IPFM
INTERNATIONAL PANEL
ON FISSILE MATERIALS

Global Fissile Material Report 2011

Nuclear Weapon and Fissile Material Stockpiles and Production

Sixth annual report of the International Panel on Fissile Materials

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On the cover: the map shows existing and planned uranium enrichment and plutonium separation (reprocessing) facilities. See pages 32–33 of this report for more details.

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About the IPFM

The International Panel on Fissile Materials (IPFM) was founded in January 2006. It is an independent group of arms-control and nonproliferation experts from sixteen countries, including both nuclear weapon and non-nuclear weapon states.

The mission of the 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 disarmament, halting the proliferation of nuclear weapons, and ensuring that terrorists do not acquire nuclear weapons.

Both military and civilian stocks of fissile materials have to be addressed. The nuclear weapon states still have enough fissile materials in their weapon and naval fuel stockpiles for tens of thousands of nuclear weapons. On the civilian side, enough plutonium has been separated to make a similarly large number of weapons. Highly enriched uranium is used in civilian reactor fuel in more than one hundred locations. The total amount used for this purpose is sufficient to make hundreds of Hiroshima-type bombs, a design potentially within the capabilities of terrorist groups.

The Panel is co-chaired by Professor R. Rajaraman of Jawaharlal Nehru University, New Delhi and Professor Frank von Hippel of Princeton University. Its 27 members include nuclear experts from Brazil, China, France, Germany, India, Japan, South Korea, Mexico, the Netherlands, Norway, Pakistan, Russia, South Africa, Sweden, the United Kingdom, and the United States. Short biographies of the panel members can be found on the IPFM website, www.fissilematerials.org.

IPFM research and reports are shared with international organizations, national governments and nongovernmental groups. It has full panel meetings twice a year in capitals around the world and elsewhere in addition to specialist workshops. These meetings and workshops are often in conjunction with international conferences at which IPFM panels and experts are invited to make presentations.

Princeton University's Program on Science and Global Security provides administrative and research support for the IPFM. The lead authors for *Global Fissile Material Report 2011* were Zia Mian and Alexander Glaser.

IPFM's initial support is provided grants to Princeton University from the John D. and Catherine T. MacArthur Foundation of Chicago and the Carnegie Corporation of New York.

Summary

Fissile materials are essential in all nuclear weapons, from first-generation bombs, such as those that destroyed Hiroshima and Nagasaki more than sixty years ago, to the much more powerful thermonuclear weapons in arsenals today. The most common fissile materials in use are uranium highly enriched in the isotope uranium-235 (HEU) and plutonium.

Global Fissile Material Report 2011 provides updated estimates for global and national stockpiles of HEU and plutonium, and recent developments in military and civilian fissile material production capabilities. This is the sixth *Global Fissile Material Report* by the International Panel on Fissile Materials.

The current report builds on the more comprehensive assessment in *Global Fissile Material Report 2010: Balancing the Books—Production and Stocks* of historical fissile material production and stockpiles in weapon states. The 2010 report also included a review of the stocks of HEU and plutonium held by the non-weapon states collectively.

In 2011, the global stockpile of nuclear weapons is estimated at over 19,000 weapons, including operational warheads and warheads awaiting dismantlement, with the United States and Russia together holding over 18,000 of these weapons and the other seven nuclear-weapon states holding a combined total of about 1000 weapons. All the weapon states are modernizing their arsenals and in some cases building new weapon production infrastructure.

Fissile materials that can be directly used in nuclear weapons do not occur in nature. The production of HEU for weapons, which typically contains over 90% uranium-235, from naturally occurring uranium (with 0.7% uranium-235) requires isotope separation technology. The most common uranium enrichment technology today is the gas centrifuge, which also is in commercial use to make low-enriched uranium for use in power reactor fuel. Plutonium can be separated from spent nuclear reactor in a chemical "reprocessing" operation.

The global stockpile of highly enriched uranium (HEU) was about 1440 ± 125 tons, about 35 tons less than one year ago, but still enough for more than 60,000 simple, first generation implosion fission weapons. About 98 % of this material is held by the nuclear weapon states, with the largest HEU stockpiles being held by Russia and the United States. The large uncertainty in the estimate is due to Russia not declaring how much HEU it produced before stopping production in the late 1980s. The United States, which ended production in 1992, has published an official history of its HEU production. The United Kingdom, which ended production in 1962, also has declared its military HEU stockpile. France too has officially announced an end to HEU production for weapons, while China has indicated this informally.

The global HEU stockpile is shrinking as Russia and the United States each blend down HEU that they have declared to be excess to their military needs. Russia is blending down over 30 tons per year of HEU to low-enriched uranium, which can be used for power reactor fuel. This is about 10 times the current rate of down-blending in the United States. India and Pakistan continue to produce HEU, for naval fuel and weapons respectively, but at a much lower rate than the blend-down by Russia and the United States. North Korea has a uranium enrichment program, but it is not known if it is producing HEU. Israel also has expertise in isotope separation and may have produced enriched uranium for military purposes in the past.

The non-nuclear weapon states account for about 20 tons of HEU, almost all of which was provided to them as research reactor fuel by the weapon states. This stockpile is declining as research reactors are converted to low-enriched uranium fuel or closed down, and the HEU fuel is blended down or returned to the countries of origin, largely the United States and Russia.

The global stockpile of separated plutonium in 2011 was estimated at about 495 ± 10 tons. About half of this stockpile was produced for weapons, while the other half has mostly been produced as part of civilian reprocessing programs in nuclear weapon states. As a result, about 98 per cent of all separated plutonium is in the nuclear weapon states today.

The stockpile of separated plutonium for weapons continues to increase because of production in India, Pakistan, and perhaps Israel. The five nuclear weapon states of the Non-Proliferation Treaty (NPT) stopped production decades ago, but Russia, the United States, and the United Kingdom so far have not begun to dispose of stocks that they have declared excess. France and China have not declared any plutonium as excess to military purposes.

There are about 10 tons of plutonium in Japan, the only non-weapon state with a significant program to separate plutonium from spent nuclear fuel today. The nuclear energy policy review launched after the March 2011 nuclear accident at Japan's Fukushima reactors is considering the future of Japan's already troubled reprocessing program.

Nuclear Weapons

There are today nine nuclear weapon states: the United States, Russia, the United Kingdom, France, China, Israel, India, Pakistan, and North Korea. The first four of these have been reducing their deployed arsenals from much higher Cold War levels. China and Israel did not produce such large weapons stockpiles, and they are believed to have kept their arsenals roughly constant for the past few decades. India and Pakistan, which carried out their first nuclear tests in 1974 and 1998, respectively, are building up their weapon stockpiles.

Estimates of the current nuclear-weapon stockpiles held by the nine nuclear weapon states are shown in Table 1.

Country	Current Nuclear Warheads
United States	about 8500, with about 4000 awaiting dismantlement
Russia	about 10,000, with a large fraction awaiting dismantlement
France	fewer than 300
United Kingdom	fewer than 225
China	about 240
Israel	100 – 200
Pakistan	90 – 110
India	80 – 100
North Korea	fewer than 5

Table 1. Estimated total nuclear-weapon stockpiles, 2011. *Source: FAS/NRDC.*[1] The estimate for North Korea assumes that the weapons stockpile consists only of plutonium weapons and does not include possible HEU weapons.

United States and Russia. The United States and Russia made uneven progress in 2011 in meeting their obligations under the April 2010 New-START Treaty. Under the terms of this bilateral treaty, each country commits to reduce the number of its deployed strategic warheads to 1550 weapons by the year 2018. Accounting for these reductions is not straightforward, however. The accounting and declaration rules of the New-START Treaty count individual warheads on ballistic missiles but assign only one warhead to each nuclear bomber, even though bombers may be deployed with many nuclear warheads each.[2] This means the actual number of deployed weapons may be larger than those counted under the Treaty. As in previous U.S.-Russian arms limitation treaties, New-START does not require warheads taken off deployment to be dismantled.

The New-START Treaty entered into force in February 2011. As of September 2011, the data released as part of the Treaty requirements indicates that the United States and Russia together had a slight net increase of 19 deployed strategic warheads.[3] The reduction by the United States of 10 deployed strategic warheads was more than offset by Russia's deployment of an additional 29 strategic warheads. Russia was below the New-START final limit prior to this increase, and is now 16 warheads above the limit of 1550 warheads to be met by 2018.

