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The Influence of the International Trade of Nuclear Materials and Technologies on the Nuclear Non-proliferation Regime

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Introduction

Today it is almost impossible to imagine life without nuclear materials, which are widely used to create nuclear energy for the atomic industry or military objectives. These heavy elements with a quantity of more than 90 protons occur by the spontaneous fission in the atomic nucleus of splitting neutrons. In nature, the self-induced reaction of this fission is possible only in Uranium-235 (U-235), but in practice these results can also be derived artificially: Uranium-233 (U-233) and Plutonium-239 (Pu-239). Such materials allow for the realization of a nuclear chain reaction.

The uranium found in nature consists of a mixture of three isotopes: Uranium-238 (99.3 percent), Uranium-235 (0.7 percent) and Uranium-234 (less than 0.1 percent). Uranium-238 is much more available, and it is customary to call it a fertile material, because during its irradiation by neutrons it is possible to form a fissile material. As such, it is possible for Thorium-232 and artificially derived Plutonium-240 to appear.

Uranium is considered highly enriched (HEU) if it contains 20 percent or more of the Uranium-235 isotope. In an operable nuclear installation, the quantity of this isotope consists of 80 percent or more (high-quality, highly-enriched uranium), uranium is considered weapons-grade with a level of enrichment of 90 percent or higher. HEU is used in nuclear warheads, and also in the capacity of nuclear fuel – in research reactors and the propulsion reactors in nuclear submarines.

Plutonium is created in a nuclear reactor during the irradiation of uranium fuel. Separation facilities for spent nuclear fuel are necessary in order to separate plutonium from unused uranium fuel and other radioactive substances. As a rule, weapons-grade plutonium is created in special nuclear reactors and consists of less than 6 percent of the Pu-240, Pu-238, Pu-241 and Pu-242 isotopes, with the remaining 94 percent being Pu-239. Plutonium is used in nuclear warheads and also in the capacity of MOX fuel for nuclear energy reactors.

Natural uranium, thorium and uranium depleted by the U-235 isotope are customarily considered source materials, while Plutonium-239 (Pu-239), Uranium-233 (U-233) and HEU are considered special fissionable materials[1]. According to Chapter III of the Nuclear Non-proliferation Treaty (NPT), each of the NPT member countries is required "to withhold: a) source or special fissionable materials or b) equipment or materials, specially designated or prepared for the manufacture, use, or production of special fissionable materials, to any non-nuclear weapons states for peaceful purposes if that source of special fissionable material is not covered by IAEA safeguards[2]."

In this article, nuclear materials are understood as: natural uranium, plutonium, and substances resulting from them. Tens of thousands of tons of such materials, from which a small percentage could be used in the construction of nuclear explosive devices, are traded on the world market. An enormous volume of trade of nuclear materials and technologies creates the potential danger of their theft and illegal use either by other states or a number of non-state terrorist organizations that have significant financial resources and are dispersed over the territory of many countries. At the same time, the international trade of nuclear materials and

[1] Political and technical aspects of the international control for the nuclear Non-Proliferation (the Center for Arms Control, Energy and Environmental Studies, the Moscow Institute of Physics and Technology), available at URL <http://www.armscontrol.ru/course/lectures02b/vir_021101.htm>.
[2] The Nuclear Non-proliferation Treaty, available at URL <http://www.un.org/russian/documen/convents/npt.htm>.

technologies itself has been insufficiently examined, and its investigation has significant importance for considering the issue of nuclear non-proliferation.

Current conditions and perspectives (until 2010) on the development of uranium mines and production of uranium concentrate

At the beginning of the 1990s, 55 uranium mines existed in 21 countries throughout the world, and those mines produced nearly 1.9 million tons of natural uranium from the period of 1938-1999[3]. Natural uranium was never used directly as a fuel for nuclear power plants. Even for heavy-water nuclear reactors, which use natural uranium as a fuel, ore must be refined, converted, and changed into a different form (for nuclear power plants it is fuel rods).

At the beginning, uranium ore is extracted from rock by means of explosion, crushed, sorted out, and pulverized. Later the powder is processed by a solvent of grey acid or carbon nitrate for dissolving the uranium in it. The remaining solid pieces are extracted and placed into long-term storage in special reserves. The reserves are created in such a way to guarantee the reliable storage of the radioactive substances in the ore, such as radium. Later, the solvent containing uranium is concentrated and purified by sorption on an ion-exchange resin or extraction by organic solutions. The result is a precipitate of bright yellow colour, otherwise known as “yellow cakes”.

The extraction of uranium from porous ore of sedimentary composition usually requires the in-situ leaching method. For this a drilled hole is continually filled with alkaline or acidic solution. As this solution concentrates and purifies, a precipitate will be formed. After high-temperature drying, the uranium oxide concentrate (U_3O_8) will have a green colour. This material has the same isotopic composition as ore, whose content of U-235 does not exceed 0.7 percent. Production of uranium oxide concentrate (U_3O_8) is attempted as close to areas where uranium is mined as possible.

In the last decades, the level of world production of uranium oxide concentrate has appreciably changed to the point where there have been noticeable changes in its market value. After very high prices at the end of the 1970s (more that $44 for 1 kg), the price of uranium concentrate at the beginning of the 1990s fell dramatically and its production in many companies became unprofitable (around $15 for 1 kg). Consequently, in the period from 1984-1993, world production of uranium concentrate decreased, though the demand for it increased. In the period from 1994 to 2001, production increased and then gradually starting decreasing (approximately 1% each year): in 2001 the world produced 42.9 thousand tons of uranium concentrate whereas in 2003 it produced 42.2 thousand tons. There was such a flood of these products on the market at very low prices that in general there was a fall in world values. More recently, the prices of uranium concentrate have began to rise again sharply, reaching $67.5 for 1 kg in May 2005[4].

Australia has the largest natural uranium reserves in the world (23% of world reserves, please see Table 1). Australia’s deposits comprise more than 560 thousand tons of natural uranium and more than 300 thousand tons of uranium are found in the gold deposits of Olympic Dam. Kazakhstan occupies second place in the world for general reserves of natural uranium (472 thousand tons; 13% of world reserves). Its Inkai, Mynkuduk, and Harasan sites hold hundreds of thousands of tons of uranium in rich, compact ore. However, these deposits are not developed and require considerable investment. Canada has the third largest natural uranium reserves in the world (437 thousand tons; 12% of world reserves), with large mines at MacArthur Lake and MacLean Lake.

Russia is developing a number of uranium mines: the Streltsovskoe mining field (reserves of 170 thousand tons, average content of the uranium-18%), Zauralye (reserves of 17 thousand tons), the Vitimskiy mining region (reserves of 75 thousand tons), and the Western

[3] Orlov, V. (ed.), The Nuclear Non-Proliferation: Textbook in 2 volumes (PIR-Center: Moscow, 2002), vol. 1, p. 50.
[4] Koksharov, A., ‘Den atomnogo curka (A day of the atomic marmot)”, *Expert*, 13 June, 2005.

Siberian region (reserves of 10 thousand tons). Russia has the fourth largest natural uranium reserves in the world (7 percent of world reserves).

General reserves of natural uranium on the territory of Uzbekistan are estimated at 185 thousand tons (fifth largest in the world, 5% of world reserves), but there are also unexplored resources expected to be around 240 thousand tons. Since 1995, uranium extraction by open shaft mining methods was halted on the territory of Uzbekistan and *in-situ* leaching methods are currently being used for the goals stated below at the following sites: Uchkuduk, Sugrali, North and South Bukinai, Ailendy, Beshkak, Ketmenchi and Sabyrsai.

Table 1. World natural uranium reserves by country

Country	Natural uranium reserves in thousand tons	Quota (in %) from world reserves
Australia	860	23.00
Kazakhstan	472	12.62
Canada	437	11.69
Russia	272	7.27
Uzbekistan	185	4.95
Niger	160	4.28
Namibia	136	3.64
South Africa	134	3.58
USA	110	2.94
Ukraine	100	2.67
China	70	1.87
Others countries	803	21.49
World Total	3739	100

Table 2. Production of natural uranium and uranium oxide concentrate in tons from 2001-2003[5]

Country	Year		
	2001	2002	2003
Canada	12520	11604	10457
Australia	7756	6854	7572
Kazakhstan	2050	2800	3300
Niger	2920	3075	3143
Russia	2500	2900	3150
Namibia	2239	2333	2036
Uzbekistan	1962	1860	1770
USA	1011	919	846
Ukraine	750	800	800
South Africa	873	824	758
China	655	730	750
Czech Republic	456	465	345
Brazil	58	270	310
India	230	230	230

[5] World Uranium Mining. World Nuclear Association, available at URL <http://www.world-nuclear.org/info/printable_information_papers/inf23print.html>.

