7 Consolidating Fissile Materials in Russia's Nuclear Complex

Pavel Podvig

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The mission of IPFM is to analyze the technical basis for practical and achievable policy initiatives to secure, consolidate, and reduce stockpiles of highly enriched uranium and plutonium. These fissile materials are the key ingredients in nuclear weapons, and their control is critical to nuclear weapons disarmament, to halting the proliferation of nuclear weapons, and to ensuring that terrorists do not acquire nuclear weapons. IPFM research and reports are shared with international organizations, national governments and nongovernmental groups.

The Panel is co-chaired by Professor R. Rajaraman of the Jawaharlal Nehru University of New Delhi, India and Professor Frank von Hippel of Princeton University. Its members include nuclear experts from sixteen countries: Brazil, China, France, Germany, India, Ireland, Japan, the Netherlands, Mexico, Norway, Pakistan, South Korea, Russia, Sweden, the United Kingdom and the United States.

Princeton University's Program on Science and Global Security provides administrative and research support for IPFM.

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Overview

Russia has the world's largest stocks of weapon-usable fissile materials. Most of this material is a legacy of the Cold War, when the Soviet Union and the United States each created nuclear industries sized to produce tens of thousands of nuclear weapons. Significant quantities of weapon-grade material also are present on the civilian side of nuclear complex, in storage, or being transferred from one facility to another, or used for research and other purposes. Providing security for all this material will continue to be a major task for Russia for decades.

Since the end of the Cold War, Russia has undertaken significant efforts to downsize its nuclear complex, some of it with assistance from the United States. The basic structure of the nuclear industry, including most of its production facilities and fissile materials, however, remain intact. Although Russia generally acknowledges the dangers associated with the continuing existence of its weapon materials, the task of reducing these dangers, by either eliminating the material or consolidating it in a small number of safe, secure storage sites, has proven difficult.

One challenge in discussing the issue of fissile materials in Russia is that the amount of these materials is known only with a very large uncertainty by independent analysts. It is estimated that in 2008 Russia had about 950 metric tons of highly-enriched uranium (HEU) and about 145 tons of weapon-grade plutonium. These estimates, however, have accuracy of no better than +/- 30 percent.

About 350 tons of HEU and about 55 tons of plutonium is in nuclear warheads that are either operationally deployed or stored awaiting redeployment or dismantlement. All warheads are in the custody of the Ministry of Defense, which is responsible for their safety and security. The military also has control over the material contained in fuel for nuclear submarines, which is estimated to be as much as 100 tons of HEU. This leaves about 500 tons of HEU and 90 tons of weapon-grade plutonium in the custody of Rosatom, the state corporation that is responsible for the nuclear weapon production complex and civilian nuclear industry.

Providing security for the material in the Ministry of Defense and in Rosatom presents different challenges. On the military side, Russia has consolidated its warheads in a relatively small number of storage sites and has accepted U.S. assistance to improve security there.[1] The United States also has helped the Russian navy to consolidate and secure its fuel handling facilities.[2] Most of the transfers of nuclear warheads that are performed these days are related to dismantlement of nuclear warheads. Accounting for the material during transfers and storage is relatively straightforward, since it is contained in countable items – warheads and fuel assemblies. Finally, the Ministry of Defense sites are guarded by the troops of the 12th Main Directorate, which has extensive experience with protecting nuclear weapons.

In contrast to the situation in the military, Rosatom's material is scattered across numerous sites and facilities, some of which may not have adequate security or material accounting systems. The United States has provided assistance to secure a substantial fraction of these sites, but some remain outside of the scope of the assistance program.[3] Even with security measures in place, significant amounts of weapon-grade materials are routinely transferred within and between facilities, constantly creating security risks. Unlike the situation with countable nuclear warheads, a large fraction of that material is in bulk form, which creates measurement uncertainties and additional risks of diversion.

Although the Russian government has implemented measures aimed at improving security and accounting of nuclear materials, it has not developed a comprehensive strategy. Various U.S. assistance programs have been effective in addressing some of the most pressing issues, but most of these programs are likely to be phased out in the next few years, after which the task of setting priorities and implementing security programs will be mostly Russia's responsibility. It is, therefore, important to look into the current situation with weapon-grade materials in Russia and to outline a set of goals and measures that could provide a framework for policies that would be most effective in eliminating the risks and that would be sustainable in the long term without outside assistance. The proposed measures, while setting aggressive goals, should take into account the existing practices of the Russian nuclear complex and concentrate on those policies that would have maximum effect. This also means that consolidation and fissile material elimination efforts should give the highest priority to the material in the custody of Rosatom.

Most of the weapon-grade material in Rosatom is plutonium and highly enriched uranium previously used in weapons. As Russia has been dismantling its excess nuclear warheads, the recovered materials have been sent to large material storage facilities, located in Rosatom's closed cities. The number of these facilities is not known, but it appears that at least five closed cities have large storage sites: Sarov, Snezhinsk, Ozersk, Seversk, and Zheleznogorsk. These facilities are estimated to hold tens of tons of fissile material each. Together they probably hold most of the very roughly 600 tons of the weapon-grade material in Rosatom's custody.

The dismantlement of excess warheads in Russia releases at least the 30 tons of weapon-grade uranium annually required for sale to the U.S. under the 1993 "HEU-LEU deal" and at least five tons of plutonium from the same warheads. The plutonium is sent to storage, while the HEU is converted and blended down to LEU to be sent to the United States. These processes create substantial flows of materials in the weapon production complex. Five of Rosatom's closed cities are actively involved in this program – Lesnoy, Ozersk, Seversk, Novouralsk, and Zelenogorsk.

In addition to the plutonium recovered from warheads, Russia has a stock of 18 tons of weapon-grade plutonium produced since 1995 that Russia pledged not to use in its weapon program. This material is currently stored in Seversk and Zheleznogorsk.

Russia also has been running a commercial plutonium reprocessing program, which has produced more than 42 tons of reactor-grade plutonium, which is stored in Ozersk.

Weapon-program related activities that involve handling of fissile materials include research and development, conducted at two weapon laboratories – VNIIEF in Sarov and VNIITF in Snezhinsk. These labs also take part in civilian research programs.

Although the production of new weapon materials has been discontinued, Russia appears to maintain some level of production of new nuclear warheads using recycled fissile materials. It is most likely that the new land-based and sea-based strategic missiles that Russia is currently deploying are equipped with newly manufactured nuclear warheads. This activity most likely involves Ozersk, which provides materials and produces some components, and the warhead assembly facilities in Lesnoy and Trekhgorny.

The civilian part of the nuclear complex includes more than 20 research institutes that have research nuclear reactors, critical and subcritical assemblies containing weapon-grade materials. Only two of these – VNIIEF and VNIITF – are located in closed cities. Security and material accounting at these sites is probably the most pressing problem that Russia will have to deal with. The United States provided assistance with security upgrades for most of these sites, but questions about sustainability of this effort remain. Efforts to clean out these facilities have so far resulted in removal of fissile materials from only one site. Russia has only recently agreed to consider a possibility of converting some of its HEU-fueled research reactor to LEU fuel.

In addition to research reactors, Russia operates naval reactors on submarines and icebreakers, a breeder reactor, and tritium and plutonium production reactors, all of which are fueled with HEU. While Russia's last plutonium-production reactor is to stop operations in May 2009 and completely shut down in 2010, the other classes of HEU-fueled reactors will continue to operate, resulting in a continuing flow of weapon-grade fissile materials through the system.

To supply fuel for these reactors, Russia's two main fuel fabrication-facilities routinely handle substantial amounts of weapon-usable materials. Research on new fuels, conducted in three research institutes, also involves weapon-usable materials.

Russia also continues to supply HEU fuel to the Soviet-built research reactors abroad. There are 16 organizations outside Russia with research reactors or critical and subcritical assemblies supplied by the Soviet Union that still have fresh and/or spent HEU fuel on site. Russia has been involved in the U.S.-led program Global Threat Reduction Initiative that aims at cleaning out these sites and converting their reactors to LEU. This program has been very successful, but many sites still await fuel removal and reactor conversion.

This report reviews the task of consolidating and securing Russia's fissile materials, eliminating transfers, and cleaning out civilian sites. The following sections describe the nuclear complex in more detail and suggest measures that would help consolidate fissile materials at a smaller number of sites and reduce unnecessary activities and risks.

I. Weapon-usable Fissile Materials

Russia does not produce new fissile materials for weapons. The Soviet Union stopped producing highly enriched uranium (HEU) in 1988.[4] Russia continued to operate three plutonium-production reactors that together produced more than a ton of weapon-grade plutonium annually, but since 1995, that plutonium has been sent to U.S.-monitored storage, so it cannot be used for weapon purposes.[5] Two of the reactors finally shut down in the summer of 2008 and the third was scheduled to stop operations in May 2009.[6]

Given the large amounts of fissile materials that have been produced already and the dramatically reduced size of its nuclear weapons arsenal, it is extremely unlikely that Russia will ever need to resume production of fissile materials for weapons. Indeed, Russia and the United States each have declared some of their fissile material excess for weapons use. As part of this process Russia declared excess up to 50 tons of weapon-grade plutonium and 500 tons of highly-enriched uranium as.[7]

The total amount of weapon-usable fissile material remaining in Russia's inventory has been estimated only with a very large uncertainty. It is believed that the Soviet Union produced up to 1400 tons of highly-enriched uranium.[8] Some of that material has been consumed in nuclear tests, reactor fuel or by blend-down of the HEU recovered from reprocessed HEU-spent fuel or blended down by the U.S. Materials Consolidation and Conversion program but all of these uses may only have totaled perhaps 100 tons.[9] Taking into account that about 340 tons of HEU has been down-blended as part of the HEU-LEU deal with the United States, the amount of HEU remaining as of mid-2008 is about 950 tons.[10] Only part of this material is in Rosatom's custody. Some of it is in weapons, and some in naval-reactor fuel.

The total amount of weapon-grade plutonium that has been produced is estimated to be about 145 tons.[11] Russia also declared that it had about 45 tons of separated civilian plutonium as of the end of 2007.[12]

It is believed that, at the peak of the Cold War, in the mid-1980s, the Soviet Union had more than 40,000 nuclear warheads of all types.[13] By 2008 that number had been drastically reduced to about 3100 deployed strategic warheads and about 2300 operational non-strategic warheads. Taking into account the warheads in storage or awaiting dismantlement, Russia probably has over 10,000 nuclear warheads.[14]

Assuming 25 kilograms of weapon-grade uranium and 4 kilograms of plutonium in the average warhead, Russia may have about 350 tons of HEU and 56 tons of weapon-grade plutonium still in warheads. Nuclear warheads are handled by the 12th Main Directorate of Russia's Ministry of Defense and by the services of the Russian armed forces that operate strategic weapon systems. It is believed that the warheads that are not deployed on sea-based or land-based ballistic missiles are stored at centralized storage facilities.