United States. The United States has not made new statements about its weapons stockpile since the May 2010 Nonproliferation Treaty Review Conference when it released the Defense Department fact sheet, *Increasing Transparency in the U.S. Nuclear Weapons Stockpile*.[4] The fact sheet declared a total U.S. stockpile of 5113 operational nuclear warheads (as of September 2009) and noted that "several thousand additional nuclear warheads are retired and awaiting dismantlement." All weapons retired before 2009 are scheduled for dismantlement by 2022.[5]

The 2010 fact sheet also reported that 8748 nuclear warheads had been dismantled in the 15-year period between 1994 and 2009. The United States has not released an updated figure for the number of warheads that have been dismantled since then, and there is no evidence that the warhead dismantlement rate has increased since 2009, when 356 warheads were dismantled. Largely due to the extensive nuclear warhead life-extension and upgrade programs underway, this annual dismantlement rate is much below the level of over 1300 warheads per year achieved in the early 1990s. Dismantlement and life-extensions are both carried out at the U.S. National Nuclear Security Administration's Pantex plant in Texas and can involve the same facilities and personnel.

The United States is planning an extensive modernization of its nuclear warhead production infrastructure. The Chemistry and Metallurgy Research Replacement Nuclear Facility (CMRR-NF) to be constructed by 2022 at Los Alamos National Laboratory is to support a capacity to produce 80 plutonium components (pits) for warheads each year, with a storage vault for 6 tons of plutonium.[6] Even without CMRR-NF, however, Los Alamos would have the capacity to produce up to 80 pits per year as a result of the planned upgrade of the existing Plutonium Facility-4 (PF-4).[7] The Uranium Processing Facility (UPF) planned for the Y-12 site at Oak Ridge will be able to produce a similar number of the thermonuclear secondary components by 2022 as well as dismantle excess components.[8]

Work also has started on plans for a next generation intercontinental ballistic missile (ICBM), long-range cruise missile, strategic bomber fleet, and ballistic missile submarines—the last to begin service in 2029.[9] The U.S. Navy intends to extend the life of its current *Trident II (D5)* submarine-launched ballistic missiles until at least 2042.[10]

Russia. Russia has offered no significant new information about its nuclear weapons stockpile over the past year other than the data required under the New-START Treaty. It has never released official data on its warhead dismantlement program. It has been estimated that the current net dismantlement rate in Russia is on the order of 200–300 warheads a year, with another 200 warheads being dismantled but then replaced with remanufactured warheads.[11] Russia currently has two operating nuclear-weapon assembly/disassembly plants, at Lesnoy (formerly Sverdlovsk-45) and at Trekhgorny (Zlatoust-36).[12]

Russia is extending the life of some of its old intercontinental ballistic missiles, while it deploys a replacement single-warhead mobile missile, Topol-M, and its multiple-warhead version, RS-24.[13] In addition, Russia announced a plan to develop a large new silo-based multiple-warhead ICBM that is expected to be deployed after 2018. It also has been testing its new *Bulava* submarine launched ballistic missile (with three successful tests in 2011).[14] Russia is building a series of eight new ballistic missile submarines that will be armed with the *Bulava* missile.

United Kingdom. In June 2011, the UK Government informed Parliament that the planned reductions in operationally deployed warheads to 120 weapons would be accomplished within the term of the current parliament, i.e., by early 2015, with the excess warheads to be dismantled by the mid-2020s.[15] The UK Government had previously announced in October 2010 plans to reduce its total nuclear weapons stockpile to no more than 180 weapons by the mid-2020s. The 60 warheads that are not deployed are to be maintained intact to support the maintenance and management of the operational force. The UK stockpile is estimated to have peaked at about 520 nuclear warheads in the 1970s.[16]

The United Kingdom has delayed its decision on modernizing its nuclear forces. The planned follow-on to the Trident missile submarine is not expected to be approved until 2016, and a decision on a new warhead may not be taken until the 2030s. Britain, however, is investing in modernizing its nuclear weapon complex. This includes the new *Pegasus* facility for manufacturing uranium components for weapons to be built at Aldermaston, and the *Mensa* plant for warhead assembly and disassembly to be located at Burghfield.[17] Both plants are expected to enter service between 2016 and 2020.[18]

China. There is little official information about China's nuclear arsenal. The U.S. Department of Defense report *Military and Security Developments Involving the People's Republic of China 2011* suggests China is moving a larger fraction of its warheads to relatively more survivable delivery systems such as mobile solid-fueled missiles.[19] China is estimated to have 40 operational land-based missiles able to reach the continental United States, while problems with its nuclear submarines and related missiles suggest that it may have at present no operational submarine-launched ballistic missiles.[20] This modernization of China's arsenal does not seem to involve adding significant numbers of warheads to its total stockpile. China's total arsenal is estimated to be about 240 weapons and to have remained at about this level for 30 years.[21]

France. In 2008, President Nicolas Sarkozy announced a planned reduction in France's stockpile to "fewer than 300 nuclear warheads."[22] He also declared that France "has no other weapons beside those in its operational stockpile." Since then, France has not indicated if this reduction goal has been met, nor revealed any plans for the disposition of the fissile materials contained in the warheads that are to be removed from the stockpile. It is estimated that at its peak, in 1992, the French arsenal had about 540 warheads.[23]

Israel. Israel is the least transparent of the nuclear weapon states in that it has an official policy of neither confirming nor denying even its possession of nuclear weapons. It is estimated to have 100–200 warheads in its nuclear arsenal. In November 2011, Israel conducted a ballistic missile test described as an "examination of a new missile currently being developed by the defense establishment."[24] The test may have involved a *Jericho-III* missile, first tested in January 2008, with a range of 4800–6500 km.[25] Israel has already deployed *Jericho-I* and *Jericho-II* missiles, with ranges of 1200 km and 1800 km, respectively. Israel also has *Dolphin* submarines able to launch nuclear-capable cruise missiles.[26] In 2011, Israel agreed on terms for the purchase of a sixth *Dolphin* submarine from Germany.[27]

India. India's arsenal of nuclear weapons is estimated to be 80–100 warheads. India continues to develop and test the delivery systems and platforms for its nuclear weapons. In 2011, India's Army Strategic Forces Command carried out a user-trial test of the 2000 km-range *Agni-II* missile.[28] India also carried out a development test of the 3500-km range *Agni-IV* missile.[29] After more test flights, it is expected to be in operation by 2013.[30] India's Defence Research and Development Organisation (DRDO) plans to test the 5000-km range *Agni-V* missile in early 2012 and to have it ready to enter service by 2014.[31] DRDO also is developing multiple independently targetable re-entry vehicles (MIRVs) for the *Agni* missiles.[32]

India expects to begin sea trials of *Arihant*, its first nuclear-powered ballistic missile submarine, in early 2012 and to have the submarine in service by the end of that year.[33] The reactor propelling the submarine was expected to go critical in 2011, but this was delayed until early 2012 because "some things are yet to be settled."[34] In 2011, India started work on its second nuclear submarine; plans call for a fleet of five submarines.[35]

Pakistan. Estimates of Pakistan's nuclear weapons stockpile have grown as it continues to produce fissile material for nuclear weapons and to expand its fissile material production capacity, especially for plutonium. In January 2011, *The New York Times* reported that the U.S. Government estimates Pakistan's stockpile to range from 90 to over 110 weapons.[36] This compares to early 2008 U.S. estimates of a Pakistani arsenal of 70 to 80 weapons, but possibly ranging from 60 to 90 weapons. These government estimates are similar to those by independent analysts.[37]

Like India, Pakistan is developing a range of delivery systems for its nuclear weapons. In 2011, Pakistan carried out the first test of the 60-km range *Nasr* missile, described in an official statement as able to carry "nuclear warheads of appropriate yield," and as "consolidating Pakistan's deterrence capability at all levels of the threat spectrum."[38] Pakistan has a range of medium and longer-range ballistic missiles in development, including the *Shaheen-II* with a range of 2000 km, as well as nuclear-capable air-launched and ground-launched cruise missiles, with ranges of about 300 km and 600 km, respectively, which were both tested in 2011.[39]

North Korea. North Korea, the country that most recently acquired nuclear weapons, halted plutonium production and began to disable key parts of its production facilities in 2006, after its first nuclear weapon test. Radionuclide data from the 2006 test collected and analyzed by detectors that are part of the Comprehensive Test Ban Treaty verification system suggested that this test used plutonium as the fissile material.[40] North Korea carried out a second nuclear test in 2009, but there was no radionuclide signature. Radionuclide signatures collected in South Korea, Japan, and Russia in May 2010 could indicate a possible third North Korean test that may have used HEU rather than plutonium.[41] In 2010, North Korea revealed an advanced uranium enrichment program that it claimed as civilian but that could have allowed it to produce HEU for weapons.[42] The existence of this program had been suspected since at least 2002.[43]

Highly Enriched Uranium

The current global inventory of highly enriched uranium (HEU) is estimated to be about 1440 ± 125 tons (Figure 1). About 98 per cent of this material is held by the nuclear weapon states, and most of it belongs to Russia and the United States. The large uncertainty is due to a lack of accurate public information about Russian HEU production and consumption.