Germany	27	212	150
Romania	85	90	90
Pakistan	46	38	45
Spain	30	37	0
Argentina	0	0	20
France	195	20	0
Portugal	3	2	0
World Total	36366	36063	35772
Uranium Oxide Concentrate	42886	42529	42186

General reserves of uranium in Africa consist of around 430 thousand tons, half of which are located in gold deposits. Uranium extraction takes place in Niger, Namibia, and South Africa. In Niger, uranium supplies are 160 thousand tons, and the primary mines at Akuta and Arli are being developed by pit and open methods. In Namibia, the Rossing site is being developed by similar methods with supplies of lower-grade uranium ore (.05 percent) at more than 100 thousand tons. South Africa has similar reserves of natural uranium, which is being extracted from gold deposits by shaft methods.

General reserves of natural uranium on U.S. territory are estimated at 110 thousand tons. Since the end of the 1980s, extraction by in-situ leaching methods has occurred at four sites: Reno Creek, Smith Ranch, Highland and Krod Boot. Similar uranium reserves are found in Ukraine where mining of lower grade uranium ore (0.1 percent) is done through deep pits. Natural uranium reserves in China are estimated at 70 thousand tons. The remaining countries of the world have around 800 thousand tons of natural uranium, or 21 percent of world reserves (please see table 1).

Canada is the largest extractor of uranium ore in the world. In 2004, extraction reached 11.6 thousand tons (30% of world extraction of natural uranium, please see table 2). Currently, there is a significant realignment of the structure of Canada's enterprises. In 2000-2001, uranium extraction by pit mining was halted at the Key Lake site, which earlier was the primary Canadian producer, as well as at the Knaff Lake and Rabbit Lake sites. Since that period of time, the MacArthur River site has been developed with extraction of higher-grade ore by the shaft method (average content is 21%; reserves at 208 thousand tons; annual extraction greater than 4 thousand tons). Since 2000, the project at MacClain Lake stabilized at an annual extraction of 2.3 thousand tons of uranium. In 2005, extraction by the shaft method was started at the Cigar Lake site (average content of 18%; reserves of 135 thousand tons). All of this will allow for the volume of low-cost uranium ore extraction to be brought up to 16 thousand tons by the year 2010.

In 2003, Australia produced 7.6 thousand tons of uranium and occupies second place in the world for production (21% of world mining). Since 2001, in-situ leaching methods were started for extraction at the new Beaverly and Honeymoon sites (reserves are rather small with annual extraction at 1 thousand tons). At Olympic Dam, 4 thousand tons of natural uranium are mined annually. Australia plans to increase mining of low-grade uranium to 11 thousand tons by the year 2010. At the same time, because of the end of development at the Ranger site in 2007 and the introduction of a 10-year moratorium at the Jabiluka site, there is a danger of Australia not reachingits 11 thousand ton target.

In the 1980s, Kazakhstan produced up to 5 thousand tons of natural uranium. Due to low world prices, 3.3 thousand tons of uranium are produced annually now, but the last few years have witnessed an adequate rise in production (please see table 2). Since the mid-1990s, all uranium extraction has been done by in-situ leaching methods at five sites: Uvanas, East Mynkukuk, Kanjugan, and North and South Karamurun. Currently, Kazakhstan occupies third place in the world for uranium ore extraction (9% of world extraction) and is planning to increase production of low-cost uranium to 8.3 thousand tons by 2010.

Russia occupies fourth place in the world in uranium ore extraction (3.2 thousand tons in 2003). At the Streltsovskoe mining field the extraction of uranium is done by shaft methods; yearly volume of extraction is around 2.5 thousand tons and an increase is planned in connection with the development of poorer mines. In Zauralye, three sites are being developed by the in-situ leaching method, but their growth is not planned in the near future. The Vitimskii mining area includes five sites, the largest of which is suitable for *in-situ* leaching. In the area, roads and electric-security systems are completely absent, which means the yearly output does not surpass 100 tons. The Western Siberia region includes eight small sites suitable for *in situ* leaching, but industrial extraction of natural uranium here is not planned until 2010.

Due to the absence of significant new exploratory efforts, an increase in uranium mining in Russia is not planned and will remain at the level of 3 thousand tons of mostly middle-grade uranium per year. Because of the low profitability of its mines and the planned 5 gigawatt total yield capacity increase of its nuclear power plants by 2010, Russia in the future will become an importer of natural uranium, especially since the current deficit of uranium needs has already reached 5 thousand tons per year. Consequently, there will actually be joint development of uranium ore mines on the territory of Kazakhstan.

In 2003, 3.1 thousand tons of uranium were extracted in Niger, which allowed this country to occupy fifth place in the world for uranium ore extraction. An annual extraction at a level of around 3 thousand tons of uranium of middle-grade is planned for the future.

Namibia is currently extracting more than 2 thousand tons of natural uranium. By 2007, the end of development at the Rossing site is expected. Therefore, despite new extraction at a new mine at Langer-Heinrich, uranium extraction is planned to gradually decrease to 1 thousand tons of middle-grade uranium.

The volume of uranium mining in Uzbekistan is 1.8 thousand tons and all uranium is exported. Over the course of the next 5-10 years, production will be guaranteed only by continued extraction from existing sites, exhausting the remaining uranium to a significant degree. Increasing production is only possible by investing in extraction at new sites: Bahaly, Meilisai, Aktau, Lyavlyakan, Terekuzek, Baradjan, Northern Maizak, Argon, and Shark. This, however, will require significant outside investment. Without such investment in the development of new mines, the volume of annual mining will remain at current levels of around 2 thousand tons.

In the 1970s and 1980s, the United States was one of the world's largest uranium producers. However, many projects were cancelled, mines abandoned, and new ones not developed. As a result, the annual production of uranium fell to 850 tons by 2003. The current level of mining middle-grade uranium, which does not exceed 1 thousand tons, will be maintained until 2010.

In the Ukraine, over the course of many years, the shaft method was completed at three natural uranium sites: Vatutinskoe, Michurinskoe, and Tsentralnoe. The current volume of uranium extraction does not surpass 800 tons, a slow rate of extraction with no real potential for increasing. By 2010, limited production of 500 tons of middle and high-grade uranium, or a complete halt in production altogether, is anticipated.

In the 1980s, South Africa produced up to 6 thousand tons of uranium. Extraction later significantly decreased because of a significant decrease in the price of gold (uranium is extracted simultaneously) and a halt in the military nuclear program. At present, yearly extraction at the Vaal-Pifs site is around 760 tons. By 2010, extraction of middle-grade natural uranium is expected to be around 400 tons per year.

The volume of middle-grade uranium ore extraction in China is supported at a level of 800 tons per year. Therefore, it is inevitable that China will become an importer of uranium in the medium term due to the intensive development of its atomic energy sector.

Uranium is also mined in Argentina, Brazil, the Czech Republic, Eastern Germany, India, Pakistan, Portugal, Romania, Spain and France. Portugal, Spain, and France ended their programs in 2003, while the remaining countries will continue production until 2010 at a level no greater than 300 tons per year.

Uranium Enrichment

As was demonstrated earlier, uranium concentrate consists of no more than 0.7% U-235, and the remaining parts are the heavier U-238 isotope (with a small concentration of U-234). The majority of power reactors, that is – light water reactors, cannot work with that type of fuel. Heavy-water and gas-graphite nuclear reactors, for example the "CANDU" and "Magnox" types, can work using non-enriched uranium. For all the remaining power reactors, the concentration of U-235 must be increased to approximately 2-4 percent. This process is called enrichment and is done in several stages.

At the beginning, the uranium oxide concentrate (U_3O_8) is converted to uranium hexafluoride (UF_6). For this, uranium concentrate is deoxygenated to UO_2 using water-free ammonia, from which UF_4 is derived with the help of fluoric acid. The last step involves straight fluorine acting on the UF_4 to get uranium hexafluoride. The final material appears as a solid product, subliming at room temperature and normal pressure, and melting with slowly increasing pressure.

The next step is producing a higher concentration of U-235 in UF_6, usually through the methods of gaseous diffusion or gas centrifuges. Through the gaseous diffusion method, solid uranium hexafluoride is brought to a gaseous state by decreasing pressure and is pumped through porous tubes of special alloys, through rods which gas can permeate. In the process of diffusion, gas enriches the U-235 isotope – the gas being depleted through the tubes. The enriched gas again goes through the tubes, continuing the process until the concentration of the U-235 isotope reaches the necessary level. This particular method is characterized by high-energy output and is used by the USA, Russia, France, and China.

The centrifuge is a different means of enriching Uranium (by the lighter U-235 isotope) used by Great Britain, Germany, the Netherlands, Pakistan, Russia, China, and Japan.

In the final stage, characteristic of both the methods of gas diffusion and the gas centrifuge, of enriching uranium hexafluoride by hydrolysis involves the processing of $U0_2F_2$ by ammonia hydroxide. Laden down ammonium diuranate precipitate is filtered and burned, obtaining uranium dioxide UO_2. The obtained material is compressed and baked into the form of small ceramic tablets. In this final form they are inserted into tubes of zirconium alloy and fuel rods are obtained, called heat-generating elements, which join approximately 200 pieces to comprise the prepared fuel assemblies.