The amount of material that is reserved for future use in naval reactors is not known, but could be about 100 tons.[15] This stockpile would be in the custody of Rosatom.

Taking all these estimates in into account, Russia's nuclear industry currently has up to 500 tons of HEU and about 90 tons of weapon-grade plutonium outside of warheads. These estimates are in agreement with the number of 600 tons of Russian weapon-usable material outside of warheads that is usually used in discussions of U.S. Department of Energy material protection, control, and accounting (MPC&A) activities in Russia.[16] But the uncertainty in this number is very large – on the order of 300 tons -- underscoring the fact that Russia is yet to conduct a detailed inventory of its fissile-material stockpiles as the U.S. has done.

Whatever the uncertainty, the amount of material in the Russian nuclear complex is unlikely to change significantly in at least the next decade. The remaining 160 tons of highly-enriched uranium that Russia has committed for down-blending to LEU and sale to the U.S. will most likely come from disassembled weapons and Russia has stated that it intends to stop down-blending after the contract ends in 2013.[17] As for plutonium, Russia has made a commitment to eliminate about 34 tons, but that process is unlikely to begin for a number of years.[18]

II. Nuclear Weapon Complex

The industrial complex created by the Soviet Union to support development, production, and maintenance of nuclear warheads is a large conglomerate of enterprises that were traditionally managed by a single government ministry. For most of post-World-War-II Soviet history it was known as the Ministry of Medium Machine Building (or Minsredmash). In Russia it became known as the Ministry of Atomic Energy or Minatom. In March 2004, the ministry was transformed into the Federal Agency for Atomic Energy, usually referred to as Rosatom. In 2008 the Agency was transformed into the state corporation *Rosatom*. The basic responsibilities of the organization remained the same.

Rosatom is responsible for most aspects of nuclear-related activity, both military and civilian. Its enterprises and subdivisions manage all aspects of the nuclear fuel cycle – from uranium mining to fuel fabrication and spent fuel reprocessing and waste disposal. Rosatom and its daughter companies and research institutes also operate all civilian power reactors as well as most research nuclear facilities. On the military side, Rosatom is responsible for managing weapon-usable fissile materials and the development and production of nuclear weapons.

The core of the Rosatom nuclear complex consists of ten closed cities, all of which were involved in weapon-related activities. These sites are described in detail in the next section.

Recent changes. During Soviet times, all the closed cities were involved in production and handling of weapon usable fissile materials. Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26 produced plutonium. Enrichment facilities in Sverdlovsk-44, Krasnoyarsk-45, and Tomsk-7 produced highly enriched uranium. (A fourth enrichment site, Angarsk, never produced HEU.) The main chemical and metallurgical facilities for processing of weapons materials and for pit fabrication were located in Chelyabinsk-65 and Tomsk-7. These two cities also most likely served as major storage sites for weapon-grade material. Substantial amounts of weapon materials are also stored and handled by the two nuclear weapon laboratories, VNIIEF in Arzamas-16 and VNIITF in Chelyabinsk-70.

Production of nuclear weapons and their components was concentrated at the Avangard plant in Arzamas-16 and at the Electrochemical Instrument Combine in Sverdlovsk-45. These two plants appeared to have had the capability to manufacture fissile material components, as well as perform weapon assembly and disassembly work. The other two assembly plants, in Penza-19 and Zlatoust-36, were assembling weapons and warheads from “physics packages” supplied by other production facilities. They were also involved in weapon disassembly work.

Russia relies on continuous remanufacture of the fissile-material components of nuclear weapons. It also appears that very few (if any) nuclear components were designed to be interchangeable between different types of warheads. This means that, unlike the United States, Russia is unlikely to have large strategic stocks of plutonium pits and HEU-containing “secondaries.” Instead, the Russian nuclear complex relies in its ability to manufacture these components as needed.

The restructuring of Russia's nuclear complex that took place after the end of the Cold War resulted in a number of important changes in the flow of weapon-usable fissile materials. As already noted, production of new weapon-grade material for weapons purposes has stopped. Nuclear weapons assembly and disassembly has been concentrated at two sites: Trekhgorny/Zlatoust-36 and Lesnoy/Sverdlovsk-45. Only one of Russia's three HEU production facilities is today licensed to produce HEU and that one is limited to producing HEU with enrichment of no more than 30 percent. It is not clear if it is producing HEU at all. All three of the sites that formerly produced HEU down-blending for sale to the U.S. under the 1993 HEU-LEU deal.

The first phase of restructuring was largely completed in 2003. In 2007, Russia's government initiated consolidation of some nuclear-power-related activities. As part of that initiative, some enterprises of the nuclear weapon-complex were removed from the list of companies that cannot be privatized. Notably, this list no longer includes the Siberian Chemical Combine in Seversk/Tomsk-7, which formerly produced plutonium, HEU and weapon components; the Mining and Chemical Combine in Zheleznogorsk/Krasnoyarsk-26, which formerly produced plutonium (and will continue to do so till 2010); and the Avangard component-production and warhead assembly/disassembly plant in Sarov/Arzamas-16. This indicates that these companies will no longer be involved in weapon-related work. At the same time, this change does not necessarily mean that all weapon-grade material will be removed from these sites. For example, Rosatom is planning to move all plutonium component fabrication activities from Mayak to Seversk.[19]

Details of the fissile material storage and handling arrangements are generally not publicly known. According to a 2003 U.S. Department of Energy estimate, there were 87 building in the Russian weapon-production complex that stored weapon usable materials.[20] It is not publicly known, however, how these buildings are distributed among the sites, and the quantities of material they contain. The United States and Russia are undertaking an effort to upgrade security at most of the sites as part of the MPC&A program. Some sites and buildings, however, are not covered by this program.[21] The lack of detailed information makes it difficult to determine whether the restructuring of the Russian nuclear complex has completely removed all weapon-usable material from any site.

III. Individual Sites

Russia's nuclear weapons production complex consists of ten closed cities. All of these cities were involved in nuclear weapon-related activities during the Cold War.

Mayak Production Association at Ozersk/Chelyabinsk-65

Located in Ozersk/Chelyabinsk-65, the Mayak Production Association is one of Russia's oldest nuclear material production facilities. At different times, it operated five plutonium production reactors, five tritium production reactors, several reprocessing plants, a plutonium metallurgy plant, and various supporting facilities. It is also a major storage site for weapon-grade materials as well as for separated reactor-grade plutonium.[22]

Mayak is no longer producing weapon-grade fissile material. Its plutonium production reactors were shut down during 1987-1990. The radiochemical plant that was separating weapon-grade plutonium was closed down in 1987.[23]

Radiochemical reprocessing of spent fuel from civilian power reactors as well as spent HEU fuel from naval and other reactors continues at Mayak's RT-1 reprocessing plant. This results in an additional 1-2 tons of separated reactor-grade plutonium annually. As of the end of 2007, according to its declaration to the International Atomic Energy Agency, Russia had 44.9 tons of civilian reactor-grade plutonium. This is stored as plutonium oxide at the RT-1 site.[24]

Mayak is likely also to have a major storage site for weapon-grade plutonium and highly-enriched uranium.[25] No information about these national-level storage facilities is available, but they might hold on the order of 100 tons of weapon-grade plutonium and HEU.[26]

Table 1: Plutonium production sites and activities

Mayak Production Association, Ozersk

Past:	Production and separation of weapon-grade plutonium
Continuing:	Storage of weapon-grade plutonium and uranium; Production of plutonium pits and HEU components for nuclear weapons (scheduled to end by 2014); Separation and storage of reactor-grade plutonium from spent fuel; Production of radioisotopes and tritium
New:	Storage of excess weapon-grade plutonium at Fissile Materials Storage Facility

Siberian Chemical Combine, Seversk

Past:	Production and separation of weapon-grade plutonium (separation to end in 2010); Fuel production for plutonium-production reactors;
Continuing:	Storage of weapon-grade plutonium and uranium Production of plutonium pits and HEU components for nuclear weapons (to be resumed by 2014);
New:	Storage of weapon-grade plutonium oxide under U.S. monitoring

Mining and Chemical Combine, Zheleznogorsk

Past:	Production and separation of weapon-grade plutonium (production to end in 2009, separation to end ca. 2012)
New:	Storage of weapon-grade plutonium and uranium (possible); Storage of weapon-grade plutonium oxide under U.S. monitoring

Figure 1. Interior picture of Mayak storage facility. A stack of containers, each holding two 2-kg plutonium-metal balls, can be stored under each square.[27]

A separate store, the Fissile Materials Storage Facility (FMSF), was constructed at Ozersk with U.S. assistance in 2003 (Figure 1). The current Rosatom plan is to use this store for about 25 tons of excess plutonium from dismantled nuclear weapons.[28] After a delay caused by a dispute between Russia and the United States about transparency arrangements, the facility began accepting fissile materials in July 2007.[29] The United States and Russia are still negotiating transparency measures on material stored in this facility.

Mayak today is the primary facility in Russia's nuclear complex for large-scale manufacturing of plutonium and HEU components of nuclear weapons. The chemical metallurgical plant, Plant 20, has been in operation since the early days of the Soviet nuclear weapon program.[30] Since 1997, the plant has also been involved in the HEU-LEU program. It converts uranium metal into uranium dioxide that is then sent to another site, probably Zelenogorsk, for conversion to UF_6.[31]

Mayak also continues to operate two HEU- fuelled tritium-production reactors, *Ruslan* and *Lyudmila*. Because Russia has a plentiful supply of tritium from excess weapons, these reactors have been converted to the production of radioisotopes for civilian use, although they probably maintain the capability to produce tritium if necessary.[32] *Ruslan* is a pool-type light-water reactor that has operated since 1979. The reactor underwent a major overhaul in 1998-1999.[33] *Lyudmila* is a heavy-water reactor that has been in operation since 1988.[34] Fuel for these reactors is supplied by the Novosibirsk Chemical Concentrates Plant.[35]

Given the role of Mayak in the Russian nuclear complex, it will probably remain one of the sites that handle weapon-grade material in any restructuring and consolidation of the industry.

Siberian Chemical Combine at Seversk/Tomsk-7

For most of the history of the Soviet/Russian nuclear complex, the Siberian Chemical Combine, located in Seversk/Tomsk-7, has been a major fissile material production site. It operated five plutonium production reactors, a reprocessing facility and a chemical and metallurgical weapon-component production plant and uranium enrichment plant. Tomsk-7 also has been a major weapon-material storage site. Most of this activity has been discontinued in recent years.

Three of the five plutonium production reactors were shut down in 1990-1992. Two reactors, ADE-4 and ADE-5 (Figure 2), continued to operate until April 2008 and June 2008 respectively to provide heat and electricity to nearby cities, but, since 1995, the plutonium that they were producing was no longer used in the weapon program.[36]

Figure 2. ADE 4 and 5 reactors, Seversk, July 10, 2000. The large building at the center is the turbogenerator building. The smaller building just below it houses the two reactors, of which only one was operating.