Global Fissile Material Report 2010: Balancing the Books presented detailed estimates for historical national HEU production and stocks. The United States and United Kingdom are the only weapon states to have declared the size of their HEU stockpiles. France declares only its civilian HEU stockpile, while the other weapon states release no information on their HEU holdings. Pakistan and India are currently the only states producing HEU. North Korea in 2010 disclosed a centrifuge enrichment plant at Yongbyon, but it is not known whether this enrichment program has produced HEU.[44]

The global stockpile of HEU is declining as Russia and the United States continue to blend down HEU declared as excess for weapons and military purposes to low-enriched uranium (LEU) for use as fuel in power reactors.

Military HEU

Russia. Russia has the largest HEU stockpile of any state. As of late 2011, Russia had an estimated 737 ± 120 tons of highly enriched uranium. This stockpile includes material in and available for weapons, and material reserved for naval and research reactor fuel. This amount is what remains of an estimated 1250 ± 120 tons of 90% enriched HEU that Russia produced.[45] An additional 220 tons of HEU, most of which contained less than 90% uranium-235, was used to manufacture fuel for naval reactors, research reactors and fast reactors. About 700 tons of the original total of about 1450 tons of HEU has been consumed in naval and other reactor fuel, in plutonium and tritium production reactors, nuclear weapon tests, through down-blending to make LEU, and lost in waste.

As of the end of September 2011, Russia had blended down to LEU a total of 433 tons of the 500 tons of excess weapon-grade HEU it had agreed to sell to the United States by 2013 for use in light-water reactor fuel.[46] In the previous 12 months, Russia blended down about 33 tons of HEU. The down-blending of a further 67 tons will complete the agreement. There is no prospect of a similar follow-up HEU arrangement after the current deal ends in 2013, and Russia has not indicated what its future plans are for remaining HEU stockpiles that are excess to its current weapons requirements.

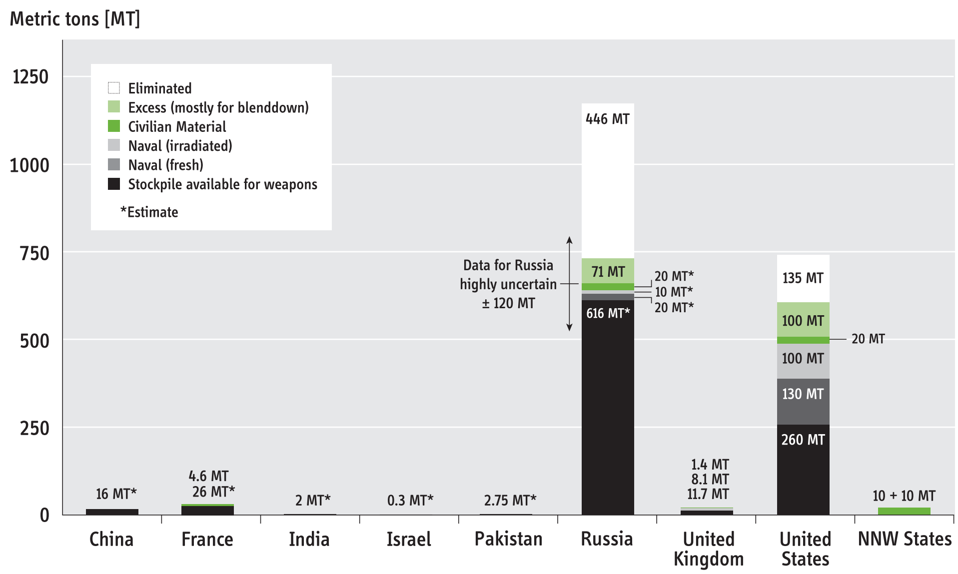

Figure 1. National stocks of highly enriched uranium as of 2011. The numbers for the United Kingdom and United States are based on their publications. The civilian HEU stocks of France, the United Kingdom are based on their public declarations to the IAEA. Numbers with asterisks are IPFM estimates, often with large uncertainties. HEU in non-nuclear weapon (NNW) states is under IAEA safeguards. A 20% uncertainty is assumed in the figures for total stocks in China and for the military stockpile in France, about 30% for Pakistan, and about 40% for India. The 446 tons of eliminated Russian HEU include 433 tons from the 500-ton HEU deal and 13 tons from the Material Consolidation and Conversion (MCC) project. About 4 tons of HEU remain for blend-down within the MCC project. About 10 tons of HEU in non-nuclear weapon states (NNWS) is irradiated fuel in Kazakhstan with an initial enrichment of about 20%.

A second, much smaller Russian HEU down-blending effort, the Material Conversion and Consolidation (MCC) program, funded by the United States National Nuclear Security Administration, covers excess non-weapons HEU. It aims to eliminate 17 tons of HEU by 2015. As of early 2011, Russia had down-blended about 13 tons of HEU as part of this program.[47] Together with the 67 tons from the blend-down agreement, these remaining 4 tons make up the 71 tons of Russian excess HEU.

United States. The total U.S. HEU stockpile is estimated as 610 tons, as of mid-2011. In 2006, the United States declared that, as 30 September 2004, a total of about 690 tons of HEU remained from the 850 tons of HEU it had produced or acquired since 1945.[48] The stockpile is declining because of the continuing blend-down of 210 tons of HEU declared as excess to military requirements. As of May 2011, about 135 tons of HEU had been sent for down-blending, of which 123 tons has already been processed and another 12 tons are to be processed by 2013.[49]

The U.S. HEU down-blend rate is now about 3–4 tons per year, down from about 10 tons per year reached previously.[50] The timescale for down-blending is set in part by the low rate of warhead component dismantlement from which much of this HEU will be recovered. Down-blending of all the HEU that the United States has declared excess is currently scheduled to take at least until 2050.[51]

United Kingdom. The United Kingdom has declared that, as of 31 March 2002, it had a stock of about 21.9 tons of HEU, including HEU in spent naval-reactor fuel.[52] It is estimated that by 2011 about 0.7 tons of this HEU may have been consumed through fission in the UK's nuclear-powered submarines, leaving an estimated stockpile of about 21.2 tons of HEU.[53] This includes an inventory of about 10–15 tons of unirradiated HEU, part of which is likely assigned to the naval propulsion reactors. As of the end of 2010, the United Kingdom also had declared a stockpile of 1.4 tons of HEU as civilian.[54]

Over half of the total HEU held by the United Kingdom may have been supplied by the United States under the 1958 Mutual Defence Agreement, which remains in force today. HEU production at the UK Capenhurst gaseous diffusion plant ended in 1962, after which the plant was used for (unsafeguarded) LEU production. The plant was shut down in 1982 and is now being decommissioned.

France. France's current inventory of military HEU is estimated as 26 ± 6 tons.[55] France has not officially declared its total HEU stockpile, but it has declared to the International Atomic Energy Agency (IAEA) a civilian HEU inventory of 4.6 tons, as of 31 December 2010.[56] France ended the production of HEU in 1996. In 2008 President Sarkozy invited international observers to view the dismantlement of the Pierrelatte gaseous diffusion enrichment plant, where France's stockpile of military HEU was produced.[57]

China. It is estimated that China has a stockpile of 16 ± 4 tons of HEU, and that an additional 4 tons of HEU may have been consumed in nuclear-weapon tests and in research reactor fuel.[58] China produced its HEU at the Lanzhou gaseous diffusion enrichment plant from 1964 to 1980, and at the Heping plant from 1975 to 1987. China does not release any information on its stockpile of HEU and has not declared any of its HEU as civilian.