There is no difference between the principle technological processes for obtaining highly enriched and low-enriched uranium. The degree of enrichment is determined by the time and energy consumption used to obtain the necessary material quality. Consequently, even the process of creating low enriched uranium (LEU) always carries potential dangers for nuclear proliferation.

The present and intermediate-term demands for uranium conversion services ($U\ F_6$, $U\ F_4$, $U\ O_3$) will remain steady at a level of nearby 60 thousand tons of natural uranium a year in light of the reuse of uranium and plutonium. The largest uranium conversion enterprises are located in Russia, France, Canada, and Great Britain (see table 3). Analysis of the table shows that significant unutilized capacity is available only in Russia, while Great Britain plans to close down its uranium conversion facilities completely.

Table 3. Capacities and production levels of uranium conversion enterprises
(thousand tons, raw uranium)

Country	Company	Production capacity	Actual production in 2005	Planned production capacity in 2010
Russia	RosAtom	22	10	10
France	Comurhex	14	12	12
Canada	Cameco	11	10	10
Great Britain	BNFL	5	4	0
Others		13	12	12
Total		62	48	44

At present there are more than 20 uranium enrichment facilities in 12 countries: Russia, the USA, France, Great Britain, Germany, the Netherlands, China, Japan, India, Pakistan; Australia and Brazil (pilot-plant production). Additionally, uranium enrichment activities have been conducted in Argentina, South Africa, South Korea, and Iran (whose program was halted in November 2004, while its officials, however, insist the program be restarted under IAEA control). The majority of experts believe that similar technologies exist in Israel and North Korea.

There are four dominant firms in the market for uranium enrichment: Consortium Eurodif (France), Tenex (Russia), USEC (USA), and the Consortium Urenco (Great Britain, Germany, and the Netherlands). Significant firms in this sector also include the CNEIC Corporation (China) and the JHFL firm (Japan).

Enriching uranium is a key stage of the nuclear fuel cycle, which allows not only the production of nuclear fuel for reactors, but also accumulation of a necessary quantity of HEU for producing nuclear weapons. According to IAEA estimates, only 25 kg of U-235 or 8 kg of Pu-239[6] (by American facts; 8-10 kg U-235 or 4 kg Pu-239) are sufficient for producing a nuclear weapon. Moreover, a “gun” type nuclear device using weapons-grade uranium is easier than the “implosion” type device using weapon-grade plutonium. For these reasons, there are principal concerns about the presence of such facilities in India and Pakistan, de-facto[7] nuclear states, which do not come under IAEA guarantees.

In July 2005, India and the USA concluded a cooperation agreement on the peaceful use of atomic energy. The agreement connects India, not singing the NPT, to the regime of nuclear non-proliferation. In particular, India agreed to not share uranium enrichment technologies or distribute plutonium to countries that haven’t submitted their atomic industries to the control of the IAEA, that work in the interests of defence, or that haven’t accepted the additional protocols of the IAEA from 1997[8]. At the same time it is necessary to note that India does not produce its own nuclear fuels and imports them in their entirety, therefore any endeavours to enrich uranium would be military in character and not in the accordance of IAEA guarantees.

Apart from India, Pakistan has no prevalent international agreements regarding nuclear non-proliferation. Actions by this country’s leaders in this area are only voluntary and thus carry unpredictable consequences for the whole world. For this reason, a similar agreement absolutely must be concluded in the very near future.

Furthermore, countries not bound by IAEA guarantees for non-proliferation include the official nuclear states of Russia, the USA, and China. The Soviet Union halted production of enriched uranium for nuclear weapons in 1982. Russia, inheriting such programs from the

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[6] Ferguson C.D., Potter W.C., ‘Improvised Nuclear Devices and Nuclear Terrorism, Weapons of Mass Destruction Commission, Working Materials, No 2 (Stockholm, 2004, p. 35.

[7] According to the NPT, there are only five countries (the USA, the USSR, whose rights have been inherited by Russia, Great Britain, France, and China), each developing nuclear weapons before January 1, 1967, which have the official right to possess such arms (considered official or de-jur nuclear countries). The rest, who created their nuclear weapons afterwards, are considered illegal or de-factor nuclear countries (Israel, India, and Pakistan).

[8] Implications of Proposed India-U.S. Civil Nuclear Cooperation, available at URL <http://www.nti.org/e_research/e3_67b.html>.

USSR, didn't restart such production. The USA also halted such production long ago. Both countries contended that they could place their enterprises under IAEA guarantees without compromising its national security, considering that they have substantial stockpiles of fissile materials. After that, the remaining question of placing uranium enrichment enterprises under the IAEA guarantees rests with China.

Separately, the question of how a state, possessing sensitive technologies (uranium enrichment and plutonium allocation), can exit the NPT requires consideration. Such a state, as a member of the NPT, can take advantage of the results of international cooperation in the sphere of peaceful nuclear power (according to clause IV), and after that openly exit the agreement with 3 months notice (according to clause X[9]), and create a nuclear weapon. With the goal of avoiding such a situation, it is necessary to create laws regulating the mechanism by which a country can exit from the NPT, including the liquidation of key parts fuel development cycle under IAEA controls. This would strengthen the means of nuclear non-proliferation, stimulate cooperation in peaceful atomic engineering, and reduce the appeal for states to exit the NPT.

Plutonium Production and its Use for Peaceful Purposes

Plutonium appears during the work of any nuclear reactor. The quantity of plutonium and its isotopic composition are subsequently determined by the type of reactor. After ordinary uranium is loaded into the light water reactor of a nuclear power plant, each ton of the resulting spent nuclear fuel contains 5.3 kg of Pu-239 after completing a three-year discharge cycle. It is possible to increase the separation of Pu-239 by altering the operation of the reactor (the fuel consumption rate). The spent fuel from a heavy water power reactor, "CANDU" type or gas-graphite "Magnox" reactor, consists of two times more plutonium compared to a light water reactor and its isotopic composition is closer to weapons-grade plutonium.

Facilities to reprocess spent nuclear fuel and separate plutonium are found in France, Great Britain, Russia, India, Germany, South Korea, and Japan. Apparently, radiochemical manufacturing exists in Israel and North Korea.

Russia stores spent nuclear fuel from power reactors of the VVER-1000 and RMBK types, continues reprocessing of fuel from the VVER-440 type, and separates and stores by-products (plutonium). Its own production capacity allows it to process 200 tons of spent fuel in a year, and projections predict this capacity will be increased to 400 tons a year. Russia also has large-scale industrial type BN-600 fast breeder power reactor (560-megawatt), which functions in the capacity of a third power-generating unit for the Beloyarskoy nuclear power plant. Russia is also building the BN-800 nuclear reactor there. A similar fast breeder reactor with a yield of 233 megawatts exists in France. These nuclear reactors are designed to produce thermal energy and burn industrial and weapons-grade plutonium.

Production capacity for reprocessing spent nuclear fuel exists in France (Cogema) and Great Britain (BNFL). Their capable of reprocessing over 4,000 tons of spent nuclear fuel per year (more than half the world's capacity). Their costs of reprocessing spent nuclear fuel is estimated at approximately 1,000 dollars per kg, comparable with fresh fuel. Nine countries, including Japan, use such services.

Today, Japan doesn't have significant spent fuel reprocessing capabilities, and therefore relies on France and Great Britain to reprocess its spent nuclear fuel. After that, a portion is stored in Japan and the rest is stored in France and Great Britain. Japan does, however, have its own program to reuse plutonium. In particular, there are facilities for reprocessing spent nuclear fuel with a yield of 210 tons per year located in Tokay-mura. A facility for reprocessing fuel will start operating in 2007 in Rokkasho-mura, where it is planned to reprocess 800 tons of fuel and separate 7 tons of plutonium each year. India also separates plutonium from spent nuclear

[9] The Nuclear Non-proliferation Treaty, available at URL <http://www.un.org/russian/documen/convents/npt.htm>.

fuel and plans to use it in advanced fast breeder reactors. In the entire world, around 50 tons of plutonium are being produced for civilian purposes.

Plutonium is used for civilian purposes in producing mixed-oxide (MOX) fuel, which consists of a mix of uranium and plutonium dioxides. The amount of plutonium in MOX fuel consists of 5 to 7 percent, and yearly uses of such fuels is around 200 tons. In Europe, 34 nuclear reactors in France, Germany, Belgium and Switzerland already can use such fuel, and 75 are being redesigned for MOX fuel. In particular, the majority of power reactors (13 of 18) in Germany can use such fuel; in France, 7 of 59 reactors operate on 30 percent MOX fuel, a capability that all Soviet produced light water reactors have. In the United States, 3 nuclear reactors can fully operate on this fuel. By 2010, it is planned to convert up to 18 power reactors in Japan and a number of reactors in South Korea to MOX fuel. France has the most successful program for producing MOX fuel. The United States is planning to build a plant to produce this fuel in the nuclear complex at Savannah River (South Carolina) and Russia at the Siberian Chemical Combine in Seversk (Tomsk Oblast).

The current international market for nuclear materials is only just forming in terms of plutonium.