The ADE-type reactors used natural-uranium fuel, but their cores also contained some HEU "spike" fuel assemblies that were used to even out the neutron flux radially across the reactor core. Each reactor contained about 80 kg of HEU and consumed about 200 kg of HEU annually.[37]

The Seversk reprocessing plant will continue for some time to separate weapon-grade plutonium from irradiated production-reactor fuel. The plutonium is stored as oxide at a storage facility on the territory of the plant.[38] Under the U.S.-Russian agreement on cessation of production of plutonium for weapons, this storage facility is open to U.S. inspections.[39] As of summer 2008, it held about 10 tons of plutonium.[40]

Like its counterpart at Ozersk/Chelyabinsk-65, the chemical and metallurgical plant at Tomsk-7 manufactured metal plutonium and HEU components for nuclear weapons during the Cold War. The 1998 restructuring plan called for moving all activity of this kind to one site, presumably Ozersk.[41] Weapon-related work at the metallurgical plant in Seversk had stopped by 2001, but may be resumed in the future as Rosatom is planning to move this activity from Mayak by 2014.[42] It appears that the only weapon-material work that is currently conducted at the metallurgical plant is related to the HEU-LEU deal. Since 1994, Seversk has been performing conversion of metallic uranium into HEU oxide. Since 1996, the oxide has been converted to UF_6 at Seversk and then down-blended at a facility constructed for the purpose.[43]

Uranium enrichment infrastructure in Seversk includes a centrifuge plant with a capacity of about 2.8 million SWU/year, and two large conversion facilities that produce UF_6 for the enrichment complex.[44] The enrichment plant no longer produces highly enriched uranium.

In addition to the storage facility for plutonium produced by the production reactors since 1994, Seversk has two older facilities for storing fissile materials and weapon components with a reported capacity for about 23,000 containers.[45] In 2003, the U.S. Department of Energy reported that it concluded contracts with Minatom to secure 80 tons of weapon-usable fissile material at Tomsk-7.[46] In addition to material storage facilities, Seversk also has at least one facility for storing nuclear weapon components located on the territory of one of the reactor sites.[47]

The Siberian Chemical Combine appears to be one of the sites that will eventually be converted to support civilian nuclear power activities. As already noted, in 2007, the Combine was excluded from the list of companies that cannot be privatized. At the same time, even though Seversk may no longer take part in weapon-related activities, it will remain a major site for storage and handling of weapon-usable fissile materials. Rosatom plans to move the 10 tons of weapon-grade plutonium that were produced since 1995 to Zheleznogorsk.[48] There seem to be no plans to remove other weapons materials from Seversk.

Mining and Chemical Combine at Zheleznogorsk/Krasnoyarsk-26

Zheleznogorsk/Krasnoyarsk-26 was the Soviet Union's third plutonium-production city. Built in the 1950s, the Mining and Chemical Combine includes a number of underground facilities: three plutonium-production reactors, a reprocessing plant, and supporting infrastructure.

Two reactors at Zheleznogorsk were shut down in 1992. The third one, ADE-2, continues to produce heat and electricity for the city, as well as weapon-grade plutonium. It is expected that it will stop operations on May 31, 2009 and will be completely shut down in 2010.[49]

The reprocessing plant in Zheleznogorsk continues to extract plutonium from irradiated fuel produced by ADE-2. The plutonium is then stored on site underground as plutonium oxide in a U.S.-monitored storage facility.[50] Since January 1, 1995, when, by agreement, storage in a U.S.-monitored on-site storage facility began, the reactor has produced about 8 tons of plutonium.[51] Given that Rosatom plans to bring 10 tons of similar material from Seversk, it seems likely that Zheleznogorsk would remain one of the major storage sites in the future. It is unclear, however, whether Zheleznogorsk has the infrastructure for storage of larger amounts of fissile materials or whether significant quantities of weapon usable materials were routinely stored there during Soviet time. Unlike Ozersk and Seversk, Zheleznogorsk does not have a plant for producing weapon components. In the past the plutonium oxide produced here was sent to either Chelyabinsk-65 or Tomsk-7 for conversion to metal and further use.[52]

Some reports indicate that Russia may be building a new nuclear-material storage facility in Zheleznogorsk that would be separate from the one that holds the plutonium produced after 1995.[53] This also indicates that weapon-usable materials may remain in Zheleznogorsk for a long time after shutdown of the plutonium-production reactor and reprocessing plant. These storage facilities may be in the underground complex that housed the plutonium-production reactors.

The Mining and Chemical Combine at Zheleznogorsk is no longer directly involved in any weapon-related activity. The 2007 restructuring plan indicated the intent to fully convert the Combine to civilian activities, which are proposed to include storage and reprocessing of spent power-reactor fuel. The weapon-material storage facilities would most likely operate separately.

Scientific Research Institute of Experimental Physics and Avangard plant at Sarov/Arzamas-16

Sarov is the site of the first Soviet nuclear weapon laboratory, currently known as the Russian Federal Nuclear Center - All-Russian Scientific Center Research Institute of Experimental Physics (VNIIEF), and of the Soviet Union's first plant for large-scale production of nuclear warheads, Avangard.

VNIIEF. The institute conducts a wide range of research and development activities, including on new nuclear warheads. It therefore has access to and routinely handles significant amounts of weapon-usable fissile materials. According to one estimate, the two Russian weapon laboratories, VNIIEF in Sarov and VNIITF in Snezhinsk, together hold at least 30 tons of weapon-usable material.[54]

The role that VNIIEF plays in the process of nuclear weapons development and maintenance assures that it will continue to handle and store nuclear materials.

Avangard. The Avangard plant appears to be one of the few facilities that have discontinued all weapon-related activities. As a warhead-production plant, Avangard apparently was involved in the complete range of work from manufacturing of components to assembly and disassembly of the "physics packages" of nuclear weapons. During the 1990s, this activity was gradually discontinued. A 1998 restructuring plan called for ending of all warhead assembly at Avangard by 2000 and of disassembly in 2003.[55] All these activities apparently have indeed ended. As a result, Avangard too is no longer on the "no-privatization" list of facilities of Russia's nuclear complex.[56]

Table 2: Nuclear weapons R&D and assembly

Scientific Research Institute of Experimental Physics, Sarov

Continuing:	Nuclear-weapon R&D; Small-scale pit production; Weapon-grade plutonium and uranium storage

Scientific Research Institute of Technical Physics, Snezhinsk

Continuing:	Nuclear-weapon R&D; Small-scale pit production; Weapon-grade plutonium and uranium storage

Electrochemical Instrument Combine, Lesnoy

Continuing:	Production of HEU weapon components; Warhead assembly and disassembly; Weapon material and component storage

Instrument Building Plant, Trekhgorny

Continuing:	Warhead assembly and disassembly

Avangard Plant, Sarov

Past:	Production of HEU weapon components; Warhead assembly and disassembly; Weapon material and component storage

Start Production Association, Zarechny

Past:	Warhead assembly and disassembly

Research Institute of Technical Physics at Snezhinsk/Chelyabinsk-70

The Russian Federal Nuclear Center - All-Russian Research Institute of Technical Physics at Snezhinsk/Chelyabinsk-70 (VNIITF) is Russia's second weapon laboratory. Like VNIIEF in Sarov, it has the capabilities to carry out a full range of fissile-material related activities, including small-scale production of nuclear explosives. As noted above, Snezhinsk and VNIIEF together possess more than 30 tons of materials.[57]

Although, in theory, Russia could consolidate all weapon design and maintenance work in one laboratory, it does not seem to have plans to do so. Snezhinsk appears to be actively involved in development of new nuclear warheads that would support the modernization of Russia's strategic forces.[58] Like Sarov, it is likely to maintain its status as a weapon development center and to continue activities that involve handling and storage of weapon-usable fissile materials.

Electrochemical Instrument Combine at Lesnoy/Sverlovsk-45

The Electrochemical Instrument Combine in Lesnoy/Sverdlovsk-45 was one of the four nuclear weapon production facilities that were built during the Soviet era. Along with the Avangard plant in Arzamas-16/Sarov, the Combine was involved in production of HEU components of nuclear weapons, as well as in assembly and disassembly work.[59]

After the Avangard plant ended its weapon-related work, Lesnoy became Russia's primary weapons assembly/disassembly site. It is probably involved in remanufacturing nuclear weapons for Russia's arsenal. Lesnoy also is involved in disassembly of weapon components to recover highly enriched uranium for the HEU-LEU program. The HEU is sent to Ozersk and Seversk, where the metal is oxidized and converted to UF_6.[60] Lesnoy is likely to remain the center of Russia's weapon assembly/disassembly activity and therefore will continue to have substantial amounts of weapon-usable material on site.

Instrument Building Plant at Trekhgorny/Zlatoust-36

As a result of the 1998 downsizing program, the Instrument Building Plant in Trekhgorny/Zlatoust-36 is now Russia's only other warhead assembly and disassembly facility. The plant appears to be mostly involved in integration of physics packages into finished weapon systems and does not seem to have facilities for manufacturing nuclear-weapon components.[61] It also does weapon-disassembly work. Trekhgorny apparently has facilities for storage of nuclear weapon components and assembled weapons, but these stores are probably rather small.[62]

It is not clear to what extent handling of nuclear materials in Trekhgorny is essential to Russia's nuclear-weapon complex. Its primary role may be production of electromechanical and electronic components and instrumentation systems. It seems to have some facilities for processing weapon-grade materials and for mechanical-component production, but it is not clear if these are operational.

Start Production Association at Zarechny/Penza-19

The role of the fourth serial production site, the Start Production Association in Zarechny/Penza-19, was similar to that of the Trekhgorny plant. The Start plant was involved in production of electronic and electro-mechanical components of nuclear weapons and in integration of physics packages supplied from elsewhere into finished weapon systems such as ballistic-missile reentry vehicles. It also has done disassembly of nuclear weapons. The 1998 Minatom restructuring plan called for ending all assembly activities here in 2000 and all disassembly work in 2003. This plan has been implemented and the Start plant no longer works with or stores components containing fissile materials. Some non-nuclear weapon-related work seems to continue.[63]

Uranium enrichment facilities

Russia's uranium enrichment complex no longer produces highly enriched uranium for weapons. Of the four enrichment facilities that are operational today, only one, in Novouralsk, is believed to be licensed to produce HEU enriched to 30 percent. The other plants – in Seversk, Zelenogorsk, and Angarsk – have licenses that limit enrichment of the uranium they produce to 5 percent.[64] All the enrichment plants have the capability, however, to produce weapon-usable HEU. The need is unlikely to arise for the foreseeable future, however. Russia can satisfy most of its HEU requirements for naval and research reactors by blending down excess weapon-grade HEU.