India. India continues to produce HEU at its Rare Materials Plant (RMP), a centrifuge uranium enrichment facility in Rattehalli, Mysore (Karnataka). The HEU is believed to be enriched to between 30 and 45% uranium-235, i.e., much less than weapon-grade, and is intended for India's nuclear submarine propulsion program. As of the end of 2011, India's HEU stockpile was estimated to be 2.0 ± 0.8 tons.[59]

Figure 2. New construction at India's enrichment complex, the Ratehalli Rare Materials Plant, near Mysore in April 2005 (left) and Feburary 2011 (right). The existing enrichment halls are in the upper left of the image and construction of possible new halls is visible in the lower left and far right of the image. *Source: Google Earth.*

India is rapidly expanding its uranium enrichment capacity. In recent years, new generations of more powerful centrifuges have been developed and centrifuge production capacity has been increased. Recent satellite imagery suggests that India also may be adding new enrichment halls at the Rattehalli site, signficiantly increasing the footprint of the plant (Figure 2).[60] In November 2011, the Chairman of India's Atomic Energy Commission confirmed that the Rattehalli site was "more than adequate" for fueling the submarine fleet.[61]

India is planning a second enrichment complex, the "Special Material Enrichment Facility," in Chitradurga district in Karnataka. According to the Chairman of the Atomic Energy Commission, this facility will not be safeguarded since India is "keeping the option open of using it for multiple roles."[62] These roles could include enrichment of HEU for fueling the nuclear submarine fleet, production of enriched uranium for weapon purposes, production of slightly-enriched uranium to fuel indigenous civilian heavy water reactors that are currently fueled with natural uranium, and the production of low-enriched uranium to fuel light-water power reactors.

Pakistan. Pakistan continues to produce HEU for its nuclear-weapon program. Accurate estimates are limited by the uncertainty about Pakistan's enrichment capacity, the operating history of its centrifuge plants at Kahuta, and the possible but unconfirmed existence of an additional plant at Gadwal.[63] It is estimated that, as of 2011, Pakistan could have a stockpile of about 2.75 ± 1 tons of weapon-grade (90%-enriched) HEU. An additional 0.1 tons may have been consumed in Pakistan's six nuclear weapon tests in 1998.

North Korea. In November 2011, North Korea claimed that it is "progressing apace" with its uranium enrichment activities.[64] A year earlier, North Korea revealed a uranium enrichment plant at the Yongbyon site, with an estimated 2000 centrifuges and a total enrichment capacity of 8000 SWU per year, set up to produce LEU.[65] North Korea claims the enrichment plant is civilian and intended to produce LEU for the light-water reactor that is being built at the same site. North Korea withdrew from the NPT in 2003. Its nuclear facilities are therefore not under IAEA safeguards.

According to a November 2002 declassified U.S. Central Intelligence Agency assessment "North Korea was constructing a plant that could produce enough weapons-grade uranium for two or more nuclear weapons when fully operational—which could be as soon as mid-decade."[66]

Civilian Use of HEU

In addition to its use in nuclear weapons and naval propulsion reactor fuel, HEU is used in many countries in research reactor fuel and as a neutron irradiation "target" to make medical radioisotopes. Since 1978, there have been international efforts spearheaded by the U.S. Reduced Enrichment for Research and Test Reactor (RERTR) program, which is now part of the U.S.-led Global Threat Reduction Initiative, to convert existing HEU-fueled reactors to low-enriched fuel and to design all new research reactors to use LEU fuel.[67] In spite of these efforts, there are still over one hundred research reactors worldwide that use HEU today, some of which contain large quantities of weapon-grade material (90–93% U-235). HEU also is used to fuel propulsion reactors in 11 Russian civilian icebreaker and container ships.

Starting in the 1950s, the United States and Russia exported research reactors to other countries as part of their respective Atoms for Peace programs. The United States supplied about 17.5 tons of HEU as fuel for these reactors.[68] About 10 tons remain in Germany, France, and Japan, mostly as spent fuel, with a further 2 tons in EURATOM member states other than Germany and France.[69] Figure 3 shows the current geo-graphical distribution of civilian HEU.

The Global Threat Reduction Initiative is charged with securing and removing U.S.-origin HEU at civilian sites worldwide. It has removed a total of over 1240 kg of HEU from 24 countries, with 15 of these countries having been cleaned out of all U.S. origin HEU.[70] Seven countries that were supplied with Soviet-origin HEU had been cleaned out of a total of 980 kg of HEU as of 2011.[71] There remain an estimated 20 tons of HEU in non-weapon states, with about half of this in the form of irradiated initially slightly higher than 20%-enriched fuel from the BN-350 fast breeder reactor in Kazakhstan.[72] In November 2010, the United States worked with Kazakhstan to move these 10 tons of HEU to a more secure Cask Storage Facility, in the east of the country.[73]

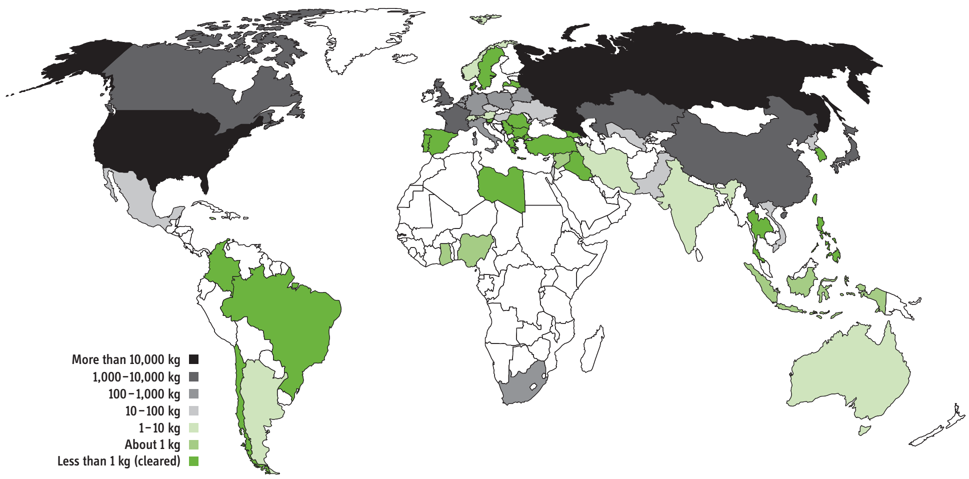

Figure 3. Distribution of civilian HEU worldwide as of 2011. There are still more than 50 sites in about 30 countries where the material can be found in significant quantities, at operational or shut down, but not yet decommissioned HEU-fueled reactors.

In Germany, the FRM-II operated by Technische Universität München (TUM) has not been converted to a fuel with reduced enrichment of 50% by the end of 2010 as originally mandated by an agreement between the Federal Government and the Bavarian State Government from 2001.[74] The reactor currently requires about 35 kg of weapon-grade HEU per year. A Bavarian State Government official announced in 2010 that the reactor would continue to use this fuel until 2018 even though sufficient HEU has been secured to fuel the reactor only until 2015 or 2016.[75] Conversion of the other major high-flux reactors in Europe and the United States also awaits the certification of high-density LEU fuel, whose development has taken longer than originally expected.

In spite of the global efforts to eliminate the use of HEU in civilian reactor fuel, China and Russia have each built a new HEU-fueled reactor. China's 20 MWe (65 MWth) Experimental Fast Neutron Reactor went critical in July 2010 and began producing electricity in July 2011.[76] Designed and built with help from Russia, its initial fuel core contains about 250 kg of HEU enriched to 65% uranium-235 supplied by Russia. It is planned eventually to shift this reactor to plutonium fuel.[77]

Startup of the HEU-fueled high-flux research reactor (PIK) that Russia is completing in Gatchina, near St.-Petersburg has been delayed again and is now scheduled for late 2012.[78] The reactor, which has been under construction since 1976,[79] was supposed to begin operation in 2011. Once operational, it will require on the order of 100 kg of weapon-grade HEU fuel per year.

Civilian Uranium Enrichment Plants

In 2011, civilian enrichment plants were operating in nine countries, not including Japan (see Appendix 2). The number and capacities of these enrichment plants is growing. In November 2010, North Korea revealed a small centrifuge enrichment plant that it claimed as civilian.

United States. By far the largest expansion of civilian uranium enrichment capacity worldwide is underway in the United States, with one new centrifuge plant beginning operation, another plant having been licensed, and a proposed third centrifuge plant seeking a U.S. Government loan guarantee. There are also plans for a uranium laser enrichment plant.

