

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/icarusiansecurity.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/cm³ were successful. Experts believe that fuel with uranium densities of 6 gU/cm³ will be qualified by mid-2005. Denser fuel (8–9 gU/cm³) 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.