Table 3: Uranium enrichment sites and activities

Siberian Chemical Combine, Seversk	
Past:	HEU production
Continuing:	LEU production
New:	HEU-LEU program: conversion of HEU metal into oxide, fluorination, and down-blending
Mayak Production Association, Ozersk	
New:	HEU-LEU program: conversion of HEU metal into oxide
Electrochemical Plant, Zelenogorsk	
Past:	HEU production
Continuing:	LEU production
New:	HEU-LEU program: fluorination
Urals Electrochemical Plant, Novouralsk	
Continuing:	HEU and LEU production
New:	HEU-LEU program: down-blending

One of Russia's enrichment plants, in Angarsk, has never produced HEU and most likely has never had weapon-usable material on site. According to the current Rosatom plan, Angarsk will host an international enrichment facility, so it will probably remain HEU free.

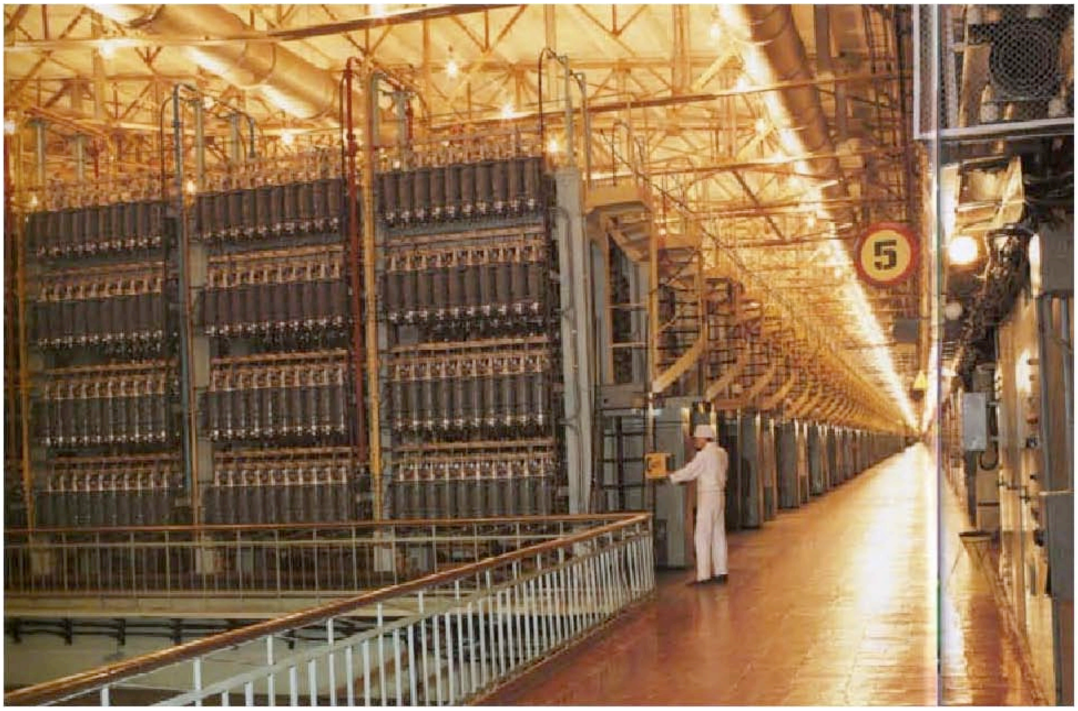

Figure 3. Centrifuge hall, Novouralsk enrichment plant. Russian centrifuges are small and stacked on racks.[65]

The three other enrichment plants – the Urals Electrochemical Plant in Novouralsk/Sverdlovsk-44 (Figure 3), Electrochemical Plant in Zelenogorsk/Krasnoyarsk-45, and the enrichment facility in Seversk/Tomsk-7 – do not normally produce HEU. They routinely handle materials containing weapon-grade uranium, however. As part of the HEU-LEU deal, these three plants are involved in blending down weapon-grade uranium. Seversk deals with HEU in metal, oxide and UF_6 forms; Zelenogorsk receives HEU oxide and converts it into UF_6 on site. Novouralsk receives HEU as UF_6.[66]

The HEU-LEU contract and the material transfers associated with it will end in 2013. After that the activities in Zelenogorsk and Novouralsk involving weapon-grade HEU will most likely stop. Novouralsk, however, will probably retain its role as a producer of HEU with enrichment of up to 30%. It appears to be the only Russian enrichment plant with cascades that have not been contaminated by irradiated uranium recovered from production-reactor fuel.[67]

IV. Research Reactors and Critical and Subcritical Assemblies

Substantial amounts of weapon-usable materials are used in applications that are not directly related to weapon production. Highly enriched uranium is widely used in research reactors, and critical and subcritical assemblies. Some research facilities also use plutonium. HEU fuel is used in submarine and other naval reactors as well as in the sodium-cooled fast-neutron breeder reactors that were built by the Soviet Union. Fuel fabrication plants that produce HEU fuel therefore routinely handle and ship out significant amounts of weapon-useable materials. Some highly-enriched uranium and plutonium is also present in research institutes that conduct research related to development of reactor fuel.

Although the quantity of material involved in non-weapon activities is small in comparison to what is used in the weapon-production complex, it amounts to many tens of tons of weapon-usable material, primarily HEU. About 2.2 tons of Russian-origin HEU is estimated to be outside of Russia.[68]

Research reactors in Russia. The fissile material in the fuel cycles of Russia's reactors is distributed among a large number of facilities that may not have the degree of security and centralized control over the material that is normally associated with weapon sites. Consolidation of this material should therefore be a very important part of any program that aims at reducing the dangers associated with weapon-grade fissile materials.

The Soviet Union built more than hundred research reactors, including critical assemblies. Today, twenty-one different organizations in Russia -- almost all of them research institutes -- have operating or shutdown HEU-fueled reactors (see Table A). Only two of these organizations – VNIIEF at Sarov and VNIITF at Snezhinsk – are located in closed cities that are directly involved in weapon development and production. Others are part of the reactor-development and nuclear-science complex of Rosatom or of the research complex of the Ministry of Defense.

Weapon-usable material at these facilities can exist in several forms. Operational reactors with a thermal power greater than a few megawatts normally have a supply of fresh HEU fuel on site and require regular shipments. Such reactors require from several kilograms to tens of kilograms of U-235 annually in fresh fuel from a fuel fabrication plant for their normal operations.[69] In the U.S., fresh fuel with these amounts of material would require protection similar to that of directly-useable weapon material.[70] Irradiated research-reactor fuel also requires significant level of protection, depending on the amount of HEU in it, the degree of irradiation and the number of years it has cooled since discharge from the reactor.[71]

A number of research reactors have been shut down and some have had fuel removed from their cores. It appears that few of these sites have been cleaned out completely, however. Most of them still have spent HEU fuel on site. The only site from which weapon-grade material has been completely removed so far is the Krylov Shipbuilding Scientific Research Institute.[72] The institute had one research reactor, two critical assemblies and one subcritical assembly, all of which contained HEU in their cores. In 2006, with assistance provided by the United States'

Material Consolidation and Conversion Program, Russia completed removal of all fissile material from the site.[73]

The fissile material in pulsed reactors and critical and subcritical assemblies is normally not subject to significant degree of burnup (Figure 4). It therefore does not develop a protective fission-product-generated gamma-radiation field and requires the same level of protection as fresh fuel. As indicated in Appendix A, a number of pulsed reactors and critical assemblies have been shut down. Their fuel may not, however, have been removed yet. These facilities should be assumed to have HEU on site unless there is reliable information that they have been cleaned out.

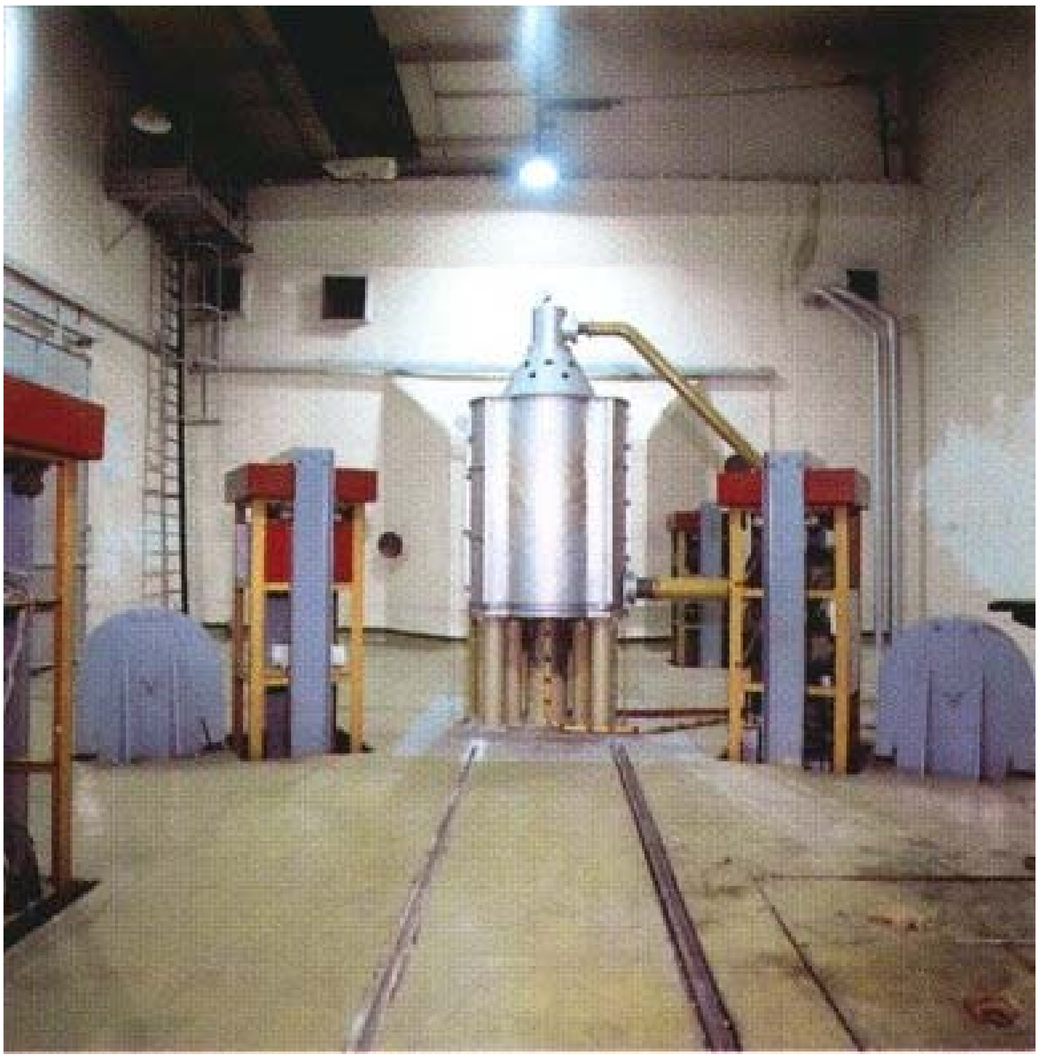

Figure 4. The BIGR Pulsed Reactor at VNIIEF. It contains 833 kg of barely irradiated weapon-grade uranium.[74]

