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Weapons to Fuel

Oleg Bukharin[a]

The economic implications of the U.S.-Russian HEU agreement remain uncertain, and will depend on the health of the uranium market and the performance of the U.S. gaseous diffusion enrichment plants. The agreement, however, could be essential for the dismantlement of nuclear weapons in Russia. It also provides an opportunity to develop security, economic and institutional arrangements that would be useful in dealing with fissile materials from weapons in the future.

THE US-RUSSIAN HEU AGREEMENT*

The idea for the U.S. government to buy Russian bomb-grade uranium from dismantled weapons was originally formulated in October 1991.[1] Formal negotiations on this arrangement started in the summer of 1992, and on 18 February 1993 the governments of the United States and Russia signed an umbrella agreement outlining the purpose and the scope of the US-Russian HEU agreement: The U.S. will purchase approximately 500 metric tonnes (MT) of highly enriched uranium (HEU) recovered from Russian weapons—10 MT HEU per year for the first five years and 30 MT HEU per year during the subsequent 15 years.[2] The material will be converted into low-enriched uranium (LEU) fuel and sold to U.S. commercial nuclear power reactors. The principal goal of the agreement is to "arrange the safe and prompt disposition for peaceful purposes of highly enriched uranium resulting from the reduction of nuclear weapons." The parties involved confirmed their commitment to comply with "all applicable nonproliferation, physical protection, nuclear material accounting and control, and environmental requirements."

a. Visiting Researcher, Center for Energy and Environmental Studies, Princeton University, Princeton, New Jersey.

* The safeguards aspects of the agreement are discussed in Oleg Bukharin and Helen M. Hunt, "The U.S.-Russian HEU Agreement: Internal Safeguards to Prevent Diversion of HEU," in this issue.

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The umbrella agreement directs the U.S. Department of Energy (DOE) and the Ministry of Atomic Power of the Russian Federation (Minatom) to negotiate two additional documents—an initial implementing contract and a transparency agreement[3]—outlining details of implementation of the government-to-government agreement.

On 1 May 1993, the parties agreed on the negotiating principles of an initial implementing contract. The principles set a price of $780 per kilogram of 4.4 percent uranium in the form of uranium hexafluoride (UF_6) of each delivery order placed in fiscal year (FY) 1994, established the procedure for payments and deliveries, and covered other financial and technical arrangements for the first year of the agreement. In subsequent years, the parties will annually review the implementing contract.

The umbrella agreement stipulates that a transparency agreement "shall establish transparency measures to ensure that the objectives of [the] Agreement are met." Through implementation of a transparency agreement, the U.S. seeks assurances that LEU is indeed derived from HEU from the weapons stock; Russia wants to verify that uranium sold to the U.S. is not used for military purposes. On 2 September 1993, the parties signed a memorandum of understanding calling for specific transparency measures which are described in more than a dozen annexes.

The pace of negotiations has varied from very fast to very slow.[4] The slowness has been caused by bureaucratic sluggishness and internal conflicts of interests of different groups and agencies within the respective governments. The slow-down of the agreement gave V. Mikhailov, Minister of Minatom, an opportunity to press the U.S. by linking resolution of the HEU agreement to changes in the suspension agreement.[5] It is, however, unlikely that this attempted linkage represents a real problem. As of December 1993, the agreement is mainly stalled by uncertainty about revenue-sharing negotiations between Russia and Ukraine, and Russia and Kazakhstan.

A revenue-sharing agreement between Russia and Ukraine has been held hostage to bitter and often intractable political and economic disputes between the two countries. Recently, the parties agreed that compensation for HEU derived from the Ukraine-based weapons will be paid in the form of both cash and LEU fuel for Ukrainian power reactors. This formula was included into the "Massandra agreement," a package of documents signed during the Russian-Ukrainian summit in Massandra, Crimea, in the spring of 1993. The agreement, however, was denounced by Russia shortly after the summit, when it was discovered that Ukrainian representatives unilaterally changed the text of the agreement. The prospects for resigning of the Massandra agreement in the near-term future are uncertain.

Ural Electrochemistry Plant at Verkh-Neyvinsk

The plant—the first industrial-scale enrichment facility in the Soviet Union—began producing uranium for weapons using the gaseous-diffusion enrichment method in 1949. In 1957, it became the first Soviet pilot-scale and, subsequently, full-scale centrifuge enrichment plant. In the formerly integrated Soviet enrichment complex, the cascades have produced weapons-grade uranium using products of other enrichment facilities as feed stock. The plant has also produced LEU that has been exported to the West since the 1970s. After the production of HEU was discontinued in 1987, the plant was reconfigured for sole production of LEU. Currently, the plant has a capacity of two to three million separative work unit per year, or about 20 percent of the total enrichment capacity in Russia.