The expanding number of states capable of reprocessing spent nuclear fuel and separating plutonium has become a serious test for the nuclear non-proliferation regime, since there exists the potential to convert corresponding facilities, even ones under IAEA safeguards, in a short time period to manufacturing nuclear weapons. While South Korea obtained the technology to reprocess spent nuclear fuel from France, West Germany transferred it to Brazil. Attempts to acquire such technologies from France were undertaken by Pakistan, Taiwan and Iran. Several states are prepared to pay for the reprocessing of their spent nuclear fuel in other countries under condition of returning the plutonium extracted from it. All the state-importers in question, including Japan, can under certain foreign policy conditions create their own nuclear weapons, which forces leading nuclear states to strengthen their own export control systems.

International Trade of Nuclear Materials

Current information about international trade in nuclear weapons is extremely limited and sometimes conflicting, which makes it very difficult to examine the issue. Inaccessible information is a problem with a number of democratic countries, particularly Great Britain, which do not provide such information to the world community. The United States and Australia are characteristically the most open in this regard. In connection with this, it is important to expediently exchange this information inside the NSG and to publish such information on the IAEA's website. This will reduce a number of countries' concerns regarding the illegal distribution of nuclear materials and technologies, and consequently reinforce the non-proliferation regime.

In the following analysis, the term nuclear materials is understood to be uranium concentrate, enriched uranium in the form of uranium hexafluoride, enriched uranium in the form of uranium dioxide, and nuclear fuel. All these concerned materials will be counted as uranium concentrate and all financial measurements will be in U.S. dollars.

In the world today, there are 439 working power reactors, 30 reactors being constructed, and stated plans to construct another 35 reactors. Nuclear reactors have a total yield of around 360 gigawatts and require about 66 thousand tons of natural uranium each year[10]. According to Table 2, only 35.6 thousand tons of uranium was produced in 2003 (around half the required quantity). Consequently, to meet the significant demands for nuclear fuel requires repeated use of natural uranium in addition to plutonium and HEU from dismantled nuclear warheads, tapping into the accumulated reserves of nuclear materials.

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[10] 'Uranium Markets', Nuclear Issues Briefing Paper 36, October 2004, available at URL<http://www.uic.com.au/nip36.html>.

In 1993, the U.S.-Russian HEU-LEU agreement was signed (HEU Purchase Agreement). This involved HEU being extracted from nuclear warheads to be down-blended to LEU in Russia and sent to the United States, where the U.S. Enrichment Corporation transforms it into fuel for nuclear reactors and sells it on the open market. By agreement, the volume of HEU was 500 tons, the cost was $8 billion, and the completion date was 20 years. In connection with this agreement, Russia must receive compensation from the United States in two forms: money payments reflecting two-thirds of the cost of HEU; and deliveries of uranium hexafluoride as compensation for the natural uranium used during the down-blending of HEU.

Deliveries started in 1995 with growing volumes until the middle of 2004 at the equivalent of 217 tons of HEU. Planned deliveries must be equal to 30 tons of HEU each year or the equivalent of 10.6 thousand tons of uranium concentrate.

The existing HEU-LEU Agreement allows Russia to occupy first place in the world for exports of nuclear materials (23% of world volume; see table 4), which comprise three sources: natural uranium extracted from mines; stored uranium; down-blended HEU from dismantled nuclear warheads. Every year Russia exports 16 thousand tons of nuclear materials[11] to the USA, France, Great Britain, Germany, South Korea, Belgium, Spain, the CIS, and Eastern Europe[12]. Thirty to thirty-five percent of nuclear materials exported to Europe are of Russian origin. In the last several years, Russia has also provided 90 percent enriched uranium for research reactors in France (230 – 600 kg.) and Germany (400 kg.), which don't violate NPT and IAEA agreements.

Table 4. Export volumes of nuclear materials by country (2003, per 1000 tons)

Exporting Country	Receiving Countries	Export Volume	Percent of World Exports
Russia	USA, France, Great Britain, Germany, South Korea, Belgium, Spain, Ukraine, Czech Republic, Bulgaria, Lithuania, Hungary, Slovakia, Armenia, and Finland	16.0	22.7
Canada	USA, France, Japan, Great Britain, Germany, South Korea, Taiwan, Argentina, Spain, China, Mexico, Czech Republic, and Sweden	13.6	18.4
Australia	USA, Japan, France, Great Britain, South Korea, Germany, Canada, Belgium, Spain, Sweden, and Finland	9.6	13.0
USA	Japan, Great Britain, South Korea, Taiwan, Kazakhstan, Sweden, Germany, Canada, France, Spain, and the Netherlands	9.0	12.2
France	USA and South Korea	5.0	6.8
Kazakhstan	USA and others	3.8	5.2
Niger	France and Japan	3.1	4.2

[11] Under Russian exports of nuclear materials we understand not only direct exports from Russia, but also the re-export of nuclear materials from the USA in accordance with the HEU-LEU agreement.
[12] Russia: Uranium Mining and Milling Overview, available at URL<http://www.nti.org/db/nisprofs/russia/fissmat/minemill/overview.html>.

Great Britain	USA and South Korea	2.9	3.9
Namibia	USA and others	2.0	2.7
Uzbekistan	USA and others	1.8	2.4
The Netherlands	USA	1.4	1.9
Germany	USA	1.3	1.8
Japan	USA	1.0	1.4
China	USA	0.9	1.2
South Africa	USA	0.9	1.2
Others	-	1.5	1.0
World Total	-	73.8	100

Currently, Russia has 15 nuclear reactors of the "VVER" type and 11 of the "RBMK" type, and also 4 gas-graphite reactors and one fast-neutron reactor with a total yield of 22 gigawatts. Yearly requirements of nuclear fuel in Russia are from 7.3 to 9.1 thousand tons. Russian nuclear power plants require from 3.5 to 5.3 thousand tons of nuclear materials and around 1.2 thousand tons of such materials are used as fuel in submarine reactors. Also, Russia provides 2.6 thousand tons of materials as nuclear fuel to nuclear power plants built during the Soviet Union in the CIS countries and Eastern Europe (Ukraine, Czech Republic, Bulgaria, Lithuania, Hungary, Armenia, Finland, and Slovakia).

Canada occupies second place among exporters of nuclear materials (18% of world exports). In 2002, Canada exported 13.6 thousand tons of such materials to the USA, France, Japan, Great Britain, Germany, South Korea, Taiwan, Argentina, Spain, China, Mexico, Czech Republic, and Sweden. Including supplies of radioisotopes and heavy water, Canada's yearly exports are around $850 million. Fifteen percent of exported nuclear materials to Europe come from Canada. The largest supplies are to the United States, France and Japan.

There is a plant in Canada for producing uranium hexafluoride, which is capable of producing more than 12.4 thousand tons annually of this material. Around 20 percent of the nuclear materials produced in the country are used for internal needs.

Australia occupies third place on the list of exporters of nuclear materials (13% of total world volume). In 2003 it exported these materials for $268 million; current exports have reached 9.6 thousand tons (please see Table 5). Over the course of the last five years, Australia has exported 44.9 thousand tons of this material for more than $1.2 billion to 11 countries: the USA, Japan, France, Great Britain, South Korea, Germany, Canada, Belgium, Spain, Sweden, and Finland. Annual supplies of nuclear materials are the following: 3.7 thousand tons to the United States; 2.6 thousand tons to Europe (13% of all exports); 2.4 thousand tons to Japan and Canada; and 0.9 thousand tons to South Korea.

Table 5. The volume of Australian nuclear material production and exports from 1996-2004[13]

Nuclear materials	Year								
	1996	1997	1998	1999	2000	2001	2002	2003	2004
Production in tons	5866	6473	5799	7055	8937	9119	8083	8930	10592
Exports in tons	5424	6916	5553	7578	8757	9239	7637	9612	9648
Exports in millions $	196.0	182.6	180.8	185.7	213.5	257.5	196.0	278.0	267.7

[13] Australia's Uranium and Who Buys It, UIC Nuclear Issues Briefing Paper 1, February 2005, available at URL<http://www.uic.com.au/nip01.html>.

The USA occupies forth place in the world for exports of nuclear materials (12% of total world volume; re-exports from Russia and a number of different countries). In 2004, it exported more than a billion dollars of these materials (9,000 tons in conversion of uranium concentrate). The USA exported enriched uranium in the form of uranium dioxide to Japan – $573 million, Taiwan - $60 million, Kazakhstan - $25 million, South Korea - $3 million, Great Britain – $500,000, and Germany - $500,000. The USA also exported enriched uranium in the form of uranium hexafluoride to South Korea ($148 million), Japan ($113 million), Great Britain ($90 million), Sweden ($23 million), Germany ($7 million), Canada ($3 million), France ($2 million), and Spain ($1 million). Additionally, the USA provides HEU. In particular, from the period of 1994 to 2002, the USA delivered 93% enriched uranium to Canada (150 kg) and the Netherlands (110 kg), while 280 kg of HEU were delivered to France and were down-blended to 19%. In comparison with 2003, the volume of exports of nuclear materials decreased by 15% in volume, but the financial payments received remained practically the same (dropping less than 1%).