A number of programs have been launched to convert HEU-fuel research reactors to LEU and clean out spent HEU fuel and unused fresh HEU fuel from sites at which HEU-fueled reactors have operated. The Reduced Enrichment for Research and Test Reactors (RERTR) program has been run by the United States since 1978. The Soviet Union had a similar program that reduced the enrichment level in fuel of many Soviet-supplied research reactors outside the Soviet Union from 80-90% to 36%. In 2003 the United States and Russia established the Russian Research Reactor Fuel Return (RRRFR) program to convert to LEU fuel foreign HEU-fueled reactors and bring fresh and spent HEU fuel exported by the Soviet Union and Russia to other countries back to Russia. This program is now part of a broader U.S.-led effort, the Global Threat Reduction Initiative (GTRI), which also has offered to assist Russia in conversion of its own research reactors to LEU fuel. Although Russia has developed replacement LEU fuel suitable for some of its research reactors, none of Russia's reactors has been converted to LEU yet. Also, as indicated in Appendix A, substantial number of Russian facilities remain outside of the scope of the GTRI effort.[75] In 2008, however, Russia initiated feasibility studies of conversion of six of its research reactors and critical assemblies – IR-8, OR, and Argus at the Kurchatov Institute, IRT at MEPhI, MIR and SM-3 at the Research Institute of Atomic Reactors in Dimitrovgrad (there are also critical facilities FM MIR and FM S-3 associated with these reactors, which would probably be converted as well), and IRT-T in Tomsk.[76] Although no firm commitment has been made so far, these reactors would most likely be eventually converted to LEU fuel.

Russia also has research-reactor construction and modification projects underway. A new high-powered research reactor, PIK, is being built at the St.-Petersburg Institute of Nuclear Physics in Gatchina; the Scientific Research Institute of Instruments (NIIP) in Lytkarino is building the IRV-2M reactor to replace the dismantled IRV-1M; and an experimental accelerator-driven system, Electro-Nuclear Neutron Generator (XADS or ELYANG), is being constructed at the Institute of Theoretical and Experimental Physics in Moscow.[77] The PIK reactor will use HEU fuel, while IRV-2M and XADS could use either LEU or HEU fuel.

Soviet/Russian designed research reactors outside Russia. Appendix B lists Soviet-supplied research reactors and critical and subcritical assemblies that are located outside of Russian territory.[78] Thus far, five reactors have been converted to LEU fuel: LVR-15 and VR-1P in the Czech Republic, IRT-1 in Libya, VVS-SM in Uzbekistan, and the Dalat Research Reactor in Vietnam.[79] A number of Soviet-supplied research reactors also have been permanently shut down and fresh fuel has been removed from the sites – usually to Russia. Only five reactor sites have been completely cleaned out, however, i.e. have had HEU spent fuel removed as well. These are the LVR-15 reactor in Czech Republic, the VVS-SM in Uzbekistan, IRT-M reactors in Georgia and Latvia, and two land-based reactors for training submarine reactor operators in Estonia. The other facilities still have either fresh or irradiated fuel on site.

Russia appears to be committed to supplying HEU fuel for Soviet-designed, HEU-fueled research reactors until they are converted to LEU. In January 2008, for example, Russia supplied fuel enriched to 36% to the Maria reactor in Poland.[80]

V. Propulsion and Breeder Reactors

Russia has both military and civilian nuclear propulsion reactors that use highly enriched uranium fuel. It also has a breeder program that uses HEU fuel and has plans for plutonium fuelled breeder reactors.

Propulsion Reactors. Russia has an extensive fleet of submarine and civilian icebreaker propulsion reactors. Most of these reactors use highly enriched uranium with enrichment levels of up to 90 percent, although average enrichment levels appear to be lower.[81]

Nuclear-powered submarines and Russia's one remaining nuclear-powered surface military ship, the *Kirov*-class cruiser, *Admiral Nakhimov*, are with Russia's Northern and Pacific Fleets. The infrastructure that allows the Russian Navy to handle fresh and spent nuclear fuel at these bases has received substantial upgrades in the years after the breakup of the Soviet Union. The security upgrades were done with assistance from the United States and have been largely completed.[82]

The facilities that handle the fuel of the nuclear-powered icebreaker reactors have also been receiving security upgrades with Western assistance.[83] Conversion of these reactors to LEU fuel has been suggested.[84]

Russia has no plans, however, to convert its submarine or civilian icebreaker reactors to LEU fuel. This means that operations that involve production and shipment of significant amounts of HEU-containing fuel for these reactors will continue indefinitely.

Breeder reactors. One power reactor that uses highly enriched uranium in its fuel is the fast reactor BN-600, which has been operating at the Beloyarsk Nuclear Power Plant since 1980. The reactor currently uses uranium fuel with three different enrichment levels – 17%, 21%, and 26%.[85] The reactor was to be decommissioned in 2010, but Rosatom is working on modernizing it, which is expected to extend its service life by as much as 15 years.[86] The BN-600 reactor can use plutonium-based fuel, but only for a portion of its core because of safety reasons. The new BN-800 fast reactor that is being built at the Beloyarsk power plant is designed to work with a full core of plutonium-based fuel but is to be fueled initially with HEU fuels.

VI. Fuel Fabrication and R&D

Most of the fuel for Soviet-designed nuclear reactors in Russia and abroad is manufactured by two major production facilities: the Machine-Building Plant (MSZ) in Electrostal and the Novosibirsk Chemical Concentrates Plant (NZKhK). These plants are owned by the TVEL Corporation.[87] These are shown in Table 4.

The Machine-Building Plant in Electrostal can produce uranium oxide-pellets from uranium hexafluoride feed. It makes only uranium dioxide fuels and manufactures fuel elements and assemblies for four types of power reactors of Soviet design: VVER-440, RBMK, EGP-6, and BN-600. It also supplies the fuel for all military naval reactors and civilian icebreaker reactors. It is also the only major supplier of fuel for research reactors that use uranium dioxide-based fuels: the SM-3, BOR-60, and PIK. The plant apparently does not have a capability to manufacture fuel elements based on plutonium-dioxide.[88]

The Novosibirsk Chemical Concentrates Plant produces fuel for VVER-440 and VVER-1000 light-water power reactors. It also produces a range of cermet (uranium-oxide particles dispersed in metal) fuels that are used in research reactors of various types – MR, VVR, IRT, and IVV. Most of these fuels contain highly enriched uranium with enrichments of 36% and higher. However, the Novosibirsk plant is working on the development of fuels, based on a high-uranium-density uranium-molybdenum alloy that will make it possible to convert high-power research reactors to LEU fuel.[89]

The Novosibirsk plant also supplies HEU fuel for the two isotope and tritium production reactors at Mayak – *Ruslan* and *Lyudmila*.[90] Finally, it supplies the cermet HEU "spike" fuel that is used in a small number of peripheral fuel channels of ADE-type plutonium production reactors to achieve a more even distribution of neutron flux in the reactor core.[91] As already noted, the last of these reactors, is to be shut down in 2010.

In addition to the industrial-scale fuel production facilities in Electrostal and Novosibirsk, several research organizations have the capability to produce reactor fuel or fuel components on a pilot scale and have weapon-usable materials on their sites.

The primary nuclear fuel development research center– the Bochvar Research Institute of Inorganic Materials (VNIINM) in Moscow – does not appear to have significant fuel production capacity. It has, however, several hundred kilograms of weapon-usable materials on site.[92]

The Scientific Research Institute of Nuclear Reactors (NIIAR) in Dimitrovgrad handles some of the fresh reactor fuel that is repatriated to Russia from foreign reactors. It also takes part in the U.S. DoE-funded Material Consolidation and Conversion program by down-blending HEU recovered from various sites in Russia to LEU.[93] NIIAR also has a pilot production line that can produce experimental plutonium oxide-based fuels for fast and thermal reactors. This line was used to produce MOX fuel for the pilot-scale BOR-60 breeder reactor.[94]

Table 4. Fuel fabrication and R&D facilities

Facility	**LEU fuels**	**HEU and Pu fuels**
Machine-Building Plant, Electrostal	VVER-440, RBMK, EGP-6	Fuel for civilian and military naval reactors Oxide fuels for SM-3, BOR-60, PIK reactors HEU fuel for BN-600 reactor
Chemical Concentrates Plant, Novosibirsk	VVER-440, VVER-1000 LEU cermet fuel for converted reactors	HEU cermet fuels for MR, VVR, IRT, IVV research reactors Fuel for tritium production reactors Spike fuel for ADE reactors
Scientific Research Institute of Nuclear Reactors (NIIAR), Dimitrovgrad		Research and development Pilot MOX fuel production for BN-600 reactor
Bochvar Research Institute of Inorganic Materials (VNIINM), Moscow		Research and development
Luch Production Association, Podolsk		Research and development

Finally, the Luch Production Association in Podolsk has been involved in development of fuels for experimental high-temperature nuclear reactors, nuclear power sources for spacecraft, and fuel elements for various pulse reactors.[95] As a result, it has the capability to process and manufacture small batches of HEU and plutonium of fuel elements. Luch also participates in the down-blending activity of the Material Consolidation and Conversion project.[96]

VII. Conclusion: Possibilities for further consolidation

Although some work has been done to downsize Russia's nuclear complex and consolidate its weapon-useable fissile materials, HEU and plutonium are still present at a large number of sites. Substantial amounts of weapon-usable materials also remain in circulation -- currently mostly related to the HEU-to-LEU blend-down project and the continuing operations of Russia's nuclear-powered fleet and a large number of HEU-fueled reactors.

Consolidation of weapon-usable materials at a smaller number of facilities would be a difficult task. The consolidation work that Rosatom has done so far was mostly done in response to the economic pressures in the 1990s. These factors now play a far smaller role. There is no reason to doubt that the Russian government and Rosatom are committed to the goal of reducing the risks that are associated with circulation of weapon-usable materials. This political commitment has not been translated, however, into a set of specific actions and incentives that would help reduce the risks. Rosatom activities in this area are part of a Federal Program on Nuclear and Radiation Safety in 2008 and through 2015, which was approved in October 2007. The program, however, emphasizes radiation safety and issues related to handling of spent fuel and radioactive waste. The efforts to ensure security of weapon-usable materials and consolidation of the nuclear complex could be further strengthened.

One way to provide an incentive for Rosatom and its enterprises would be to make sure that it and its facilities that handle fissile materials pay the full cost of providing security for their fissile materials. This incentive is helping to drive consolidation in the U.S. nuclear complex.[97] Under the current arrangements, security for closed cities and most nuclear installations is provided by several different ministries and agencies, so Rosatom does not have to pay the full security costs associated with its nuclear activities.

Proposals for additional consolidation initiatives group naturally by activity area: weapon development and production, and research and propulsion reactors.