The plant is a shareholder of the Minatom's marketing agent Techsnabexport (Tenex). Tenex, a joint-stock company, is the only Russian organization licensed to market uranium and SWUs. With a total enrichment capacity of some 13 million SWU per year, Russia exports 1.3 to 2 million SWU per year

Kazakhstan has been quietly watching the developments in the issue of compensation to Ukraine. Recently, however, the republic has taken a more active position: Kazakhstan's policy makers see resolution of the issues of ownership of nuclear weapons and compensation for fissile materials to be a precondition of negotiations with Russia on a variety of nuclear and military issues. It is believed, however, that Kazakhstan will be more flexible than Ukraine, and a revenue-sharing agreement will be concluded as soon as Russia negotiates an agreement with Ukraine.

MATERIAL FLOW AND CONVERSION TECHNOLOGY

The HEU weapons components that are slated for conversion are to be shipped from weapons dismantlement plants in Nizhnyaya Tura, Uruzan', Penza, and Arzamas to the Ural Electrochemistry Plant at Verkh-Neyvinsk, 30 miles northwest of Yekaterinburg. The plant operates three enrichment cascades, one of the principal Russian facilities producing uranium hexafluoride, and other HEU-processing facilities. The plant also houses a conversion and blending facility for conversion of HEU metal into uranium hexafluoride and blending it to LEU. The facility will be able to process 20 MT HEU a year.[6] In five years, it will be augmented by another plant, which will bring the combined processing capacity to 30 MT HEU per year.

The process of converting HEU metal to LEU hexafluoride will probably involve oxidation of HEU metal to uranium oxide powder and fluorination in a reaction with fluoride. The product of the reaction, HEU hexafluoride, will subsequently be blended down to 4.4 percent LEU by mixing it with 1.5 percent uranium hexafluoride.[7] The concurrent purging of chemical impurities from the gas will take place in gas centrifuges. The 4.4 percent-enriched uranium hexafluoride will be condensed and placed into standard 2.5-ton shipping cylinders of the 30B type, subjected to material acceptance tests, and shipped to the US. In the US, uranium will be custom-blended at the U.S. Enrichment Corporation's gaseous diffusion plant in Portsmouth, Ohio, and delivered to private U.S. fuel fabricators. The U.S. Enrichment Corporation (USEC) may do some additional processing of Russian uranium (e.g., if it does not meet the quality specifications). Fabrication of fuel by private U.S. companies will accommodate the requirement of involving private U.S. business.[8]

NONPROLIFERATION AND ARMS-CONTROL FUNCTIONS OF THE AGREEMENT

The HEU agreement will have an important arm- control and nonproliferation function: it would facilitate the dismantlement process in Russia by reducing the HEU storage requirements. Indeed, anticipating HEU sales, Minatom has scaled down the capacity of the proposed fissile-material storage facility in Russia from 110,000 to 40,000 fissile materials containers. The agreement might be absolutely essential for funding the dismantlement effort: the total gross revenue of Russia would amount to about $12 billion at the initially negotiated prices. Part of these proceeds will be spent to construct the second HEU conversion and blending facility. In addition, the agreement will reduce the potential for social instability by facilitating conversion of the Russian nuclear and defense industries to non-military functions and by creating jobs at the conversion and blending facility at Yekaterinburg. The agreement will also bolster the national economy by providing it with needed hard currency. A portion of the proceeds will also be spent to clean up the Russian nuclear complex and to improve its safety.

The U.S. would achieve its national security objectives by speeding up reductions of the Russian nuclear arsenal, and by transferring weapons materials out of the Russian weapons program, thus eliminating a potential source of materials for proliferation. In view of the uncertainty about the size of the Russian HEU stockpile, it is important for the U.S. to verify that the HEU it is buying is indeed derived from weapons stockpiles rather than freshly pro-

duced at Minatom's underemployed enrichment plants in Siberia. At least in part, this goal will be achieved through implementation of a transparency agreement. The proposed draft of the transparency agreement describes a number of technical and institutional measures, ranging from techniques for determining the age of the HEU to on-site presence of DOE (or USEC) inspectors at the HEU conversion and blending facility in Yekaterinburg. Similarly, Russian inspectors will be present at the gaseous diffusion plant (GDP) in Portsmouth.