Fifth in the world for nuclear materials exports is France (7% of world volume). Most of these deliveries find their way to the United States.

Kazakhstan, Niger, Namibia, and Uzbekistan are also large suppliers of nuclear materials. In particular, Niger guarantees these materials for 12 percent of the European market. Niger exports all of the nuclear materials it produces.

A number of countries, for example Great Britain, the Netherlands, Germany, Japan, and China provide uranium hexafluoride to the United States. In 2003, they delivered these materials to the tune of over $800 million.

China is not a large supplier of nuclear materials, but nevertheless supplied natural uranium to Finland, France and West Germany in 1986-87; uranium concentrate to Argentina from 1981-85, Japan in 1992, and the United States from 1990-1992. Additionally, China exported LEU to Iraq in the 1970s, to South Africa in the early 1980s and India in 1995; HEU to Argentina, Iraq, and Pakistan in the 1980s, Brazil in 1984, and Chile in 1988. Although these supplies in question were not in violation of the NPT (China joined that treaty only in March 1992), they are believed to be negative occurrences by experts with regard to nuclear proliferation.

The United States currently has 103 light water power reactors (PWR and BWR) with a total yield of 97 gigawatts and is the largest importer of nuclear materials (56% of world imports, see Table 6), of which consist of 57% uranium concentrate, 35% enriched uranium in the form of uranium hexafluoride, and 8% enriched uranium in the form of uranium dioxide.

Table 6. Volume of nuclear material imports by country (2003, per 1000 ton)

Importing Country	Distributing Countries	Import Volume	Percent of World Imports
USA	Russia, Canada, Australia, France, Great Britain, Kazakhstan, the Netherlands, Namibia, Germany, Uzbekistan, Japan, South Africa, and China	41.2	55.8
France	Russia, Canada, Niger, and Australia	12.4	16.8
Japan	Canada, Australia, Niger, the USA, and France	9.0	12.2
Great Britain	Canada, Russia, Australia, and USA	4.4	6.0
Germany	Russia, Canada, Australia, and USA	3.8	5.2

South Korea	Canada, the USA, Russia, France, Australia, and Great Britain	2.1	2.9
Others		0.9	1.1
Total	–	73.8	100

The USA has annual needs of 29.1 thousand tons of uranium concentrate (see Table 7). Of these requirements, the United States produces 5.6 thousand tons (19%) and imports the rest from 7 countries: Canada, Australia, Russia, Kazakhstan, Namibia, Uzbekistan and South Africa. In 2004, U.S. imports of uranium concentrate cost $661 million, of which $222 million went to Canada, $156 million went to Australia, $125 million went to Russia, $43 million went to Kazakhstan, $41 million went to Namibia, $28 million went to Uzbekistan, $24 million went to South Africa, and $22 million to different countries. In comparison with 2003, the volume of imports increased by 11 percent in real terms but 28 percent in financial expenditures because of the increasing world price.

In 2003, the United States imported enriched uranium in the form of uranium hexafluoride from Russia at a cost of $910 million, from France ($555 million), from Great Britain ($326 million), from the Netherlands ($154 million), from Germany ($145 million), from Japan ($108 million), from China ($99 million), from Kazakhstan ($51 million), and from Belgium ($1 million). The United States imports a small quantity of enriched uranium in the form of uranium dioxide from Japan ($8 million), from Canada ($0.2 million,) from France ($0.1 million), Great Britain ($0.1 million), and Germany ($.03 million). Total U.S. imports of enriched uranium in the form of uranium hexafluoride and dioxide exceeds $2.3 billion.

Table 7. Volume of U.S. uranium concentrate imports and requirements in 2003-04[14]

Exporter Country	Supplies in 2003		Supplies in 2004	
	Purchase in Tons	Cost (Millions of Dollars)	Purchase in Tons	Cost (Millions of Dollars)
Canada	7741	193.37	7476	221.51
Australia	4234	101.36	5294	156.01
Russia	3491	78.27	4689	124.96
Kazakhstan	1921	40.99	1912	42.87
Namibia	469	11.48	1262	40.78
Uzbekistan	1691	41.50	1046	28.45
South Africa	653	14.34	949	24.25
Other Countries	844	19.75	871	21.73
Total Imports	21044	501.06	23499	660.56
U.S	4631	110.26	5603	146.52
Total U.S. Needs	25675	611.32	29102	807.80

France has 59 operating power reactors with a total yield of 63 gigawatts and occupies second place in the world for imports of nuclear materials (17% of world volume). Since 2003, France has stopped mining uranium ore and completely imports it from Russia, Canada, Niger, and Australia. The annual requirements of France for nuclear materials are 12.4 thousand tons. In 2003, France imported 4.4 thousand tons from Russia (re-exported via the USA), 4.1 thousand tons from Canada, 3 thousand tons from Niger, and 0.9 thousand tons from Australia.

[14] Energy Information Administration/ Uranium Marketing Annual Report, available at URL<http://www.eia.doe.gov/cneaf/nuclear/umar/umartablesandfigures.pdf>.

Japan occupies third place in the world for imports of nuclear materials (12% of world volume). Japan currently has 54 operating power reactors with a total yield of 46 gigawatts, three of which (4 gigawatts) are being modernized, and is constructing 12 (14 gigawatts); by 2011, Japan is planning to increase production of atomic energy by 30 percent. Japan annually imports 9 thousand tons of nuclear materials from Canada, Australia, Niger, the USA, and France. The primary supplier of such materials is Canada, which provided Japan 58 percent of its nuclear materials in 2003.

Great Britain has 22 gas-cooling power plants of the "Magnox" or "AGR" type and one light water power plant. Their total yield is 12 gigawatts. Great Britain imports uranium concentrate from Canada, Russia (re-exported via the USA), Australia, the USA, and a number of other countries. Great Britain occupies the forth place in the world as an importer of nuclear materials (6% of world volume).

Germany, occupying fifth place for world nuclear imports (5% of world volume), has 17 operating light water power plants (BWR, PWR) with a total yield of 20 gigawatts, which were constructed by the German company Siemens-KWR. Germany annually imports 3.8 thousand tons of nuclear materials from Russia, Canada, Australia, and the USA. The primary supplier of these materials is Russia (re-exported via the USA).

South Korea has 16 operating light water (PWR) and 4 heavy water (PHWR) power reactors with a total yield of 17 gigawatts. South Korea does not have facilities to enrich uranium and is forced to important enriched uranium in the form of uranium hexafluoride from Canada, the United States and France, but converts it into nuclear fuel at a facility in Tedjon. Russia, Australia, and Great Britain provide nuclear fuel to South Korea only on the basis of natural uranium.

Thus, the leading exporters of nuclear materials are Russia, Canada, Australia, the USA, and France – accounting for 53% of the total world exports. Of these, only Canada and Australia have significant reserves of natural uranium. The rest are either reducing their reserves, dismantling nuclear weapons (Russia), re-exporting the materials (the USA), or are enriching uranium in the form of uranium hexafluoride and selling it on the world market. Other significant exporters of nuclear materials include Kazakhstan, Niger, Great Britain, Namibia, and Uzbekistan.

By volume of imports of nuclear materials, the United States is clearly in first place (56% of world imports). Second to six place are: France, Japan, Great Britain, Germany, and South Korea (43% of world imports). Each of these countries is developing atomic energy that causes a high level of internal consumption of nuclear materials, consequently also generating exports to other countries. In the medium-term, clearly one of tomorrow's main importers of nuclear materials will be China, which is rapidly developing its atomic energy industry.

The key player in the market for nuclear materials is the United States. The USA imports more than half the world's nuclear materials and provides a considerable amount of exports as well. As outlined in the U.S.-Russian HEU-LEU Agreement, Russia has taken the first place as a world exporter of nuclear materials, not considering its relatively small reserves of natural uranium. Today, the Unites States and its allies completely control imports of nuclear materials and a substantial percentage of their exports as well. It would seem that this would simplify the problem of reinforcing the multi-lateral nuclear non-proliferation regime, but in reality Washington moves towards unilateral initiatives concerning non-aligned countries.

Export and Import of Nuclear Technologies

France is the primary exporter of nuclear technology in the world. Its industry has the highest level of development and the highest level of power reactor standardization. Initially, France built gas-graphite power reactors of the "Magnox" type, but then the American company "BNFL-Westinghouse" exported two light water reactors (PWR). Since then, France has fully converted to light water power reactors and exports them to Belgium, China, South Africa, and

South Korea. There are currently two 900 megawatts French nuclear reactors operating in South Africa near Cape Town, two in South Korea in Ulchin, and four in China near Hong Kong.

The French national company Areva is the recognized leader in the market for nuclear power plant equipment. The volume of its sales in 2004 exceeded $24 billion. The company Areva is undertaking modernization and new construction of nuclear power plants in Brazil, China, the United States, and European countries.