In August 2011, the National Enrichment Facility in Eunice, New Mexico, received approval from the U.S. Nuclear Regulatory Commission (NRC) to begin operating its third and fourth cascades.[80] The plant began operating in June 2010. The original design called for a capacity of 3 million SWU/yr, but the current target is for the plant to reach a capacity of 5.7 million SWU/yr in 2015. The plant is owned and operated by a subsidiary of the European enrichment consortium Urenco, which owns centrifuge enrichment plants in Germany, the Netherlands, and the United Kingdom.

In October 2011, the NRC also issued a construction license to the French company Areva for its Eagle Rock Enrichment Facility at Idaho Falls, Idaho.[81] The Eagle Rock plant received a $2 billion loan guarantee from the U.S. Government in 2010, and construction on this centrifuge plant was planned to start in 2012, with first production of LEU in 2014. Plans call for a capacity of 3.3 million SWU/yr in 2018, and eventually of 6.6 million SWU/yr by 2022.[82] In December 2011, citing economic problems, Areva announced that it was placing several of its major projects on hold, including the Eagle Rock enrichment facility.[83]

The American Centrifuge Plant at Piketon, Ohio, proposed by the U.S. enrichment company USEC (formerly a government agency), continues to face technical and financial difficulties. In June 2011, a power failure during a test involving 37 centrifuges led to the loss of about six machines, at an estimated cost of almost $10 million.[84] USEC has so far failed to secure the $2 billion loan guarantee it has been seeking from the U.S. Government for the project. In September 2011, USEC announced that it was cutting funds for the project and warned it could end the project as early as November 2011.[85] USEC is currently negotiating with the U.S. Department of Energy for $300 million to support its centrifuge program as a technology research, development and demonstration program, instead of a loan guarantee for a commercial facility.[86]

The technology for the Global Laser Enrichment (GLE) plant proposed by General Electric (United States), Hitachi (Japan) and Cameco (Canada) in Wilmington, North Carolina, is still under development. In August 2011, the President of GLE told *The New York Times* that the company is "currently optimizing the design."[87] The NRC is expected to make a decision in 2013 on licensing the plant. Plans call for the facility to be able to enrich up to 8% uranium-235 and for the enrichment capacity to increase annually by one million SWU/yr in its first six years to a final capacity of 6 million SWU/yr.[88] Concerns have been raised about the proliferation implications of the commercialization of laser enrichment technology.[89]

China. In March 2011, a new Russia-supplied centrifuge plant started up in the southwest of Shaanxi province, in the municipality of Hanzhong.[90] It was commissioned in July 2011 with a capacity of 0.5 million SWU/yr.[91] This new module will bring the total enrichment capacity supplied to China by Russia to 1.5 million SWU/yr. This is made up of the three units in Shaanxi (0.2 million SWU/yr installed in 1996, 0.3 million SWU/yr added in 1998, and 0.5 million SWU/yr added in 2011) and one plant built in Lanzhou in 2001 with a capacity of 0.5 million SWU/yr. China also began to operate a centrifuge plant based on indigenous technology in 2010 with a capacity estimated as 0.5 million SWU/yr.[92] Taken together, these centrifuge plants give China a total enrichment capacity of 2 million SWU/yr.

France. The Areva Georges Besse (GB) II centrifuge plant operated its first cascade in March 2011 and began commercial operations in April 2011.[93] It is scheduled to reach its design capacity of 7.5 million SWU/yr in 2016.[94] The capacity increase may be delayed because of Areva's economic problems, however.[95] The plant uses centrifuge technology supplied by the Enrichment Technology Corporation (ETC), which is jointly owned by Urenco and Areva.

Areva has decided to shut down its gaseous diffusion plant George Besse I (Eurodif) by the end of 2012.[96] It will continue to operate at "minimum capacity" in 2012, and is scheduled to be dismantled between 2016 and 2025.

Netherlands. The European enrichment consortium, Urenco, was given permission by the Dutch Government in late 2011 to increase the capacity of its Almelo centrifuge plant from 4.95 million SWU/yr to 6.2 million SWU/yr.[97] This expansion forms part of a larger plan that has seen recent capacity increases at Urenco's enrichment plants in Germany, the United Kingdom, and the United States. Urenco had a total capacity of about 13.5 million SWU/yr in mid-2011.[98] It plans to achieve a total capacity of 20 million SWU/yr by 2015, which would be sufficient to supply more than a third of global requirements for enrichment work.

Iran. In August 2011, Iran reported that it had started moving centrifuges into its Fordow Fuel Enrichment Plant, near Qom.[99] By October, IAEA inspections showed that two cascades, each containing 174 IR-1 centrifuges, had been installed and work was underway on a similar-sized third cascade.[100] Iran informed the IAEA in June 2011 that the Fordow plant will be used to produce uranium enriched up to 20% uranium-235, as well as for R&D.[101]

Japan. In December 2011, Japan Nuclear Fuels Ltd. (JNFL) began operating the first set of its new centrifuges at the Rokkasho centrifuge plant.[102] The plant began operation in 1992 and was originally expected to have a capacity of 1.5 million SWU/yr. Problems with the centrifuge technology meant that the installed capacity peaked at about one million SWU/yr in 1998. JNFL began shutting down cascades starting in April 2000 when crashing machines made operation of those cascades difficult or impossible. The plant was shut down in December 2010.[103] Plans called for the plant to be outfitted with new centrifuges starting in 2011, with the plant reaching a design capacity of 1.5 million SWU/yr in 2020.

In September 2011, JNFL announced that the scheduled startup of the new centrifuges was to be pushed back to the end of year because of delays caused by the March 2011 earthquake and tsunami.[104] The new centrifuges are reported to have four to five times the separative power of their predecessors, with an installed capacity of the first unit sufficient to provide one-third of the low-enriched uranium required for a 1 GWe light water power reactor, i.e., about 40,000 SWU per year.[105] It is not yet clear how Japan's enrichment plans will be affected by the reconsideration of national nuclear policy in the wake of the Fukushima reactor accident.

Argentina. The Pilcanyeu gaseous diffusion enrichment plant was expected to begin producing low-enriched uranium by September 2011, after being reopened in September 2010.[106] As part of this return to operation, the gaseous diffusion technology was to be upgraded. There are as yet no reports that the plant has started operation.[107]

Separated Plutonium

The global stockpile of separated plutonium is estimated as 495 ± 10 tons (Figure 4). Russia and the United States have the largest stockpiles of plutonium produced for weapons. The United States has declared its history of production and use of weapons plutonium, but there remain significant uncertainties in estimates of Russia's stockpile. These uncertainties are however much smaller than before as a result of the detailed new assessment published in *Global Fissile Material Report 2010*.

The United Kingdom, France, and Russia have accumulated the largest civilian plutonium stockpiles. Among the non-weapon states, Japan has the largest stockpile, although most of it is held in France and the United Kingdom. Germany has been successfully drawing down its stockpile of separated plutonium (most of it stored in France) after it stopped sending spent fuel for reprocessing abroad in 2005.

Some previous IPFM estimates omitted a stockpile of about 10 tons of separated civilian plutonium owned by Italy, the Netherlands, Sweden, and possibly other countries. This material was produced under reprocessing contracts with the United Kingdom or France.[108] These countries are not party to the Guidelines for the Management of Plutonium and so do not submit annual INFCIRC/549 declarations to the IAEA.[109] According to information made public by Areva, Italy owns about 5.8 tons of that plutonium, which are currently stored at La Hague.[110]

India, Pakistan, and perhaps Israel continue to produce plutonium for weapons.

The stockpile of separated military plutonium will begin to shrink when Russia and the United States begin disposing of the 34 tons of weapons plutonium they each have declared excess to their military needs. The United States has declared excess and is planning to dispose of an additional 20 tons of separated plutonium.[111] In contrast, the civilian plutonium stockpile will increase if India and China go forward with their reprocessing programs. The future of Japan's reprocessing program is being debated in the wake of the March 2011 nuclear disaster at Fukushima.