Although the agreement specifies that HEU shall be derived from weapons, the U.S. would probably be willing to buy any HEU should there be some reasonable assurances that Russia will not produce any in the future. Russia declared an end to HEU production in 1989, but production was probably stopped in 1987. There are, however, no in-place arrangements to verify nonproduction of HEU in the U.S. or Russia. Such arrangements would require bilateral or international IAEA-type safeguards at all commercial and research uranium enrichment facilities. Such an effort is fully consistent with the recent Clinton-proposed initiative to negotiate a ban on the production of fissile materials for weapons (fissile cut-off). As proposed, the fissile cutoff would require safeguarding all uranium enrichment and reprocessing facilities in the involved countries.

It is also important to assure adequate protection of HEU to prevent its diversion in the course of conversion and blending. The security of HEU can be compromised by a very large annual throughput of HEU at the conversion and blending facility, prolonged direct access of workers to HEU in process, and poor detectability of shielded HEU.[9] The agreement requires application of standard physical protection measures, which "shall, at a minimum, provide protection comparable to the recommendations set forth in IAEA document INFCIRC/225/Rev.2." The agreement, however, does not specify requirements to a material control and accounting (MC&A) system at the conversion and blending facility. An MC&A system is a principal safeguards element for preventing insider diversion. The possibility that clever and experienced insiders would attempt to steal a small fraction of the material and sell it on the black market may be very real.

ECONOMICS OF THE HEU AGREEMENT

The economics of the HEU agreement will strongly depend on a combination of the following factors: health of the uranium market, cost of enrichment services at USEC's gaseous diffusion plants, and the strategy USEC will select in

dealing with HEU-derived uranium. The point can be demonstrated by the analysis of the potential impact of the HEU agreement on USEC activities in FY 94. DOE has contracted 11.4 million SWU for delivery to utilities in FY 94. At the tails, feed, and product assays of 0.30, 0.71, and 3.60 percent, the volume of uranium feed to be supplied by the utilities and the amount of 3.6 percent enriched uranium product (EUP) are 20,226 MT and 2,519 MT, respectively. Approximately 305 MT 4.4 percent LEU from Russia (the equivalent of 10 MT HEU) will be channeled by USEC through existing enrichment contracts. Custom-blending of 305 MT 4.4 percent LEU to produce 389 MT of 3.6 percent EUP will require 84 MT of natural uranium and will effectively displace 1.760 million SWU.[10] To cover the rest of its contractual obligations, USEC will have to produce 2,130 MT EUP using some or all of the remaining 20,142 MT of natural uranium feed.

USEC may select either of the two available strategies (or a combination): (1) to carry out the enrichment work at the standard tails assay of 0.3 percent and to hold the remaining feed in inventory for a maximum of 20 years or sell it on the market; or (2) to overfeed the enrichment cascades.

At the tails assay of 0.3 percent, production of 2,130 MT 3.6 percent EUP requires 9.638 million SWU and 17,102 MT natural uranium. The SWU savings will amount to 1.762 million SWU. At the SWU production cost range of $60 to $75 per SWU, USEC will save $105.7 to $132.2 million by avoiding production costs.[11] According to the agreement, USEC will not pay Russia for the uranium component of the HEU-derived uranium unless it is resold or used for overfeeding of the enrichment cascades.[12] If Russia does not get paid $86.6 million for the uranium component, it will receive $151.3 million for the enrichment component alone.[13] Thus, the avoided costs will be offset by $19.1 to $45.6 million by the payment to Russia.

In theory, USEC might be able to generate additional revenues by selling the excess of natural uranium of 3,040 MT. This, however, is unlikely. The price of one kilogram of uranium as UF_6 at today's spot market is $31.75 for restricted and $24.75 for unrestricted utilities. USEC will lose money selling uranium at less than $28.50 per kilogram. Also, sales of the uranium surplus on the European and Far Eastern markets are likely to be almost impossible because of fierce competition among suppliers. The suspension agreement will not allow USEC to sell uranium on the restricted U.S. market at least until 2003.

Thus, the surplus of uranium feed will have no practical market value. Under these circumstances, an alternative strategy might be based on overfeeding the enrichment cascades.[14] "Overfeeding" means operation of enrichment cascades at tails assays that are higher than the DOE's contract level of

0.3 percent. Overfeeding allows substitution of uranium feed for SWUs: the more feed is used to produce a given amount of EUP, the less enrichment work is required. In fact, some enrichers have been tailoring a tails assay to accommodate preferences of their clients for many years. Variation of tails assays increases flexibility of a contract by accounting for differences in sizes of uranium inventories of different utilities, prices that have been paid for uranium, and market conditions. DOE has been prohibited from this practice by the legal requirement of offering the same type of contract to all its customers. (In practice, while keeping the tails assay at 0.3 percent for contract accounting purposes, DOE has been overfeeding the cascades by using its own feedstock.) In view of the high costs of production of SWUs using an obsolete gaseous diffusion technology, USEC may significantly benefit from a reduced volume of SWU production.