Further consolidation of the weapons complex. Russia's nuclear-weapon-production complex contains the largest quantities of weapon-grade materials, mostly in storage facilities at Ozersk, Seversk, Sarov, Snezhinsk, and probably Zheleznogorsk. Assuring the security of these sites should be one of the highest priority tasks. Attempts to consolidate the stored material at a smaller number of storage facilities might be counterproductive, however, because it would require transporting hundreds of tons of weapon-grade material, creating serious additional security risks. Efforts should be made, therefore, to improve the storage facilities and isolate them physically and organizationally from the closed cities within which they are located.

Russia could make one more step toward consolidation of its weapon assembly facilities by moving all assembly and disassembly operations involving HEU and plutonium components to Lesnoy, leaving Trekhgorny to continue its work on non-nuclear components and instrumentation.

Rationalizing HEU flows in the blend-down process. A large number of shipments are associated with the activities of the HEU-LEU program (Figure 5). Currently, the uranium that is removed from weapons at the plant in Lesnoy is shipped in metal form Ozersk and Seversk where it is converted to uranium dioxide, which is then converted to UF6 in Seversk or Zelenogorsk. Some of the HEU hexafluoride is then sent to Novouralsk for down-blending.

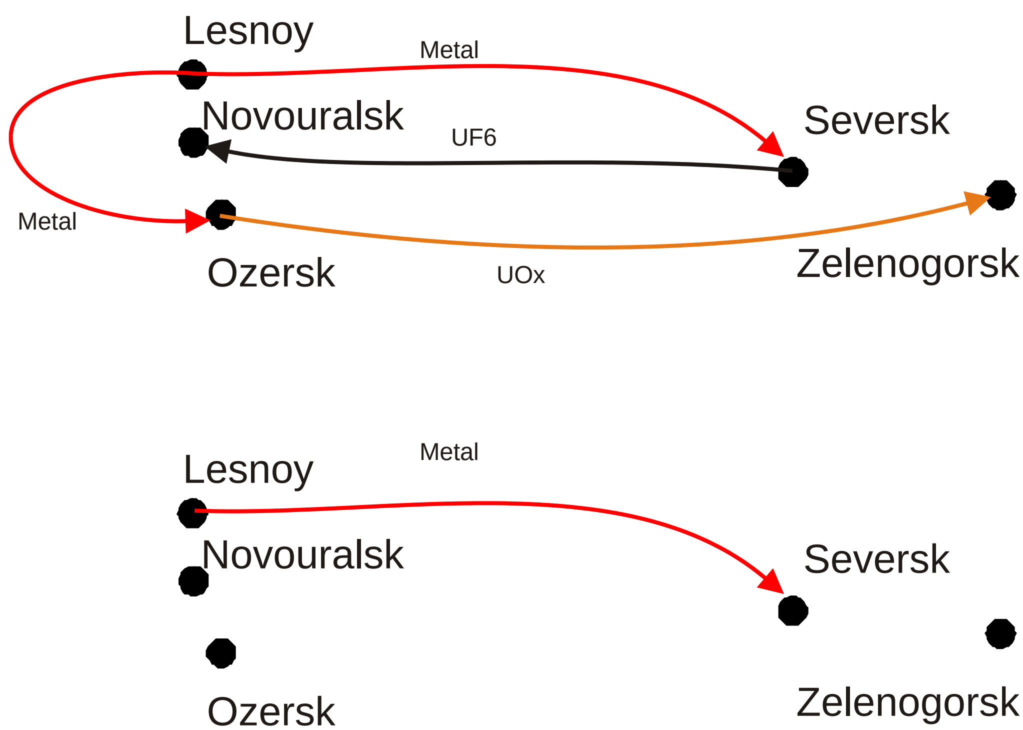

Figure 5. HEU flows in the HEU blend-down process and suggested rationalization.

This arrangement was created in the 1990s, when participation in the HEU-LEU program was an important source of income for Minatom enterprises. This is no longer the case –money from the sale of the blended-down HEU goes to the central government budget and neither Rosatom nor the individual cities benefit directly. The program therefore could be rearranged to eliminate unnecessary transfers of weapon-grade material. One way of doing so would be to move all metal to oxide conversion to Ozersk and fluorination and down-blending to Zelenogorsk. Another would be to concentrate all the activity in Seversk, which has all necessary facilities (although its oxidization capacity would have to be expanded). In either case, it would be possible to clean the HEU out of the Novouralsk enrichment plant. Although the plant is licensed to produce HEU enriched up to 30 percent, it appears that, for the foreseeable future, any demand can be satisfied by blending down excess weapons HEU.

Taking advantage of the end of the production of weapon-grade plutonium. The shutdown of the plutonium production reactors in Seversk and Zheleznogorsk also will offer important opportunities for consolidation. Reprocessing facilities at both sites can then be decommissioned and the recovered weapon-grade plutonium moved into storage. If Seversk ended its participation in the HEU-LEU program, then neither site will be involved in work with weapon-usable material, which would open a way for a complete cleanout. One possible exception is storage. As discussed above, it should be isolated from all other activities.

Clean out one weapon laboratory. Further consolidation of activities in the nuclear weapon complex could include concentrating all pilot small-scale production of weapon components in Snezhinsk. In this case, the production facilities in Sarov could be closed down, although it would probably continue research and development work with small quantities of weapon materials. One of the two U.S. weapon-laboratories is being cleaned out in this way.[98]

Consolidate sites dealing with HEU and plutonium-containing reactor fuels. On the civilian side, Russia should continue the effort to clean out small sites as well as facilities within larger sites. A substantial part of this effort should be directed at converting research and icebreaker propulsion reactors to LEU fuel.

To demonstrate its strong commitment to the conversion program, Russia could set a goal of eliminating HEU from the Novosibirsk fuel fabrication plant. Most of the demand for HEU fuel from the weapon complex will stop in 2010, after a shutdown of the last plutonium production reactor. The Novosibirsk plant will still have to supply fuel for the *Ruslan* and *Lyudmila* tritium and isotope production reactors in Ozersk. However, these reactors use fuel that is most likely similar to that used in research reactors, so it is possible that they can be converted to LEU fuel. The Novosibirsk plant is already producing LEU fuel for the two most popular types of research reactors and is developing high-density fuels for other reactors.[99]

The MSZ fuel fabrication plant in Electrostal will most likely continue to produce HEU fuel for naval reactors. It also supplies HEU fuel for fast reactors and for some research reactors. The conversion efforts at MSZ could be concentrated on development of LEU fuels for icebreaker propulsion reactors.

It might also be possible to consolidate R&D activity on HEU and plutonium fuels currently done at the Scientific Research Institute of Atomic Reactors (NIIAR) in Dimitrovgrad, the NPO Luch, and the Bochvar Institute on Inorganic Materials, in one place, probably at NIIAR.

The consolidation steps outlined here would create a nuclear complex in which weapon-grade materials would be concentrated at four or five major storage facilities – Ozersk, Seversk, Sarov, Snezhinsk, and maybe Zheleznogorsk. Ozersk would remain the key site for all chemical and metallurgical activity involving uranium and plutonium. It would retain its pit production facilities and tritium production reactors (converted to LEU). Weapon research and development activity would continue at two weapon labs – in Sarov and Snezhinsk, although only Snezhinsk would have pilot-scale manufacturing capability. All HEU fuel production would eventually be concentrated at MSZ in Electrostal.

Zelenogorsk would continue to handle HEU conversion and down-blending as part of the HEU-LEU program but, when this program ends in 2013, all enrichment facilities would be cleaned of HEU. Similarly, Seversk and Zheleznogorsk would be ready for a cleanout after shutdown of their production reactors is completed.

On the civilian side, Russia would still have a fairly large number of research facilities that have HEU or plutonium on their territory. If the research-reactor-conversion program is successful, however, it would eliminate HEU from all Russian-design research reactors abroad and from a number of sites in Russia. Russian icebreaker reactors also could be converted to LEU fuel.

Endnotes

[1] Matthew Bunn, *Securing the bomb 2008*, (Cambridge, MA: Managing the Atom, November 2008), p. 94.

[2] *Securing the bomb 2008,* p. 46.

[3] *Securing the bomb 2008*, p. 92.

[4] Oleg Bukharin, Thomas B. Cochran, Robert S. Norris, "New Perspectives on Russia's Ten Secret Cities," (Washington, DC: Natural Resources Defense Council, October 1999), p. 6

[5] Pavel Podvig, ed., *Russian Strategic Nuclear Forces* (Cambridge, MA: The MIT Press, 2001), p. 97. International Panel on Fissile Materials, *Global Fissile Material Report 2006* (Princeton, NJ: Program on Science and Global Security, September 2006), p. 20.

[6] A. Grigoriev, "Kiriyenko ostanavlivayet Zheleznogorskuyu AES", Energyland.info, May 4, 2009. C.J. Chivers, "Russians to Shut Reactor That Produces Bomb Fuel," *New York Times* April 20, 2008.

[7] Matthew Bunn, Anthony Wier, John P. Holdren, "Controlling Nuclear Warheads and Materials: A Report Card and Action Plan" (Cambridge, MA: Managing the Atom Program, 2003), p. 158. Russia and the United States have pledged each to dispose of 34 tons of this material. International Panel on Fissile Materials, *Global Fissile Material Report 2007* (Princeton, NJ: Program on Science and Global Security, October 2007), p. 33. Russia's excess HEU is being down-blended as part of the U.S.-Russian HEU-LEU deal.

[8] Oleg Bukharin, "Analysis of the Size and Quality of Uranium Inventories in Russia," Science and Global Security, Vol. 6, No. 1 (1996), p. 68.

[9] As a point of reference, the United States used about 90 tons of HEU in nuclear tests, naval and production reactors. *Highly Enriched Uranium: Striking a Balance. A Historical Report on the United States Highly Enriched Uranium Production, Acquisition, and Utilization Activities from 1945 through September 30, 1996*, Draft, Rev. 1., U.S. Department of Energy, January 2001 (publicly released in 2006), www.ipfmlibrary.org/doe01.pdf, p. 49. The Material Consolidation and Conversion project was reported to reach the benchmark of 10 tons of downblended Russian HEU by April 2008. "U.S. and Russia Cooperate to Eliminate Dangerous Nuclear Material. 10 Metric Tons of Russian HEU Successfully Downblended", NNSA Press Release, April 24, 2008, http://nnsa.energy.gov/news/1987.htm.

[10] *Global Fissile Material Report 2008*, p. 11 gives an estimate of about 930 tons with uncertainty of 300 tons.

[11] Uncertainty of this estimate is about 25 tons. Of that amount, 34 tons is pledged for disposal, and some additional amount, probably 15 tons, may be declared excess. *Global Fissile Material Report 2008,* p.16.

[12]. IAEA, "Communication received from the Russian Federation Concerning Its Policies Regarding the Management of Plutonium," 30 October 2008, INFCIRC/549/Add.9/10.