In the mid 1960s, money was spent on the first Soviet power reactors and from the 1970s they started exporting to other countries; some of whom received independence after the break-up of the USSR (Ukraine, Czech Republic, Slovakia, Bulgaria, Hungary, Lithuania, Finland, and Armenia). The Soviet Union built two main types of light water power reactors: "RBMK" and "VVER".

The accident at the Chernobyl nuclear power plant made clear the insufficient safety of domestic power reactors and, consequently, reactors were fully or partially closed in the 1990s in Bulgaria, Germany, Poland, Romania, and Slovakia. In 2004, Lithuania shut down the first atomic plant, Ignalina, and is required to shut down the second atomic plant by 2009. Russia unequivocally refused to build power reactors of the "RMBK" type and worked with German and French firms to work on light water reactors of the "VVER" type with more reliable safety systems.

Additionally, the Soviet Union exported 20 research reactors to 17 countries, some of which became independent after the dissolution of the USSR: Belarus, Bulgaria, Hungary, Vietnam, East Germany, Egypt, Kazakhstan, China, Latvia, Lithuania, North Korea, Poland, Romania, Serbia, Ukraine, Uzbekistan, and the Czech Republic. There are currently 13 Soviet research reactors operating in 10 countries: Hungary, Vietnam, Germany, Kazakhstan, North Korea, Poland, Serbia, Ukraine, Uzbekistan, and the Czech Republic.

All of these research reactors used HEU as a fuel, which increases the risks of proliferation. Because of this, the Soviet Union started producing and exporting lower enriched fuel (36 percent) for these nuclear reactors after 1978. Hungary, Poland and Vietnam are currently using exactly that type of fuel. As before, Kazakhstan uses HEU as a fuel. And even in Russia 40 research reactors, of which 9 have a total yield of more than 1 megawatt, are using uranium with an enrichment level from 36 percent to 90 percent.

As the legal successor of the USSR, Russia is likely the second largest exporter of nuclear technologies in the world. Currently the Russian company "Atomstroyeksport" is building two light water VVER-1000 power reactors for the Koodankulam nuclear power plant in India, a similar type of nuclear reactor in Iran at Bushehr, and two reactors in Taiwan. All exported power reactors use western automatic governing systems by technological processes. Primary exports of Russian materials and technologies in 1999 exceeded $2 billion, of which the export of nuclear materials consisted of $0.5 billion. The last few years have witnessed a sharp increase in general exports: from $2.5 billion in 2001 to $3.5 billion in 2004[15]. Additionally, Russia is evidently helping India create propulsion reactors for Indian nuclear submarines[16], while also training Bulgarian, Indian, Iranian and Chinese specialists to work in nuclear power plants.

One of the main exporters of nuclear technologies is the USA. In particular, the American corporations Westinghouse and General Electric are primary suppliers of nuclear reactors.

In 1947, an experimental research reactor was built in Canada. A heavy water power reactor (PHWR) of the "CANDU" type was created as its base, which found sufficiently widespread use in the world. Canada exported 12 "CANDU" type power reactors, made by the

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[15] Nuclear Power in Russia. World Nuclear Association, available at URL<http://www.world-nuclear.org/info/printable_information_papers/inf45print.html>.

[16] ATV Nuclear Submarine Program/ Russia: Nuclear Export to India, available at URL<http://www.nti.org/db/nisprofs/russia/export/rusind/nuknow.html>.

company AECL[17], to Argentina, India, China, Pakistan, Romania, and South Korea. This type of power reactor presents a greater danger for nuclear proliferation (see item about plutonium production).

Germany has engaged in significant exports of "dual-use" technologies. In particular, special equipment, which could be used for centrifuge enrichment of uranium, was sold to the DPRK in 1987 and Iraq at the end of the 1980s. Germany also helped Brazil construct nuclear reactors and create facilities to enrich uranium and reprocess spent nuclear fuel.

Argentina's self-sufficiency in the nuclear area has allowed it to become a large exporter of nuclear technologies. The risk of nuclear proliferation because of Argentina was rather great since it only joined the Nuclear Suppliers Group in 1994 and the NPT in 1995. In the 1970s and 1980s, Argentina apparently helped Libya enrich uranium and separate plutonium from spent nuclear fuel; in the 1990s, it proposed establishing facilities in Iran to produce nuclear fuel and uranium dioxide. Additionally, Argentina was involved in significant exports of research reactors. In 1989 it built such a nuclear reactor in Algeria (1 megawatt), one in Egypt (22 megawatts) in 1998, and also one in Peru.

Japan's first gas-graphite power reactor of the "Magnox" type was imported from Great Britain and functioned from July 1966 to March 1998. After this, Japan created only light water power reactors (LWRs, BWRs, PRWs) on its territory. In the 1970s, three such American nuclear reactors started operating. Later, Japanese and American companies starting building nuclear power plants jointly, and by the end of the 1970s, Japan was fully producing and started exporting power reactors and nuclear technologies to China, Taiwan and South Korea.

In China, the first two nuclear power plants were built near Hong Kong and Shanghai in the mid-1990s. The nuclear power plant at Daya Bay near Hong Kong, which was established by the French company "Electricite de France" with the involvement of Chinese engineers, has two light water power reactors (PWR) with a total yield of 1.9 gigawatts. The nuclear power plant Qinshan-1 near Shanghai, which was built by China with the help of the Japanese firm Mitsubishi, has one light water power reactor (PWR) with a total yield of 0.3 gigawatts. By 2002-03 another three nuclear power plants with a total yield of 2.2 gigawatts were built; one of these was based on French technology, the second on Chinese, and the third was created by Canada and has two heavy water nuclear reactors (PHWR) of the "CANDU" type. By 2006, Russia will complete, using Finnish and German equipment, construction of two light water reactors (VVER) in Taiwan with a total yield of 1 gigawatt each. Currently, China is one of the leading importers of nuclear technology from Germany, Russia, the U.S., France, South Korea, and Japan, since it plans to increase the total yield of its nuclear power plants to 36 gigawatts by 2020.

At the same time, China itself is actively engaged in exports of nuclear technologies to Algeria, Ghana, Iran, Niger, Pakistan, Saudi Arabia, Syria and Thailand. Until the mid-1990s China did not require IAEA safeguards for nuclear facilities to supply nuclear technologies, which created a threat for nuclear proliferation.

The U.S. and Canada built the first two light water and first heavy water power reactors in South Korea in the late 1970s and early 1980s. Later, South Korean firms started participating in such projects and by 1997 the country was able to build nuclear power plants independently. South Korea does not import nuclear technologies at this time. Currently, there are six American, two French and one Canadian power reactors operating in South Korea.

Nuclear Proliferation and the "Black Market" for Nuclear Materials and Technologies

Israel, India and Pakistan are currently de-facto nuclear states; on the threshold are Iran and North Korea. Nuclear weapons programs existed in Argentina, Brazil, South Africa, and a

[17] Canada's Uranium Production and Nuclear Power, Nuclear Issues Briefing Paper 3, May 2005, available at URL<http://www.uic.com.au/nip03.html>.

number of European countries. Several countries, such as Iraq and Libya, tried to get supplies of nuclear weapons.

Unfortunately, the leading nuclear states themselves facilitated nuclear proliferation. Especially in the case of Pakistan, where they not only developed their own nuclear weapons, but also illegally exported nuclear technologies to rogue states.

The military nuclear program of Pakistan appeared out of civilian program, which at the initial stages did not encounter any obstacles from the international community. Pakistan acquired the necessary components for its peaceful nuclear program, took advantage of existing world experience and accomplishments, and trained its specialists in science centres and laboratories in Europe and North America[18].

Pakistan's nuclear infrastructure started developing in the mid-1960s after starting a research reactor with fuel provided by the United States. In 1972, Canada built Karachi the nuclear power plant "Kanup" with one reactor yielding 125 megawatts. At first this nuclear power plant used Canadian and U.S. nuclear fuel, but later starting using fuel produced by Pakistan. It did not have a developed nuclear infrastructure, and therefore started using different secret deals and illegal operations. Abdul Qadeer Khan, who worked a number of years in Western European countries and smuggled out secret documents about uranium enrichment technologies, headed those efforts. As a result, the mining of natural uranium began, production of uranium concentrate began, and finally heavy water and uranium enrichment installations were developed. All of the actions were conducted outside the parameters of IAEA safeguards.

Great Britain, West Germany, the Netherlands, Canada, China, the United States, France and Switzerland all played a large role in the development of Pakistani nuclear power. Moreover, several international companies, particularly West German firms, sold equipment in violation of existing legislation. But China played the leading role in developing Pakistan's nuclear weapons. China not only helped create the nuclear infrastructure and supplied the necessary components for nuclear weapons, but also possibly provided the required technical documents. With China's help, Pakistan by 1998 had built a 40 megawatt heavy water research reactor in Joharabad, which, by U.S. estimates, is capable of producing from 8-10 kg of weapons-grade plutonium per year, and is also needed to produce tritium for nuclear weapons[19]. Additionally, China actively cooperated with Pakistan in the area of nuclear energy. At the turn of this century, China built the heavy water power reactor with a yield of 300 megawatts at the "Chasnup" nuclear power plant in Chasma, and also plans to build yet another similar power reactor with a yield of 200 megawatts[20]. None of these facilities are subject to IAEA safeguards[21].