Some 20,142 MT of natural uranium, remaining after custom-blending of 305 MT 4.4 percent LEU from Russia will be completely consumed in the course of production of 2,130 MT of 3.6 percent EUP at the tail assay of 0.37 percent. Overfeeding will reduce USEC's SWU requirements from 11.4 to 8.51 million SWU providing total savings of $173.4 to $216.8 million at the SWU production cost range of $60 to $75 per SWU. The U.S. will pay Russia approximately $237.9 million. The difference between this figure and the direct enrichment savings will be $21.2 to $64.5 million.

Thus, under the given SWU production cost range, the deal is not attractive to the U.S. from the budgetary perspective. Many within USEC see the question of who will foot the bill as very important for the future competitiveness of the corporation. Nick Timbers, USEC transition manager, has said that USEC will not pay a "political premium" for HEU. Many argue that the agreement reflects federal interests and, therefore, will have to be paid from the federal budget. An opposite viewpoint is that USEC, having received fully depreciated enrichment plants essentially free (and thus having been able to keep SWU production costs at the present level), has been already heavily subsidized by the federal government and, therefore, should be fully responsible for any economic implication of the HEU deal.

Also, there is a great deal of uncertainty about the size of the "political premium" and even its very existence. Indeed, calculations of SWU costs for DOE facilities have often been arcane and the real cost of a SWU may well be higher than $60 to $75. This cost may go up in the future as a result of the impact of the Clean Air Act on the cost of electricity produced by fossil-fuel plants for the USEC's GDPs. It is also possible that the HEU deal will allow closure of one of the two enrichment plants. This will both cut the production costs and eliminate the overhead burden (administration, safeguards, etc.).

U.S. Enrichment Corporation

The corporation was created as part of the Energy Policy Act of 1992. On 1 July 1993, the corporation assumed control of DOE's enrichment enterprise. A final privatization plan is due to Congress by 1 July 1995.

As of 1 July 1993, the assets of the corporation included $106.5 million in cash, $1.5 billion worth of inventories, $895.9 million in equities, and $310.4 million of "other assets." USEC's liabilities included $86.1 million of accounts payable, $1.05 billion worth of uranium held for customers, and $47.6 million in other liabilities. Congress assigned the corporation a capital stock value of $3 billion.

USEC leases two of DOE's GDPs—in Portsmouth, Ohio, and Paducah, Kentucky. It has no liability for cleanup of the plants from their previous use. DOE will continue to control safety and environment at the plants until 1995, when the regulation will be taken over by U.S. Nuclear Regulatory Commission.

The Paducah GDP was built between 1951 and 1954. It has a capacity of 11.3 million SWU and is designed to enrich uranium up to 1.95 percent. The Portsmouth GDP was built between 1953 and 1956, and is designed to produce 7.9 million SWU per year by enriching uranium to five percent. Both plants are operating below their rated capacities: Paducah produces 5.4 million SWU per year and Portsmouth produces 6.1 million SWU per year. The plants are operated by Martin Marietta Utility Services under a "cost-plus-award" contract with DOE. USEC is renegotiating this contract to replace it with a standard commercial contract. Martin Marietta employs 1,743 workers at Paducah and 2,622 at Portsmouth.

The DOE/USEC share of the Western demand for enrichment services will continue to be about 50 percent through 1995. After that, without new contracts, the volume of enrichment services that have been contracted by DOE will quickly dry up to almost zero by 2003. Thus, USEC will have to enter into competition (primarily against Eurodif, Urenco, and Tenex) for new enrichment contracts.
(based on "Outlook on USEC," *NuclearFuel*, 11 October 1993.)

When combined, production and overhead costs, at least in theory, correspond to DOE's contractual prices of $90 to $118 per SWU. Generally, it might make more sense to view the deal from the perspective of the global enrichment market. A "political premium" will be zero at the cost of $82 per SWU when using the overfeeding strategy. Selling HEU-derived SWUs at the market price of some $100 per SWU or higher, USEC would be able to generate substantial profits. In addition, USEC would be able to enhance its competitiveness by offering customers an attractive package which includes uranium feed and conversion and enrichment services.

CONCLUSION

The U.S.-Russian HEU agreement could well be vital for Russia to keep up with the dismantlement schedule and to fund conversion of its nuclear and defense industries. The agreement will also facilitate disposing of a significant amount of bomb-grade materials, thus reducing the long-term threat of nuclear proliferation. Providing that there is a sufficient level of transparency and that the HEU is reliably protected against diversion in the course of conversion and blending, the agreement will be of high value for international peace and security.