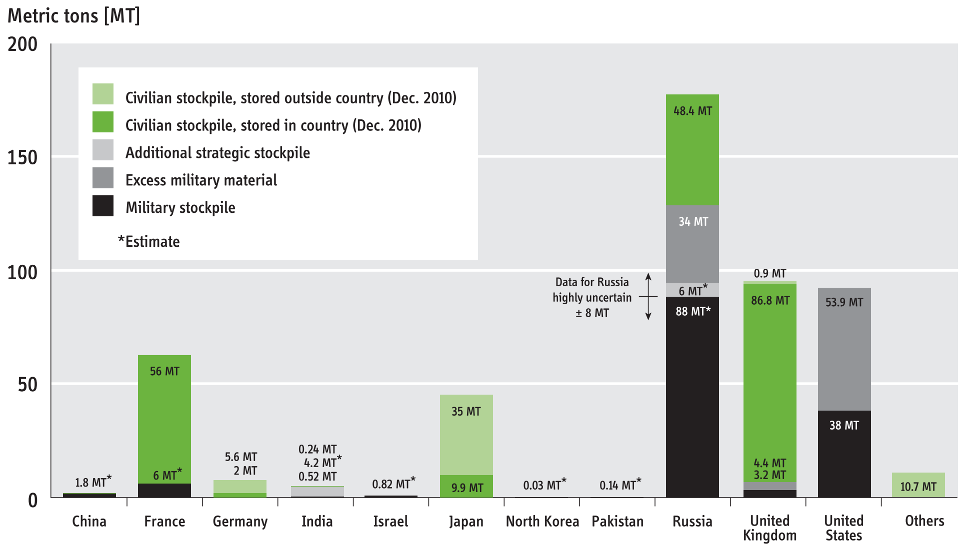

Figure 4. National stocks of separated plutonium. Civilian stocks are based on the most recent INFCIRC/549 declarations for December 2010 and are listed by ownership, not by current location. Weapon stocks are based on non-governmental estimates except for the United States and United Kingdom whose governments have made declarations. Uncertainties of the military stockpiles for China, France, India, Israel, Pakistan, and Russia are on the order of 10–30%. The plutonium India separated from spent heavy-water power-reactor fuel has been categorized by India as "strategic," and not to be placed under IAEA safeguards. Russia has 6 tons of weapon-grade plutonium that it has agreed to not use for weapons but not declared excess.

Weapons Plutonium

The United States and the United Kingdom have declared their stocks of weapons plutonium in 1996 and 2000, respectively.[112] The other nuclear weapons states have published no such information. *Global Fissile Material 2010* presented detailed new estimates for the historical plutonium production and current stocks held by the nuclear weapon states.[113]

United States and Russia. The amended bilateral U.S.-Russia Plutonium Management and Disposition Agreement (PMDA) entered into force in July 2011.[114] Under the agreement, the two countries commit to each dispose of 34 tons of excess weapon-grade plutonium by turning it into mixed oxide (MOX) fuel and using it in nuclear power reactors. According to the U.S. National Nuclear Security Administration (NNSA), the 68 tons of plutonium to be disposed of would be sufficient to make 17,000 nuclear weapons, which is consistent with the assumption that the average Russian and U.S. nuclear warhead contains about 4 kg of plutonium.[115]

The PMDA was signed in September 2000, and amended in April 2010.[116] The amendment allows Russia to use the excess plutonium as fuel in fast breeder reactors. This is a controversial strategy as Russia plans to eventually separate the plutonium again to provide startup fuel for a planned fleet of plutonium breeder reactors. The amended PMDA also reduces the agreed rate of plutonium disposition from no less than two tons per year to no less than 1.3 tons per year. Disposition is to begin in 2018.

United States. To dispose of its 34 tons of excess weapons plutonium, the United States is planning to build three new facilities to disassemble plutonium pits, fabricate MOX fuel for light water reactors, and treat the radioactive plutonium-bearing wastes from these activities. The MOX facility at the Savannah River Site in South Carolina is still under construction. A decision on the facility to extract plutonium from pits, the Pit Disassembly and Conversion Facility, which would be needed to provide feedstock for the MOX plant, is still to be made.[117]

In the interim, the United States may begin MOX fabrication by disposing of 2 tons of plutonium extracted from pits in a pit disassembly pilot plant at Los Alamos National Laboratory, 4.1 tons of plutonium oxide stored at Savannah River (mostly from the shutdown Rocky Flats plant), and 3.7 tons of plutonium that could be processed into oxide in the Savannah River Site H-canyon reprocessing line, i.e., about 9.8 tons in all.[118]

The United States plans to send about 0.5 tons of weapon-grade plutonium from the Savannah River Site for disposal at the Waste Isolation Pilot Plant (WIPP), a geological repository in a salt bed in New Mexico, over a three-year period.[119] This plutonium is among 6 tons of excess material that is unsuitable for fabrication of MOX.

U.S. and Russian disposition of plutonium in MOX is to be monitored by the IAEA but the several tons of plutonium in plutonium-contaminated waste that is being disposed of in the WIPP facility is not. This will create a large uncertainty for any future international attempt to verify U.S. plutonium production and disposition.

Russia. Russia has a stockpile of weapons plutonium estimated as about 128 ± 8 tons. This does not include the plutonium produced since 1994 at the ADE-2 reactor at Krasnoyarsk and its counterparts, ADE-4 and ADE-5 in Seversk. Russia decided in 1994 that the plutonium in spent fuel produced after 1994 by these reactors would not be used for weapons.[120] These three production reactors produced a total of about 15 tons of weapon-grade plutonium since 1994, of which 9 tons were declared excess in 2000 and an estimated additional 6 tons were produced subsequent to the declaration.

The Zheleznogorsk reprocessing plant will complete reprocessing of the final spent fuel from the ADE-2 reactor in 2012. This reactor was shut down in April 2010. It was the last operating plutonium production reactor in Russia. The separated plutonium from the two reactors at Seversk is to be moved to Zheleznogorsk for storage.

China. China is estimated to have an inventory of 1.8 ± 0.5 tons of weapon-grade plutonium. It produced 2 ± 0.5 tons of plutonium for weapons, of which about 0.2 tons was consumed in its nuclear tests.[121] China could build an arsenal of 350–450 nuclear weapons from such a stockpile.[122]

Israel. Israel continues to operate its Dimona production reactor. There is considerable uncertainty about its power level and operating history. It may be in use today largely to produce tritium. As of 2011, Dimona may have produced 820 ± 150 kg of weapons plutonium.[123]

India. As of 2011, India is estimated to have a stockpile of weapons plutonium of 0.52 ± 0.17 tons. An additional 0.09 tons may have been consumed in nuclear weapons tests and in the first core of the Fast Breeder Test Reactor (FBTR).

India has historically produced weapons plutonium at its two production reactors, CIRUS (40 MWt) and Dhruva (100 MWt), at the Bhabha Atomic Research Centre (BARC), in Mumbai. The CIRUS reactor was shut down in December 2010 after 50 years of operation.[124] The reactor first became critical in July 1960 and was used to produce plutonium for India's first nuclear test in 1974. It is estimated that CIRUS produced 160–270 kg of plutonium, which includes plutonium in the fuel still to be reprocessed. It may take 18 months to complete the removal of the remaining fuel from the core.[125]

To replace CIRUS, a new higher-power "multipurpose high flux reactor" similar to the 100 MWt Dhruva reactor is being planned for operation in 2017–2018.[126] The new reactor will be located at the new 3000-acre BARC site near Visakhapatnam, in Visakha district, Andhra Pradesh.[127]

Pakistan. As of 2011, Pakistan continues to expand its capacity to produce weapons plutonium. Its 40–50 MWt Khushab-I reactor has been operating since 1998. A second production reactor at Khushab started operation in late 2009 or early 2010, and a third production reactor at this site is nearing completion. In early 2011, satellite imagery suggested Pakistan has started work on a fourth plutonium production reactor (Figure 5).[128] All these reactors appear to be of similar power.[129] As of the end of 2011, Pakistan could have produced a total of 135 ± 45 kg of plutonium from the Khushab-I and Khushab-II reactors.