[13] "Global Nuclear Stockpiles, 1945-2006," *Bulletin of the Atomic Scientists*, Vol. 62, No. 4 (July/August 2006), p. 66.

[14] "Russian nuclear forces, 2008," *Bulletin of the Atomic Scientists*, Vol. 64, No 3 (May/June 2008), pp. 54-57.

[15] *Global Fissile Material Report 2007*, p. 10.

[16] U.S. General Accounting Office, "Weapons of Mass Destruction: Additional Russian Cooperation Needed to Facilitate U.S. Efforts to Improve Security at Russian Sites," GAO-03-482 (March 24, 2003), p. 89. Department of Energy, National Nuclear Security Administration, "MPC&A Program: Strategic Plan 2001" (July 2001), p. 4. A DoE estimate of the total amount of material available to Russia is more than 1250 tons of HEU and about 150 tons of Pu, which is also generally consistent with the numbers used here. GAO, "Additional Russian Cooperation Needed," p. 80-81.

[17] Russia may choose to continue down-blending, but it is not clear if this choice would be economical – Russia uses more SWU capacity in the process of down-blending than it would have to use by enriching natural uranium. Oleg Bukharin, "Understanding Russia's Uranium Enrichment Complex," *Science & Global Security*, Vol. 12, No. 3 (2004), p. 204. At this point the deal is profitable for Russia because it is blocked from accessing the U.S. enrichment market in any other way. This restriction, however, will be phased out beginning in 2011. "New import rules for Russian uranium", World Nuclear News Insight Briefing, 04 February 2008, http://www.world-nuclear-news.org/ENF/INSIGHT_BRIEFING_New_import_rules_for_Russian_uranium_040208.html.

[18] *Global Fissile Material Report 2007*, p. 36-38.

[19] "On restructuring of the nuclear energy industrial complex of Russian Federation," President of Russian Federation, Order No. 556 of 27 April 2007. Appendix No. 2. "Rosatom planiruyet zakryt Zavod 20", RIAN, May 4, 2009.

[20] GAO, "Additional Russian Cooperation Needed," p. 84. It appears that this number includes those sites to which U.S. does not have access, not just those that Russia and the United States agree should be covered by MPC&A assistance activities. It does not include buildings on the civilian side of Rosatom, naval fuel, or military sites.

[21] Matthew Bunn, *Securing the bomb 2007*, (Cambridge, MA: Managing the Atom, September 2007), p. 65.

[22] Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," pp. 21-25

[23] Fuel from production reactors that continued to operate in 1987-1990 was shipped to Seversk/Tomsk-7. Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," p. 24.

[24] Buildings 104 and 142. National Nuclear Security Administration, "Fiscal Year 2007 Budget Request," p. 516.

[25] Mayak has never had uranium production facilities, but its metallurgical plant was involved in manufacturing of HEU components of nuclear weapons. Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," p. 24.

[26] This assumes that Mayak has storage capacity comparable to that at Seversk/Tomsk-7, which is estimated to have at least 80 tons of fissile materials. See the description of Seversk.

[27] http://www.nti.org/e_research/cnwm/securing/mayak.asp

[28] The facility is believed to be capable of handling up to 100 tons of plutonium or 400 tons of HEU, but Russia does not intend to use its full capacity. David E. Hoffman, "Victories Come Slowly in Cleanup Of Soviet Bloc Nuclear Materials," *Washington Post*, August 30, 2007, p. A18. According to Rosatom, only 1689 of its 3168 cells will be filled with containers. "Rosatom: No Need to be Afraid of the Bomb," *Trud*, November 15, 2006.

[29] Pavel Podvig, "Mayak storage facility is in business," Russianforces.org, November 15, 2006.

[30] Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," p. 24.

[31] Bukharin, "Understanding Uranium Enrichment Complex," p. 203.

[32] Sergei Ivanov, ed., *Russia's Arms and Technologies: The XXI Century Encyclopedia. Volume XIV: Nuclear Weapons Complex* (Moscow: Arms and Technologies, 2007), p. 305.

[33] V. I. Sadovnikov, A. P. Zharov, "Istoriya atomnoy promyshlennosti SSSR", 2000, Chapter 2.

[34] The Lyudmila reactor was designed at the Institute of Theoretical and Experimental Physics in Moscow. It appears to be similar to the TVR research reactor, also designed there. See V. V. Vladimirskiy, I.V. Chuvilo, and O. V. Shvedov, "Institute of Theoretical and Experimental Physics," in *Russia's Nuclear Industry*.

[35] V. F. Konovalov et al, "Development of Production Facilities for Uranium and Lithium for Reactor Production of Plutonium and Tritium," in *Russia's Nuclear Industry* (Moscow: Energoatomizdat, 1999); Vladimirskiy et al, "Institute of Theoretical and Experimental Physics.".

[36] Since 1995 these two reactors produced about 10 tons of weapon-grade plutonium. According to Rosatom plans, this plutonium will be moved to Zheleznogorsk. "Plutonium from last Russian production reactors", http://russianforces.org/nuclear/2008/07/plutonium-from-last-russian-pr.shtml, July 16, 2008.

[37] Oleg Bukharin, "Securing Russia's HEU Stock," *Science & Global Security*, Vol. 7 (1998), p. 317.

[38] Spent spike fuel elements, which contain HEU, were normally shipped to the RT-1 plant at Mayak for reprocessing. Thomas B. Cochran, Robert S. Norris, and Oleg Bukharin, *Making the Russian Bomb: From Stalin to Yeltsin* (Boulder, CO: Westview Press, 1995), p. 141.

[39] *Agreement Between the Government Of The United States Of America and the Government of the Russian Federation Concerning Cooperation Regarding Plutonium Production Reactors,* September 23, 1997, http://www.ransac.org/new-web-site/related/agree/bilat/core-conv.html; Oleg Bukharin and Kenneth Luongo, *U.S.-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals*, PU/CEES Report No. 314 (Princeton, NJ: Center for Energy and Environmental Studies, April 1999).

[40] Personal communication from Frank von Hippel, July 2008.

[41] Oleg Bukharin, "Downsizing Russia's Nuclear Warhead Production Infrastructure", *Nonproliferation Review*, Spring 2001, p. 125-126.

[42] "Rosatom planiruyet zakryt Zavod 20", RIAN, May 4, 2009.

[43] Bukharin, "Understanding Uranium Enrichment Complex," p. 203.

[44] Bukharin, "Understanding Uranium Enrichment Complex," p. 195. Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," p. 27

[45] V. M. Kondakov, "Siberian Chemical Combine," in A. M. Petrosyants, ed., *Russia's Nuclear Industry* (Moscow: Energoatomizdat, 1999).

[46] It appears that 80 MT are stored in two separate buildings. GAO, "Additional Russian Cooperation Needed," p. 81, 90.

[47] I. V. Goloskokov, A. P. Yarygin, "Integrated Protection of Nuclear Materials at Major Industrial Nuclear Weapons Enterprise," *Proceedings of the 2nd International Conference on Material Protection, Control & Accounting, May 22-26, Obninsk, Russia.*

[48] "Plutonium from last Russian production reactors", op. cit.

[49] Bunn, Wier, *Securing the Bomb 2006*, p. 97.

[50] *Agreement Between the Government Of The United States Of America and the Government of the Russian Federation Concerning Cooperation Regarding Plutonium Production Reactors,* September 23, 1997, *op. cit*. See also Note 38 on HEU-containing spike fuel.

[51] "Plutonium from last Russian production reactors", http://russianforces.org/nuclear/2008/07/plutonium-from-last-russian-pr.shtml, July 16, 2008.

[52] Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," p. 28.

[53] Zheleznogorsk was chosen over Seversk as a site of this facility. Kondakov, "Siberian Chemical Combine."

[54] This number comes from a DoE estimate of the amount of material that could be secured after construction of new storage facilities in Arzamas-16/Sarov and Chelyabinsk-70/Snezhinsk. GAO, *Additional Russian Cooperation Needed*, p. 82.

[55] Oleg Bukharin, "Downsizing Russia's Nuclear Warhead Production Infrastructure", *Nonproliferation Review*, Spring 2001, p. 125-126.

[56] "On restructuring of the nuclear energy industrial complex of Russian Federation."

[57] This number comes from a DoE estimate of the amount of material that could be secured after construction of new storage facilities in Arzamas-16/Sarov and Chelyabinsk-70/Snezhinsk. GAO, "Additional Russian Cooperation Needed," p. 82.

[58] Podvig, "New warheads for R-29RM Sineva."

[59] Little information is available about specific activities in Lesnoy. However, the available evidence suggests that it has the HEU component production capability. It is highly unlikely that it is involved in production of plutonium components.

[60] *Global Fissile Material Report 2007*, p. 27.

[61] Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," p. 20.

[62] It should be noted that there is no military centralized weapon storage facility nearby.

[63]Ivanov, *Russia's Arms and Technologies*, pp. 226-229.

[64] Bukharin, Cochran, Norris, "New Perspectives on Russia's Ten Secret Cities," p. 31.

[65] *Arms Control and Nonproliferation Technologies: Technology R&D for Arms Control*, U.S. Department of Energy, Office of Nonproliferation Research and Engineering, Spring 2001, www.ipfmlibrary.org/doe01b.pdf, p. 51. The image appeared originally in a Russian Ministry of Atomic Energy publication.

[66] Bukharin, "Understanding Uranium Enrichment Complex," p. 213.

[67] Podvig, *Russian Strategic Nuclear Forces*, p. 101.

[68]*Global Fissile Material Report 2007*, p. 31.

[69] Robert L. Civiak, *Closing the Gaps: Securing High Enriched Uranium in the Former Soviet Union and Eastern Europe*, Federation of American Scientists, May 2002, p. 24.

[70] Depending on the amount, it would be graded as Category I or II material, requiring the same level of protection as nuclear weapons or storage in secure vault in protected area. *Global Fissile Material Report 2007*, p. 46; Department of Energy, "Nuclear Material Control and Accountability," Manual M 470.4-6.

[71] DOE, "Nuclear Material Control and Accountability."

[72] The RG-1M reactor in Norilsk used 10% enriched uranium. There is no information on the level of enrichment used in the SO-1 subcritical assembly. In any event, the core of the assembly was moved to the NPO Luch in June 2007. "NII NPO Luch osushchestvil transportirovku aktivnoi zony podkriticheskogo razmnozhitelya SO-1," Rosatom Press-release, 21 June 2007.

[73] "NNSA works with Russia to Remove Nuclear Material from Research Institute," NNSA Press Release, July 13, 2006.

[74] Originally from VNIIEF website. No longer available there.

[75] Based on Reistad, Bremer Mærli, Hustveit, "Toward Elimination of Highly Enriched Uranium as a Reactor Fuel."

[76] Parrish Staples, U.S. Department of Energy, Global Threat Reduction Initiative, Presentation at the 49th Annual Meeting of the Institute of Nuclear Materials Management, Nashville, TN, July 14, 2008.