At least for the first few years, the impact of the deal on the uranium market and the U.S. economy will be of only marginal significance. Besides, the parties will be able to correct their strategies to achieve the best result possible through annual review meetings.

Finally, whether the U.S.-Russian HEU agreement is a business deal or an arms-control deal may be inconsequential. What is important is that the agreement will be the first real transfer of bomb-grade fissile materials to civilian applications. This represents a unique opportunity to develop and test a legal and institutional framework that will support the present and future nonproliferation and disarmament effort.

NOTES AND REFERENCES

1. Thomas Neff, *New York Times*, 24 October 1991 (Op Ed).

2. DOE may order up to the amount of LEU contained in 10 and 30 MT HEU for the first five and subsequent 15 years, respectively. Additional annual amounts may be ordered subject to mutual agreement in the annual reviews. ("U.S.-Russian Agreement Regarding the HEU Contract," in *NuclearFuel*, 11 October 1993).

3. The U.S. has indicated that it will transfer the responsibilities of an executive agent to the newly born U.S. Enrichment Corporation (USEC). Tenex is authorized to enter into contracts for the sale of Russian LEU on behalf of Minatom.

4. The negotiations have been conducted by the U.S. Department of State and Minatom. Negotiation strategies and positions within respective governments have been developed through interagency discussions.

5. The suspension agreement was signed by Minatom and the U.S. Department of Commerce in October 1992. The agreement was the result of the "uranium dumping investigation," brought against uranium-producing republics of the Commonwealth of Independent States in 1991. The agreement is based on price-based quotas. At the price level of $13 to $14 per pound of U308, Russia may export to the U.S. no more than 230 MT of uranium per year. The uranium price has not yet reached the level of $13, and no Russian uranium has been imported to the U.S. since the agreement entered into force. (Some uranium continues to be delivered through "grandfather" contracts.) Some in Russia perceive the suspension agreement to be unfair, and Minatom is attempting to renegotiate it. Specifically, V. Mikhailov suggests an annual quota

of 5,000 MT U308 and three million SWU to be sold in the U.S. at agreed "fair market prices" (*NuclearFuel*, 13 September 1993, p. 10). However, U.S. uranium producers are determined to prevent any changes in the suspension agreement which would allow imports of uranium from Russia.

6. According to a source in the U.S. government, the capacity of the facility will be 10 MT HEU per year.

7. The 1.5 percent-enriched uranium for blending could be produced at the plant's operating cascades via enrichment of previously accumulated uranium tailings.

8. U.S. fuel fabricators and their fuel fabrication facilities that will receive HEU-derived uranium include: Advanced Nuclear Fuels Corporation (Richland, Washington), Babcock & Wilcox Fuel Company (Lynchburg, Virginia), ABB Combustion Engineering (Hematite, Missouri and Windsor, Connecticut), Westinghouse Electric Corporation (Columbia, South Carolina), and General Electric (Wilmington, North Carolina).

9. See, O. Bukharin and H. Hunt "The U.S.-Russian HEU Agreement: Internal Safeguards to Prevent Diversion of HEU," *Science & Global Security* 4 (2), 1993.

10. Fuel enrichment varies from some two percent to five percent U-235. USEC is likely to use HEU-derived uranium to produce EUP of higher-than-average enrichment. This will allow spending less than 84 MT uranium feed for blending and additional SWU savings.

11. The cost of producing one SWU is $60 at the Paducah GDP and $75 at Portsmouth GDP. The difference is mainly because of the cost of electricity (some 75 percent of the SWU production cost): the Paducah plant is capable of using a substantial amount of low-price off-peak electricity by storing uranium hexafluoride in the form of gas during the peak electricity-demand hours and resuming operation during off-peak hours. There is no such technology in Portsmouth. (*NuclearFuel*, "Special Report Outlook on USEC," 11 October 1993, p. 10).

12. The uranium component has to be resold or used by the end of implementation of the agreement. By that time, however, its value is likely to be significantly reduced.

13. According to the agreement regarding the HEU contract, "one kgU of LEU consists of . . . 9.9757 kgU of natural uranium at $28.50 per kgU."

14. In the context of the U.S.-Russian HEU agreement, the idea of "overfeeding" was suggested by Thomas Neff. See Thomas Neff "Integrating Uranium from Weapons into the Civil Fuel Cycle," *Science & Global Security* 3 (3–4) pp. 215–222.