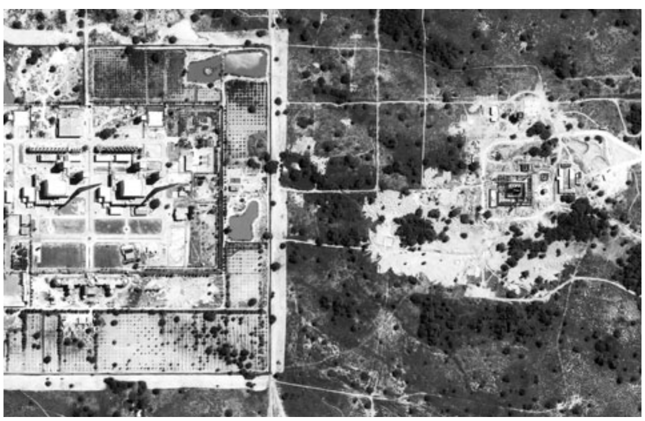

Figure 5. New construction at Pakistan's Khushab site. Khushab-II and -III are visible on the left. Khushab-II began operating in late 2009 or early 2010, and Khushab-III is still under construction. Construction of the Khushab-IV plutonium production reactor is visible on the right. Khushab-I (not shown in the image) has been operating since 1998. *Source: GeoEye satellite imagery, 20 April 2011.*

Civilian Plutonium

Since 1997, nine countries have been submitting information about their national civilian plutonium holdings to the International Atomic Energy Agency (IAEA). Over a period of 15 years, the stockpile has increased by almost 100 tons from 156.1 tons in 1996 to 255.5 tons in 2010, not including the weapons plutonium declared excess by the United States and Russia (Figure 6). The net rate of accumulation has decreased in recent years, but this could change if Japan's Rokkasho reprocessing plant begins full-scale operation. The figure also shows the net annual changes of plutonium stored in the United Kingdom, France, and Russia, which currently separate the largest amounts of plutonium.

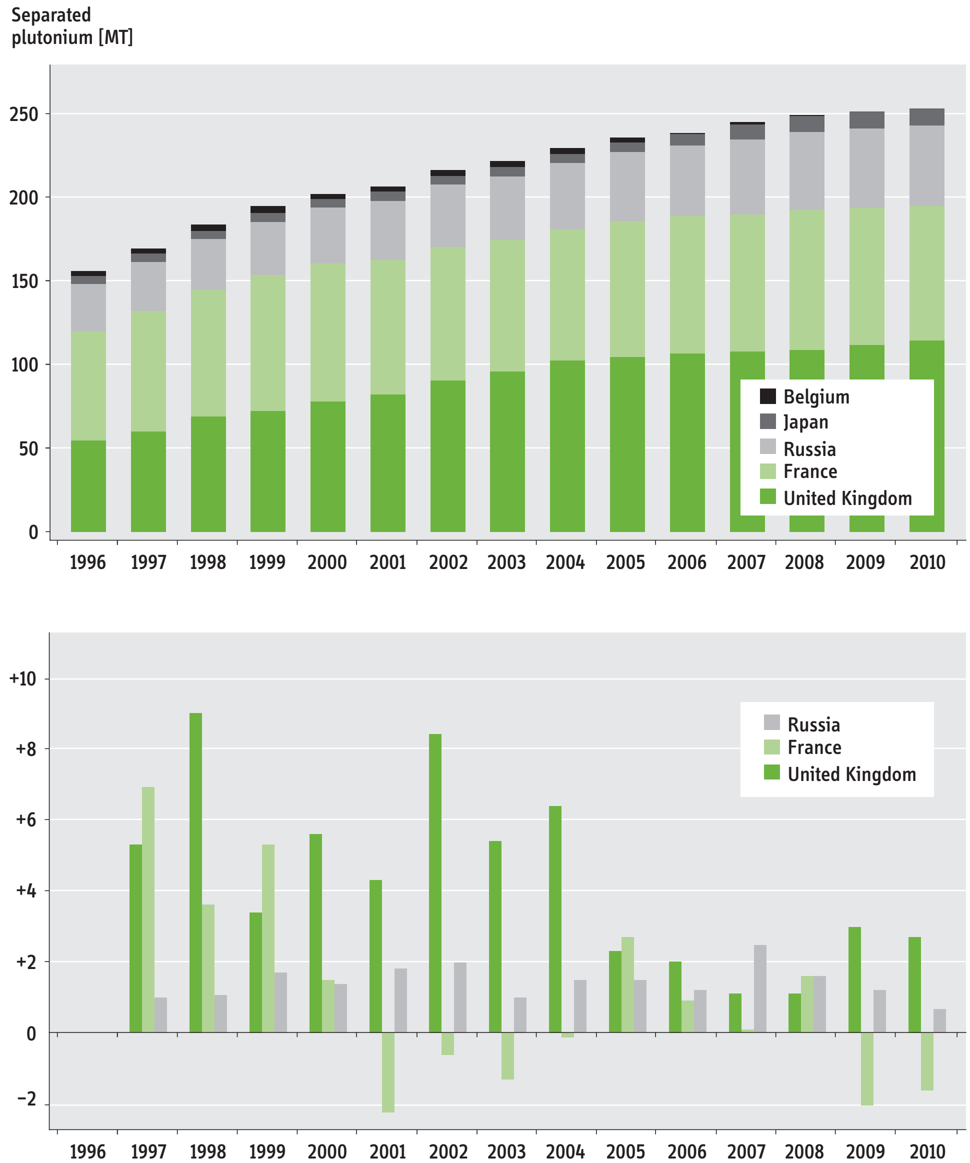

Figure 6. The top figure shows civilian separated plutonium reported in the INFCIRC/549 declarations for the respective years. These values are listed by storage location not by ownership. As of December 2010, a total of 253.3 tons had been declared by the United Kingdom, France, Russia, and Japan, an increase of 1.7 tons compared to the previous year. An estimated 2 tons of additional material is stored in Germany as MOX fuel. The bottom figure shows net annual changes in the civilian plutonium inventories stored in the United Kingdom, France, and Russia. The United Kingdom accumulates the largest amounts of civilian plutonium each year but has reduced the rate in recent years due to problems at its THORP reprocessing plant. The stockpile held in France has decreased slightly over the past two years, primarily because plutonium has been shipped back to foreign customers that have terminated their spent fuel reprocessing contracts. Russia continues to separate plutonium at about 1–2 tons per year.

Accounting for civilian plutonium is made difficult by the way the INFCIRC/549 declarations are structured and from the fact that some countries that own plutonium do not themselves submit INFCIRC/549 declarations.

France and the United Kingdom both store plutonium for other countries. As of December 2010, they together held a total of 52.2 tons of foreign plutonium. Japan owns 35.0 tons of this stockpile (18.0 tons stored in France, 17.0 tons in the United Kingdom);[130] a significant fraction of the remaining 17.2 tons are owned by Germany but the exact amount cannot be inferred from Germany's ambiguous INFCIRC/549 declarations. Based on other sources, the amount is estimated to be 5.6 tons.[131] The United Kingdom regularly declares 0.9 tons of plutonium as held abroad. In total, countries that do not make INFCIRC/549 declarations therefore own an estimated 10.7 tons of plutonium. This includes 5.8 tons of Italian plutonium and 0.3 tons of Dutch plutonium stored at La Hague.[132]

United Kingdom. The UK Nuclear Decommissioning Authority (NDA) announced in August 2011 a decision to close at the "earliest practical opportunity" the Sellafield MOX Plant, which is Britain's only commercial MOX fuel fabrication facility.[133]

The United Kingdom is considering, however, the option of building a new MOX plant to produce fuel from the projected domestic stock of about 90 tons of civilian separated plutonium.[134] In addition about 28 tons of foreign plutonium has been separated under contract with overseas customers. In December 2011, the UK Department of Energy and Climate Change announced:[135]

> "a preliminary policy view to pursue reuse of plutonium as mixed oxide fuel (MOX); converting the vast majority of UK civil separated plutonium into fuel for use in civil nuclear reactors. Any remaining plutonium whose condition is such that it cannot be converted into MOX, will be immobilised and treated as a waste for disposal … [and] overseas customers could opt to have their plutonium converted into MOX fuel in the UK … [or] the UK would be open to consider the merits of taking over ownership of that foreign plutonium and to manage it with existing UK plutonium."

The UK Department of Energy and Climate Change expects that it may be several years before any decision can be made on this option and its December 2011 report noted that:[136]

> "Only when the Government is confident that its preferred option could be implemented safely and securely, that is affordable, deliverable, and offers value for money, will it be in a position to proceed with a new MOX plant. If we cannot establish a means of implementation that satisfies these conditions then the way forward may need to be revised."