Pakistan has evoked greater concern from the international community in terms of its illegal export of nuclear technologies. It exported technologies for uranium enrichment centrifuges to Iran, Libya, North Korea, and also appears to have assisted Iraq and Saudi Arabia with implementation of their nuclear programs. The manager of these works, as noted earlier, was Abdul Qadeer Khan, a key figure in the "black market" for nuclear materials and technologies.

According to statements from Islamabad, A.Q. Khan was the official responsible and was acting outside the control of the state for both commercial and political motives. Representatives from several Western and Asian commercial structures and intermediaries from Great Britain, Germany, Dubai, Malaysia, Turkey, Switzerland, Sri Lanka, and South Africa coordinated with him. His organization received vacuum pumps from Germany, special machine tools from

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[18] Belokrenizky, V., Moskalenko, V. and Shaumyn, T., 'South Asia in International Policy' (The international relations, Moscow, 2003), pp.222-223.
[19] Pakistan Nuclear Weapons (WMD around the World), available at URL<http://www.fas.org/nuke/guide/pakistan/nuke/>.
[20] IAEA bulletin, Vol.40, June 1998, № 2, p.52.
[21] Arbatov, A. and Chufrin, G., 'Nuclear Deterrence in South Asia'(Carnegie Moscow Center, Moscow, 2005), p. 17.

Spain, furnaces from Italy, centrifuge motors and frequency converters from Turkey, uranium enrichment facility designs from South Africa and Switzerland, aluminium from Singapore, and centrifuge designs from Malaysia.

A.Q. Khan maintained contacts with several non-state organizations, including extremist movements in the Greater Middle East. There is information indicating that until the start of the Afghan crisis, Usama Bin Laden met with officials from Pakistan's Atomic Energy Commission and discussed nuclear issues with them.

In October 2003, the Italian coast guard seized cargo from the vessel "BBC China" under a German flag, which was heading towards Libya. After inspecting the vessel, high-precision, machine-manufactured aluminium tubes, molecular pumps and other components for manufacturing around 10 thousand "P-2" gas centrifuges for enriching uranium, were discovered[22]. It was determined that the supplier of these components was the Malaysian company "Skomi Precision Engineering," which manufactured the equipment in question by order of a Sri Lankan resident, Mr. Tahir. Through his company in Dubai, "SMB Computers," Tahir intended to deliver the equipment to Libya with the goal of creating nuclear weapons. Libyan leaders clearly realized both the dangers involved, technical impossibility, and unrealistic prospects for creating their own nuclear weapons program. For these reasons, they made the decision to halt their weapons program in exchange for wider cooperation with western countries.

Later it was successfully revealed that Tahir was one of the links in the organization created by A.Q. Khan. Tahir was interrogated in Malaysia and confirmed that in 1994-95 he sold Iran two containers of complex equipment from Pakistan for $3 million. In his opinion, this allowed Iran to already assemble 500 "P-1" centrifuges in 1995.

According to statements from Saudi Arabian defectors, specialists from Iraq and China helped implement a secret program to create nuclear weapons in the country in 1994. It follows to assume that Saudi Arabia is one of the primary sources of funding for Pakistan's nuclear weapons program, while the creator of the "Islamic atomic bomb," A.Q. Khan, had numerous contacts with Saudi representatives.

The above analysis reveals the enormous possibilities for non-state organizations to obtain nuclear materials through illegal transactions, as well as the deficiencies of the existing non-proliferation regime. Historically, the "black market" for nuclear materials and technologies has long existed and helped a number of countries create nuclear weapons.

American-Israeli cooperation in the nuclear area started in 1955 and the first stage was concluded with the preparation of Israeli specialists. By 1960, the United States built a light water research reactor with a yield of 5 megawatts for Israel. This reactor could not be used to create plutonium because of its low capacity, but it was from working on that reactor that Israeli specialists acquired the experience to turn to highly enriched uranium. However, France played the leading role in the early stages of realizing an Israeli nuclear program. In the opinion of foreign experts, Israel and France were engaged in close, secret cooperation in the period from 1953-67 in the area of establishing nuclear weapons. Israeli specialists participated during ongoing work in the French nuclear research centre in Saklay and were able to see the results over the course of French nuclear tests in Sahar.

In the 1960s France put in place Israel's primary nuclear infrastructure. France not only constructed the Dimona heavy water reactor with a yield of 26 megawatts, but also helped establish facilities for the reprocessing of spent nuclear fuel and separation of plutonium. Several experts believe that in the second half of the 1960s, irradiated fuel was sent to France for the process of radiochemical treatment and the separated plutonium was returned to Israel.

Later, Israel modernized its nuclear reactor several times and brought it to a yield of 150 megawatts in order to allow it to annually produce up to 40 kg of weapons-grade plutonium. Israel is now a de-facto nuclear state.

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[22] Luts, C., 'New players on the stage: A.Q. Khan and nuclear 'black market'), available at URL<http://usinfo.state.gov/journals/itps/0305/ijpr/lutes.htm>.

In order to develop weapons-grade nuclear materials, India, with Canadian help, set about in 1960 to build the "Sirus" heavy water nuclear reactor with a yield of 40 megawatts. The existing infrastructure allowed India in 1974 to conduct a "peaceful" underground nuclear explosion with a yield of 12-15 kilotons. After that, the cooperation between India and Canada in the area of heavy water reactors ceasedSubsequently, India started to independently develop a nuclear infrastructure, and its dependence on international equipment decreased by 10 percent by the mid-1990s. As a result, implementation of the nuclear weapons program was not halted and India became a de-facto nuclear state after a series of nuclear explosions in May 1998.

India is currently cooperating actively in the area of building and operating nuclear power plants with Germany, Italy, Russia, the United States and France; and in the research area with Vietnam.

As mentioned above, North Korea and Iran have scientific and technical capacities for creating nuclear weapons and are considered rogue states.

In the 1950s and 1960s, with existing resources and help from the USSR and China, the scientific-experimental base for a nuclear industry was created in North Korea, as well as the productive capability and necessary number of technical specialists. This allowed North Korea to establish a closed nuclear fuel cycle in the 1970s and 1980s. However, while the cooperation with the Soviet Union was exclusively peaceful in nature, China apparently assisted in developing nuclear weapons, as evidenced by the participation of North Korean specialists in the China's nuclear tests in the mid-1970s.

In 1974, North Korea entered the IAEA, and in 1977 signed an agreement on guarantees with the organization. From the beginning however, North Korea used the IAEA as cover for its nuclear weapons program. In the middle of the 80s, under pressure from the Soviet Union, North Korea entered the NPT, but this didn't affect the countries' leadership with regard to creating their own nuclear weapons. North Korea left the NPT in 2005 and officially declared that it had nuclear weapons.

In 1957, an agreement was signed between Iran and the United States regarding the peaceful use of nuclear energy, which included a commitment by Washington to provide Tehran with nuclear facilities and equipment and train specialists. In 1967, the United States supplied the Tehran nuclear scientific-research centre with a research reactor of a total yield of 5 megawatts. In 1974, Iran adopted a Plan to develop nuclear energy, which foresaw the construction of 23 nuclear reactors with a total yield of higher than 20 gigawatts. The primary suppliers of nuclear technologies should have become West Germany, France, and the United States. The first contract to construct a nuclear power plant was signed in 1974 between the Atomic Energy Organization of Iran (AEOI) and the West German firm Kraftverk Union. It foresaw the construction of a nuclear power plant with two PWR type reactors with a yield of 1300 megawatts each in southern Iran, near the city of Bushehr.

There were active negotiations with France about the purchase of facilities to enrich uranium and reprocess spent nuclear fuel. In 1974, the AEOI acquired, for $1 billion, 10% of the shares in a gaseous diffusion facility for enriching uranium, which was built in Tricastin (France). The facility belonged to the international consortium Evrodif with the participation of French capital. As a result of the transaction, Iran received the right to buy items from the facility and had full access to enrichment technology being developed by the consortium.

After the Iranian Revolution of 1979-80, cooperation with the West was frozen. But replacements for the Western partners quickly came to Iran: Argentina, China and Russia. Iran secretly established cooperation with several countries, particularly Pakistan, enabling it to command centrifuge technologies for enriching uranium. Currently Iran is trying to complete a closed fuel-cycle and is suspected of secretly developing nuclear weapons.

Countries, like Argentina, Brazil, and South Africa, were close to creating or having nuclear weapons, but due to several reasons abandoned them.

