapon-grade if the ratio of Pu-240/Pu-239 is less than 0.1. Neutron multiplicity counting would likely be used to determine plutonium mass.

4. Indeed, as one U.S. expert has put it, "[W]e know the Russians downblend their HEU. However, for all we know, they might be producing as much new HEU in the next building."

5. It generally takes several days for gaseous diffusion equipment to cool down to room temperatures after the power is turned off.

6. Although the Paducah equipment itself would be criticality-safe, potential criticality events could occur due to HEU deposition on equipment surfaces.

7. Fact Sheet, "Non-proliferation and Export Control Policy" (The White House, Office of the Press Secretary, September 27, 1993).

8. S. Baker, B. Dekker, P. Friend, K. Ide. *The Introduction of a Continuous Enrichment Monitor for Safeguards Applications in Centrifuge Enrichment Plants* (Marlow, United Kingdom: Urenco, undated).

APPENDIX A: HEU USES AND REQUIREMENTS IN THE UNITED STATES AND RUSSIA

At the end of the Cold War the United States had an estimated stockpile of 750 t HEU. In 1995, 174 t HEU was declared excess to military requirements. In the remaining stockpile, approximately 210 t is estimated to be associated with the weapons program. Much of the remainder (approximately 370 t) is placed in a reserve to support the nuclear naval propulsion program. As of 2000, the annual HEU requirements were estimated at 2 t HEU (five reactor cores containing 400 kg HEU each).* At this rate, the existing stockpile will be able to support the naval propulsion program for over 150 years.

As of the early 1990s, Russia's HEU stockpile consisted of an estimated 1200 t HEU (90-percent enriched uranium equivalent).** Of this, 500 t HEU was to be downblended under the 1993 U.S.-Russian HEU agreement. Some 250 t HEU could be estimated to remain in the weapons stockpile. Future uses for the remainder of the HEU stockpile (450 t) would include the following:

- 600 kg HEU per year for the three plutonium-production reactors that continue operation in Seversk and Zheleznogorsk (to decline to zero around 2005–2010);
- 1.5 t HEU per year for the tritium reactors;
- 1 t HEU per year for naval reactors; and
- 200 kg HEU per year for research reactors.

At future annual requirements of 2–3 t HEU per year, the existing stockpile would be sufficient for over 150 years.

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*Chunyan Ma, Frank von Hippel "Ending the Production of Highly Enriched Uranium for Naval Reactors," *The Nonproliferation Review* (Spring 2001) 86–101.
**O. Bukharin "Analysis of the Size and Quality of Uranium Inventories in Russia," *Science and Global Security* (1996) 6, 59–77; O. Bukharin "Securing Russia's HEU Stocks," *Science and Global Security* (1998) 7, 311–331; and D. Albright, F. Berkhout, W. Walker *Plutonium and Highly Enriched Uranium: 1996 World Inventories, Capabilities, and Policies*, Oxford, United Kingdom, Oxford University Press, 1997.

APPENDIX B: SAFEGUARDS VULNERABILITIES OF CENTRIFUGE ENRICHMENT TECHNOLOGY

Centrifuge enrichment technology is highly suitable for unauthorized HEU production. Some contributing design features of gas-centrifuge plants include the following*:

- *High separation factor per stage*. The U-235 content in product for gas centrifuges is at least 20 percent greater than in feed. Generally, some tens of stages that are connected in series are sufficient to produce HEU (compared to thousands of stages required for HEU production at a gaseous diffusion plant).
- *Small in-process material inventory*. Small in-process inventory provides for a short cascade equilibrium time. Also, only a small amount of material is required to fill an enrichment cascade.
- *Short cascade equilibrium time*. Typical equilibrium times for a centrifuge cascade are one hour and one day for LEU and HEU production respectively. Short equilibrium times reduce the risk of detection of clandestine HEU production.
- *Modular plant design*. A centrifuge plant consists of a large number of cascades that operate in parallel. This allows the operator to use a portion of the plant to produce HEU while producing legitimate LEU product in the rest of the facility.

Generally, a monitoring regime must be designed to address the following diversion scenarios.

Off-design operation of an individual cascade(s). Valve setting could be adjusted to return a portion of product back to cascade's feed point. This would increase the product enrichment to about 20 percent U-235. Medium-enriched uranium then could be enriched by using other diversion methods or in a small clandestine facility. Because of less-than-optimal cascade configuration, however, the tails assay would increase and process efficiency would decrease (by as much as 10 percent of design capacity).

Batch recycle. A recycle of enriched product back to the cascade's feed point could in principle be used to produce HEU. If a cascade is designed to produce LEU (3 percent U-235), approximately four recycles would be required to produce 90-percent HEU. Under this scenario, the facility would divert or bring from outside a required quantity of LEU, isolate some of the process cascades, and use the isolated cascades to produce higher-enrichment materials from LEU. Intermediate product would be collected, stored and then fed back into the cascade.