[77] Federal Service for Ecological, Technological and Atomic Oversight, "Annual Report, 2006" (Moscow: Gosnadzor, 2007), p. 69.

[78] In addition to reactor fuel for reactors built in Soviet time, some countries have stocks of HEU that are used for research. For example, the Kharkiv Institute of Physics and Technology in Kharkiv, Ukraine has up to 75 kg of 90% HEU. In Belarus, this material includes fuel of a dismantled Pamir reactor. See William C. Potter and Robert Nurick, "The Hard Cases: Eliminating Civilian HEU in Ukraine and Belarus", *Nonproliferation Review*, Vol. 15, No. 2, July 2008, pp. 237-263.

[79] The IRT critical assembly in Libya has also been converted to LEU. "NNSA Secures Nuclear Material from Libya," NNSA Press Release, July 27, 2006.

[80] "TVEL will supply fuel for Maria research reactor in Poland," Rosatom, January 11, 2008 (in Russian).

[81] Oleg Bukharin, "Russia's Nuclear Icebreaker Fleet," *Science and Global Security*, Vol. 14, No. 1 (2006), p. 29.

[82] "Comprehensive upgrades were completed on 100 percent of the 11 Navy fuel and other nuclear material storage sites in FY 2004." NNSA, "Fiscal Year 2007 Budget Request," p. 515.

[83] Bukharin, "Russia's Nuclear Icebreaker Fleet," p. 30.

[84] A. S. Diakov, A. M. Dmitriev, J. Kang, A. M. Shuvayev, and F. von Hippel, "Feasibility of Converting Russian Icebreaker Reactors from HEU to LEU Fuel," *Science and Global Security*, Vol. 14, No. 1 (2006) pp. 33-48.

[85] "Nuclear Fuel for BN-600 Reactor," Moscow Machine-Building Plant, http://www.elemash.ru/ru/manufacture/product/nuclear/nuclear2/.

[86] "28 years of successful work of the BN-600 reactor," Rosenergoatom, April 7, 2008.

[87] Ivanov, *Russia's Arms and Technologies*, pp. 340-343.

[88] MSZ manufactured MOX fuel assemblies for BN-350 and BN-600 reactors, but fuel elements for them were supplied by the Mayak plant. B. G. Ryazanov,V. S. Vnoukov, "Nuclear Fuel Cycle of Russia," Tripartite seminar on Nuclear Material Accounting and Control at Fuel Fabrication Plant, April 21-26, 1997, Obninsk, Russia.

[89] Ivanov, *Russia's Arms and Technologies*, p. 352.

[90] V. F. Konovalov et al, "Development of Production Facilities for Uranium and Lithium for Reactor Production of Plutonium and Tritium," in *Russia's Nuclear Industry* (Moscow: Energoatomizdat, 1999); V. V. Vladimirskiy, I.V. Chuvilo, and O. V. Shvedov, "Institute of Theoretical and Experimental Physics," in *Russia's Nuclear Industry*.

[91] D. F. Newman, C. J. Gesh, E. F. Love, and S. L. Harms,"Summary of Near-Term Options for Russian Plutonium Production Reactors" (Pacific Northwest Laboratory: Richland, Washington, July 1994), p. 32.

[92] U.S. General Accounting Office, "Nuclear Nonproliferation: Security of Russia's Nuclear Material Improving; Further Enhancements Needed," GAO-01-312 (February 2001), p. 37.

[93] "MPC&A Program: Strategic Plan 2001," p. 15

[94] Ryazanov, Vnoukov, "Nuclear Fuel Cycle of Russia," p. 17.

[95] NII NPO Luch, "History," http://www.luch.podolsk.ru/history.htm.

[96] "MPC&A Program: Strategic Plan 2001," p. 15

[97] *Global Fissile Material Report 2007*, chapter 4.

[98] *Global Fissile Material Report 2007*, chapter 4.

[99] "Proizvodstvo issledovatelskogo yadernogo topliva", Novosibirsk Chemical Concentrates Plant, http://www.nccp.ru/ir/.

Appendix A: Research Reactors and Critical Assemblies in Russia

Table A-1. Italics indicate facilities outside of the scope of GTRI. Reactors and critical assemblies under construction are in parenthesis.

Operational HEU reactors	HEU assemblies and pulse reactors	Shut down HEU reactors, HEU spent fuel on site	Shut down and dismantled reactors, LEU facilities, and cleaned out facilities
Russian Scientific Center "Kurchatov Institute", Moscow			
IR-8, Gamma, OR	Gidra, Mayak, *SF-1*, SF-3, SF-5, *SF-7, Kvant, Astra, FM MR [c], EFIR-2M, Delta, NARCIS-M2,ISKRA, SK-fiz*	MR, Romashka, VVR-2	Argus[a], RBMK, V-1000, GROG, P, UG, Garantia-2, RM-50, F-1, RTF
VNIIEF, Sarov			
	BIGR, BIR-2M, BR-K1 [c], BR-1, VIR-2M [c], GIR-2, FKBN-2M, IKAR-S [c]		
VNIITF, Snezhinsk			
	BARS-5, YAGUAR, EBR-L, IGRIK [c], FKBN-M [c], FKBN-2, FRBN-I		
Institute of Physics and Power Engineering (FEI), Obninsk			
	27/VM, 27/VT, BARS-6, *FS-1M, SGO, Strela, T-2, RF-GS [c], BR-1 [c], BFS-1, BFS-2*	BR-10	AM-1, PS-2 [d], AMBF-2, KOBR [d][c], MATR-2, GROT-2, V-1M, K-1, UKS-1M, FG-5
Scientific Research Institute of Atomic Reactors (NIIAR), Dimitrovgrad			
BOR-60, MIR-M1, SM-3, RBT-10/2[f], RBT-6[f]	FM MIR-M1, FM SM-3,	AST-1/ARBUS, RBT-10/1	VK-50
Dollezhal Scientific Research and Design Institute for Power Engineering (NIKIET), Moscow			
	FS-2[g], FS-4[g][c], FS-5[g][c]		IR-50
Sverdlovsk Branch of NIKIET, Zarechny			
IVV-2M			
Scientific Research Institute for Instruments (NIIP), Lytkarino			
(IRV-2M)	TIBR-1M [c], BARS-2, BARS-3 [c], *BARS-4*, INN-3M [c]	IRV-1M [c], VVRL-02 [c], VVRL-03 [c]	
Afrikantov Experimental Design Bureau of Machine-Building (OKBM), Nizhni Novgorod			
	ST-659L[c], *ST-1125*, *ST-659*		
Joint Institute for Nuclear research, Dubna			
	IBR-2 [e], *IBR-30* [e], PSD [c]		

Krasnaya zvezda, Moscow			
	Buk [c], Stena 111[c], U-379[c]		Argus[a]
Central Institute of Physics and Technology of the Ministry of Defense, Sergiyev Posad			
	BARS-1, Priz [c]		
Institute of Scientific Research and Technology (NITI), Sosnovyy Bor			
	KV-1, KV-2, KM-1 [c], VAU-6s		
St.-Petersburg Institute of Nuclear Physics, Gatchina			
VVR-M, (PIK)	*FM PIK*		
Machine-Building Plant, Electrostal			
	Stend-1 [b][c], *Stend-2 [c]*, *Stend-3*, *Stend-4*, *Stend-5[c]*, Stend-6 [c], Stend-7 [c]		
All-Russian Scientific Research Institute of Chemical Technology (VNIIKhT), Moscow			
	SO-2M [c]		
Karpov Scientific Research Institute of Physical Chemistry (NIFKhI), Obninsk branch, Obninsk			
VVR-Ts			
Tomsk Polytechnic Institute, Tomsk			
IRT-T			
Moscow Institute of Physics and Engineering, Moscow			
IRT			
Institute of Theoretical and Experimental Physics, Moscow			
	Maket, (ELYANG) [b]	TVR [c]	
Norilsk Mining and Metallurgical Combine, Norilsk			
			RG-1M [c]
Belgorodgeologia			
			SO-1 [h]
Krylov Central Scientific Research Institute			
			U-3 [h], G-1[h], MER [h], R-1 [h]

a. 21% HEU, 1.8 kg of U-235

b. Assumed to be HEU, no direct data available

c. Shut down. May have been dismantled

d. Appears to be LEU.

e. Converted to use Pu.

f. RBT reactors use spent fuel of the SM reactor.

g. Located at the Bauman Moscow State Technical University, Moscow

h. Cleaned out

Appendix B: Soviet-designed reactors outside Russia

Countries and organizations	Operational HEU reactors	HEU-fueled critical and subcritical assemblies	Shutdown or converted HEU-fueled reactors with fresh or spent fuel on site	Shutdown and dismantled reactors, LEU-fueled reactors, and cleaned out facilities
Belarus. Joint Institute for Power Engineering and Nuclear Research "Sosny", Minsk		Yalina-B, Giatsint	IRT-1M[a] Pamir[a]	Yalina-T
Bulgaria. Institute of Nuclear Research and Nuclear energy, Sofia				IRT-2000
Czech Republic. Nuclear Research Institute, Rez				LVR-15 [b]
Czech Technical University, Prague			VR-1P[b]	
Egypt. Nuclear Research Center, Inshas				ET-RR-1[c]
Estonia. Navy Training Center, Paldiski				VM-4 VM-A
Georgia. Institute of Physics, Tbilisi				IRT-M
Germany. Rossendorf Research Center, Rossendorf			RFR	
Hungary. Nuclear Energy Research Institute, Budapest	VVR-SZM			
Budapest University of Technology and Economics				Training reactor[c]
Kazakhstan. Institute of Nuclear Physics, Almaty,	VVR-K	FM VVR-K		
BN-350 Reactor, Aktau			BN-350	
Kurchatov Division of Institute of Atomic Energy, Kurchatov		IGR IVG-1		
Latvia. Nuclear Research Centre of the Latvian Academy of Sciences, Salaspils				ITR-M, RKS-25
Libya. Tajoura Research Center,			IRT-1[b]	IRT critical assembly[b]
North Korea. Yongbyon	IRT-DPRK			
Poland. Institute of Atomic Energy, Swierk	MARIA	ANNA AGATA	EWA MARYLA	
Romania. Institute of Nuclear Physics and Engineering, Bucharest			VVR-S	
Serbia. Institute of Nuclear Sciences, Vinca			R-A R-B	
Ukraine. Institute for Nuclear Research, Kiev	VVR-M			

Institute of Nuclear Energy and Industry, Sevastopol				Two subcritical assemblies[c] IR-100[c]
Uzbekistan. Institute of Nuclear Physics, Tashkent				VVS-SM[b]
“Foton”, Tashkent		IIN-3M		
Vietnam. Dalat			Dalat Research Reactor [b]	

a. Fresh fuel still on site

b. Converted from HEU to LEU

c LEU facility

d. The HEU stock

About the Author

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