The United States built the first research reactor in Argentina in 1958. But in 1967, Argentina had already built another three research reactors independently. In the period from

1968 to 1974, West Germany built a heavy water power reactor with a yield of 320 megawatts (Atucha 1) and later started creating a similar nuclear reactor with a yield of 780 megawatts, though the construction was frozen despite 85 percent of the work being completed. Additionally, with the help of Italy, Argentina built a facility (Ezeiza) for reprocessing spent nuclear fuel and separating plutonium, which was closed in 1973. The second heavy water "CANDU" type power reactor was abandoned in 1983. Until then, Argentina had already built a second facility for reprocessing spent nuclear fuel, with the capability to separate 10-20 kg of plutonium each year[23]. The creation of that facility was stopped in 1990 under pressure from the United States and for economic reasons. During the period from 1978 to 1983, Argentina built a uranium enrichment facility (Pilcaniyeu). These facilities were not subject to IAEA safeguards and the international community suspected Argentina of working on a nuclear weapons program. The situation changed only in the 1990s after the country's leadership refused to develop nuclear weapons and acceded to the NPT.

The United States was responsible for the primary nuclear infrastructure in Brazil. A research reactor was built in 1957 and a light water power reactor (Angra 1) was built in 1971. In 1975, active cooperation in the nuclear field started between Brazil and West Germany, which allowed Brazil's military forces to develop three different methods of acquiring weapons-grade nuclear materials: the naval forces – uranium enrichment by centrifuges; the army – plutonium production; and the air force – uranium enrichment by lasers. Additionally, the air force worked on constructing nuclear weapons and developing an underground testing complex at the military base near Cachimbo[24]. By 1990, Brazil was prepared to expand the production of nuclear weapons by means of uranium enrichment by centrifuges, but such a decision was not taken because a civilian government came to power. By the mid-1990s, both the nuclear weapons and submarine programs were halted. In 1998, Brazil joined the NPT.

In the 1960s, South Africa started research in the nuclear area, and the country's prime minister endorsed a program to develop a limited nuclear capacity in 1973[25]. Apparently, Israel and France played primary roles in the development of South African nuclear weapons. Also, West Germany was suspected of providing "swirl-nozzle" technologies. As a result, South Africa developed six nuclear weapons, which were dismantled along with the production equipment in 1989. After that, South Africa halted the nuclear weapons program, and joined the NPT in 1991. South Africa currently has one nuclear power plant with two French light water power reactors (PWR) with a total yield of 1.8 gigawatts.

Conclusion

Analyzing the international trade of nuclear materials and technologies shows that yearly transactions of nuclear materials comprise tens of thousands of tons, including tons of HEU and plutonium, which could be used for producing nuclear weapons. Consequently, there exists the potential for those materials and technologies ending up in states that oppose the existing non-proliferation regime for nuclear weapons. Such materials could also be stolen by terrorist organizations with access to sufficient finances and resources. Therefore, the danger of nuclear proliferation both through legal and illegal channels is rather significant and requires collective efforts by the international community directed at establishing rigid controls over the turnover of nuclear materials and technologies and their subsequent prevention of them entering a "black market".

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[23] Argentina from Tracking Nuclear Proliferation 1998 (Carnegie Endowment for International Peace), available at URL<http://www.ceip.org/programs/npp/nppargn.html>.

[24] Brazil from Tracking Nuclear Proliferation 1998 (Carnegie Endowment for International Peace), available at URL<http://www.ceip.org/programs/npp/nppbrazl.html>.

[25] Country Overviews: South Africa), available at URL<http://www.nti.org/i_russian/i_e4_safrica.html>.

Below are some concluding thoughts about the primary trends in the development of nuclear energy, the export-import of nuclear materials and technologies, and their demonstrable influence in the proliferation of nuclear weapons.

1. The largest world reserves of natural uranium exist in Australia, Kazakhstan, Canada, Russia, and Uzbekistan; accounting for approximately 60% of world reserves. Other significant reserves exist in Africa, the USA, Ukraine, and China. The highest levels of uranium ore extraction exist in Australia and Canada (half the world's production). These two countries, including Kazakhstan, which plan to sharply increase their uranium ore extraction, will be the fundamental producers of low-grade uranium in the period until 2010. A significant amount of uranium ore is also being extracted in Russia, Niger, Namibia, and Uzbekistan. In the remaining countries, uranium ore extraction is supported at a level of less than 1,000 tons annually. In several of these countries, extraction has either halted or is being brought to a halt, thus reducing the potential danger of illegal use of nuclear materials. Despite the construction of new nuclear power plants, the demand for uranium concentrate will not significantly increase given the use of remaining uranium stores from spent fuels and presence of large stockpiles of weapons grade nuclear materials.

Australia, Canada, and Russia have all joined the Tsangera Committee and NSG and are observing their international obligations regarding exports of fissile materials. Kazakhstan also joined the NSG. Primary attention of the world community is focused on Niger, Namibia, and Uzbekistan, who must bring their legislation in line with international export controls and likewise consider the possibility of participating in organizations like the Zangger Committee and the NSG.

International supplies of uranium concentrate do not fundamentally present a danger for nuclear non-proliferation. However, this danger can arise if importing countries of these materials cause alarm to the international community and/or independently possess the infrastructure necessary for enriching uranium. In this case where it is possible to use raw uranium concentrate to create a nuclear weapon, it would be beneficial if the IAEA would exercise reliable control over the supplies of uranium concentrate, that is, a transparent mechanism for the sale of uranium concentrate and its means of being processed.

2. The market for enriched uranium is dominated by four firms: Eurodif Consortium (France), Tenex (Russia), USEC (USA), Urenco Consortium (Great Britain, Germany, and the Netherlands). Other significant firms in this sphere include CNEIC (China) and JNFL (Japan). At the top of importing countries concerns are high prices and the ability to withhold supplies for political motivations. Thus, it is necessary to create an international consortium of nuclear fuel exporters that can deliver supplies in volume and at fair-market prices low enough for importing countries to forego a domestic, closed nuclear cycle. Countries can enter this consortium both as exporters of uranium concentrate and as significant producers of nuclear fuels. Of these countries and firms, on the Russian company Tenex has significant, unused capacity – making its presence in the consortium extremely desirable.

Enriched uranium presents the greatest value to rogue states and terrorist organizations from the perspective of creating a relatively primitive nuclear explosive device. Thus, the international community absolutely must take full control of all steps of the process of acquiring enriched uranium and the prevention of its theft.

3. The primary capacity to process spent nuclear fuels and separate plutonium, as well as significant reserves of those materials, is located in France and Great Britain. In the future, such technological capacity will be spreading to Germany, India, Russia, the United States and Japan because of the gradual conversion of nuclear power plants to using MOX fuel and the construction of fast-neutron reactors.

The increasing number of countries capable of re-processing enriched uranium and separating plutonium will challenge the non-proliferation regime, such that a possibility exists whereby enterprises under IAEA guarantees could switch to production of weapons-grade materials in a rather short period of time. The creation of new radiochemical enterprises always carries a potential danger from rogue states and terrorist organizations, trying to get their hands on plutonium. In connection, the world community faces an actual problem of preventing the realization of a closed nuclear cycle in countries with unstable military and political situations. As a possible solution, a number of countries are considering the proposal of U.S. president George Bush to NSG member states to refuse to sell equipment and technology for enriching uranium and/or reprocessing spent nuclear fuel to any country, which does not possess full-scale enrichment or reprocessing facilities.

In 2004, the G-8 adopted a one-year moratorium on deliveries of such equipment to new states, and in July 2005 the moratorium was extended for another year. The majority of NSG countries didn’t support this initiative for economic and political reasons. Resultantly, tight controls are necessary from the IAEA on all operations regarding the export and import of nuclear materials derived from enriched uranium.

4. The primary exporters of nuclear technology are: France, Russia, the USA, Canada, Germany, Argentina, Japan, and China. All of these countries are members of the NSG, which improves the development of a single export policy with regard to nuclear technologies. With the goal of strengthening the non-proliferation regime, a mechanism for control over dual-use items was included in the NSG guiding principles in May of 2004. This allows participating countries to license items that do not fall under control lists if their final use evokes concerns. Additionally, NSG members decided to strengthen the volume of information between participants of the agreement, and likewise reinforce NSG contacts with governments remaining outside of this mode. At the same time, the NSG is a voluntary association of states whose decisions are not binding. Thus it would be desirable to rework the convention such that the illegal export of nuclear technologies (including dual-use) carries the consequences of sanctions for violating the convention.

5. Germany, France, and China all facilitated nuclear proliferation, which resulted as much from political reasons as the insufficiencies of existing systems of export control. However, this doesn’t free the stated countries from the responsibilities of illegally exporting nuclear materials and technologies. In recent times, the situation has fundamentally changed. Germany and China joined the NSG (France had done so earlier) and strengthened the existing system of export control.

Pakistan has evoked greater concern from the international community in terms of its illegal export of nuclear technologies. It exported technologies of uranium enrichment centrifuges to Iran, Libya, and North Korea, and also appears to have assisted Iraq and Saudi Arabia with implementation of their nuclear programs. Abdul Qadeer Khan, creator of the “black market” of nuclear materials and technologies, coordinated these efforts.

6. At the present time, the world market for nuclear materials and technologies is not 100% controlled, and the potential exists for such materials theft and/or illegal use. Therefore it is absolutely imperative for the IAEA to create additional control mechanisms for this market and make provisions for applying sanctions against violations of these laws.

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