Cascade reconfiguration. This method would involve an isolation of an individual cascade, and reconfiguration of cascade piping to optimize the cascade for HEU production. The reconfiguration would generally increase the number of stages (from several for LEU production to approximately 20 for HEU production). This scenario would also require additional equipment and activities to withdraw HEU from the cascade.

Experimental and pilot-scale centrifuge enrichment cascades are specifically designed to be adaptable for reconfiguration. They, therefore, are usually flexible enough to allow for rapid reconnection of centrifuges into an optimized HEU cascade. An experimental cascade of 25,000 SWU/y could produce on the order of 100 kg HEU per year.

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*Safeguards vulnerabilities at a centrifuge facility are discussed, for example, in D.Gordon *Safeguards for Enrichment Plants*, (Upton, NY: Brookhaven National Library, Final Report B&R 50-19-02-03, December 1978); and *Enrichment Plant Safeguards Course* (K/ITP-341 Martin Marietta Energy Systems, May 1990).

Connection of cascades to form an HEU production cascade. Several cascades could be isolated and configured in series and in parallel to form an HEU cascade. Product from the first cascade would be fed into the next cascade until HEU product is produced. The reconfiguration could require the piping to be reconnected. Alternatively, enriched UF6 could be moved (from the product point of one cascade to the feed point of another) in cylinders.

APPENDIX C: IAEA SAFEGUARDS AT ENRICHMENT PLANTS

At present, IAEA safeguards are applied to six centrifuge enrichment facilities in Europe, Japan, and China, and a vortex-tube facility in South Africa. Safeguards measures for enrichment facilities (mainly centrifuge plants) were developed under the Hexapartite Safeguards Project in 1980–1983 by facility operators in coordination with IAEA experts. Inspections at enrichment facilities began in 1989.

The goal of IAEA safeguards at enrichment facilities is two-fold and includes: 1. detection of production of a significant quantity (containing 25 kg U-235) of undeclared HEU; and 2. detection of diversion of a significant quantity of declared LEU that could be used as feedstock in a clandestine HEU-production facility. The principal elements of IAEA safeguards are verification of material flows and balance; limited containment and surveillance; limited frequency unannounced access (LFUA) inspections; and continuous enrichment monitoring.*

Verification of material flows and balances involves a review of facility's reports and records (shipping forms, material transaction reports and journals, transfer receipts, process sample reports, weight tickets, process inventory-taking reports, material balance reports, and others); a measurement assurance program (for weight, sampling, analytical measurements); and material balance closure activities including determination of MUF (material unaccounted for), its standard deviation, and data analysis.

At least once a year, facility operators conduct a physical inventory of nuclear materials. During that period, IAEA inspectors verify randomly selected items on the inventory list for existence and consistency with item description.

Inspectors have a right to observe the removal of UF6 samples from cylinders or process streams which are then sent to the IAEA analytical laboratory for destructive evaluation. Inspectors use NDA measurements on cascade header piping and UF6 cylinders (feed, product, tailings) to detect enrichment above 20 percent U-235. Once a month, IAEA inspectors also weigh and sample UF6 feed, product, and tailings cylinders to verify their contents.

Containment and surveillance measures at enrichment facilities could involve continuous camera surveillance to detect unauthorized operations in the cascade area and use of tamper-indicating devices on process piping, valves, flanges, and UF6 cylinders.

To detect HEU production, IAEA inspectors conduct limited frequency, unannounced access inspections inside centrifuge cascade halls. These inspections involve visual observation, radiation monitoring and NDA measurements, UF6 sampling, and verification of tamper-indicating devices.

Prior to the beginning of inspections, a facility must submit design information, including data on material flows, safeguards arrangements, and facility layout. IAEA inspectors then conduct an initial inspection to confirm facility design information and the initial inventory of nuclear materials.

**Transparency Measures for DOE SNM Production Facilities* (U.S.DOE, December 1993).

A relatively new safeguards technique, which is applied at the Urenco gaseous centrifuge facilities, is the use of a Continuous Enrichment Monitor (CEMO) to confirm that UF6 in a cascade product pipe is LEU.[**] The CEMO detects the total mass of U-235 in the monitored pipe by measuring the 185.7 keV gamma rays. The process gas pressure is determined from absorption of X-rays from an external source. The level of UF6 enrichment is then calculated based on these two parameters. The CEMO then E-mails a daily message to the Euratom and IAEA headquarters to confirm its working status and nonpresence of HEU.

[**]S. Baker, B. Dekker, P. Friend, K. Ide "The Introduction of a Continuous Enrichment Monitor for Safeguards Applications in Centrifuge Enrichment Plants," (Merlow, United Kingdom, Urenco, undated).