The NDA is also considering options for the future of Sellafield's Thermal Oxide Reprocessing Plant (THORP). The NDA's preferred option described in its November 2011 report *Oxide Fuels – Credible Options*, involves operating the facility until it has completed its existing reprocessing contracts, which is now expected to happen in 2018.[137] These contracts involve about 2800 tons of spent fuel. THORP was supposed to have completed this work in 2010 but equipment failures have reduced its operating capacity. The NDA noted that "risks remain with the sustained performance of THORP and support plants over the next 7 years" that may require keeping open the option to "reprocess less than the full contracted amount of spent fuel in THORP in case it is needed."[138]

Under the preferred option, approximately 4000 tons of unreprocessed AGR fuel will go into interim storage before final disposal in a geological repository, along with the high-level waste from reprocessing operations. The UK's separated plutonium is to be kept in storage at Dounreay and at the new Sellafield Product & Residue Store facility, which received its first shipment in February 2011.[139] This marked the beginning of a one-year active commissioning of the Sellafield store.[140] Earlier plans called for plutonium to be stored at Dounreay until 2075 and at Sellafield until 2120.[141]

China. China has started to separate and store civilian plutonium following the commissioning of its first pilot reprocessing plant in December 2010 (Figure 7).[142] The plant is located in Gansu Province and currently has a capacity of 50–60 tons of spent fuel per year and can be expanded to 100 tons per year. In its annual INFCIRC/549 report of civilian plutonium holdings for 31 December 2010, China declared a stock of 13.8 kg of separated plutonium "in product stores at reprocessing plants."[143] Previous Chinese plutonium declarations did not report a civilian stockpile.

Figure 7. A cooling pond at China's pilot reprocessing plant. The plant has the capacity of processing 50–60 tons of spent fuel per year and began operating in 2011. The hot testing of the plant in 2010 yielded 13.8 kg of separated plutonium, which China declared as its civilian stockpile. *Source: news.cntv.cn, 3 January 2011.*[144]

In 2009, the China National Nuclear Corporation (CNNC) signed an agreement to explore the purchase of two Russian 800 MWe BN-800 fast breeder reactors and also plans to develop its own 1000 MWe Chinese Demonstration Fast Reactor (CDFR) design.[145]

India. In January 2011, Prime Minister Manmohan Singh inaugurated a new reprocessing plant (the Power Reactor Fuel Reprocessing Plant-2 or PREFRE-2) at Tarapur.[146] The new plant has a capacity of 100 tons of spent fuel per year. This adds to India's three existing reprocessing plants, which recover plutonium from heavy-water reactor (HWR) fuel: Trombay at Mumbai (50 tons of fuel per year, commissioned in 1964), PREFRE-1 at Tarapur (100 ton capacity, commissioned in 1977), and KARP at Kalpakkam (100 ton capacity, commissioned in 1998). The Trombay plant is earmarked for reprocessing spent fuel from the plutonium production reactors. The other plants together would have separated 3.8 to 4.6 tons of plutonium from spent power-reactor fuel as of the end of 2011.[147]

India has plans for a further expansion of its reprocessing capacity to provide startup fuel for a planned fleet of fast breeder reactors. A "fairly large" new reprocessing plant is said to be "nearing completion" in Kalpakkam; it is scheduled to be commissioned in 2013.[148] The Department of Atomic Energy announced in 2011 that it expects to build several larger reprocessing plants, "close to 500 tons per year," over the next decade.[149] This includes an "integrated nuclear recycle plant," incorporating both spent fuel reprocessing and high-level radioactive waste conditioning, to be located at Tarapur, and two additional plants at other sites.[150] Reprocessing 1000 tons of HWR spent fuel annually would yield about 3.7 tons of separated plutonium per year.

India's 500 MWe Prototype Fast Breeder Reactor (PFBR) is now expected to go critical in mid-2012. Construction started in 2004, and it was originally scheduled to be operating by 2010. There is some uncertainty about how long it may take after the reactor is completed for it to be commissioned.[151] In principle, the PFBR could be used to produce more than 100 kg of weapon-grade plutonium per year, which would significantly increase India's rate of military plutonium production.[152]

Japan. In 2010, Japan's stockpile of separated plutonium stood at 44.9 tons, which included 9.9 tons held in the country, 17 tons in the United Kingdom, and 18 tons in France.[153] The local inventory has not increased since December 2009 because of problems during the start-up testing program at Japan's Rokkasho reprocessing plant. The start of commercial operation has been delayed eighteen times; operation was originally planned to start by December 1997.

As part of the debate about Japan's nuclear policy after the March 2011 disaster at the Fukushima nuclear power plant, the Japanese Government is reconsidering the future of its reprocessing and fast breeder reactor programs. In particular, the government is apparently considering closing down the troubled *Monju* fast breeder reactor.[154]

Japan's science ministry has postponed a plan to restart the *Monju* reactor and run it at 40% of capacity for a trial period.[155] The cancelled Monju trial run was to be the first operation after an accident in August 2010, when a 3-ton piece of equipment fell into the reactor vessel.[156] This accident came soon after the reactor was restarted in May 2010 after a 14-year shutdown caused by a major sodium leak and a fire.[157] The facility has been provided funds only for maintenance, with Japan's Education Minister noting "we want to think about the role of *Monju*."[158]

Appendix 1

Fissile Materials and Nuclear Weapons

Fissile materials are essential in all nuclear weapons, from simple first-generation bombs, such as those that destroyed Hiroshima and Nagasaki more than sixty years ago, to the lighter, smaller, and much more powerful thermonuclear weapons in arsenals today. The most common fissile materials in use are uranium highly enriched in the isotope uranium-235 (HEU) and plutonium. This Appendix describes briefly the key properties of these fissile materials, how they are used in nuclear weapons, and how they are produced.

Explosive Fission Chain Reaction

Fissile materials can sustain an explosive fission chain reaction. When the nucleus of a fissile atom absorbs a neutron, it will usually split into two smaller nuclei. In addition to these "fission products," each fission releases two to three neutrons that can cause additional fissions, leading to a chain reaction in a "critical mass" of fissile material (see Figure A.1). The fission of a single nucleus releases one hundred million times more energy per atom than a typical chemical reaction. A large number of such fissions occurring over a short period of time, in a small volume, results in an explosion. About one kilogram of fissile material—the amount fissioned in both the Hiroshima and Nagasaki bombs—releases an energy equivalent to the explosion of about 18 thousand tons (18 kilotons) of chemical high explosives.

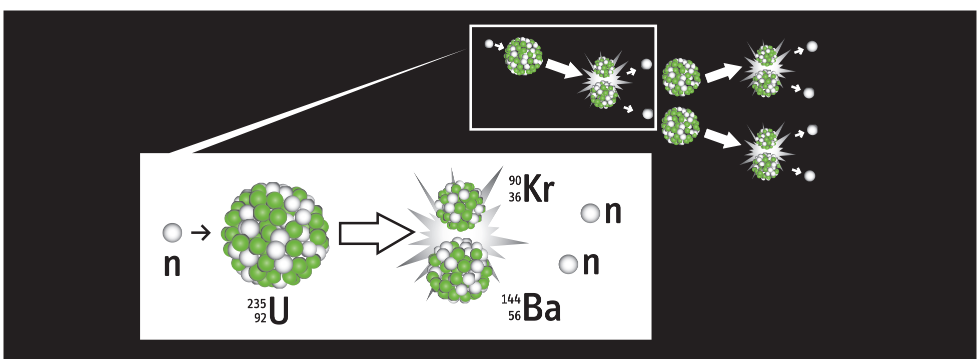

Figure A.1. An explosive fission chain-reaction releases enormous amounts of energy in one-millionth of a second. In this example, a neutron is absorbed by the nucleus of uranium-235 (U-235), which splits into two fission products (barium and krypton). The energy set free is carried mainly by the fission products, which separate at high velocities. Additional neutrons are released in the process, which can set off a chain reaction in a critical mass of fissile materials. The chain reaction proceeds extremely fast; there can be 80 doublings of the neutron population in a millionth of a second, fissioning one kilogram of material and releasing an energy equivalent to 18,000 tons of high explosive (TNT).

The minimum amount of material needed for a chain reaction is defined as the critical mass of the fissile material. A "subcritical" mass will not sustain a chain reaction, because too large a fraction of the neutrons escape from the surface rather than being absorbed by fissile nuclei. The amount of material required to constitute a critical mass can vary widely—depending on the fissile material, its chemical form, and the characteristics of the surrounding materials that can reflect neutrons back into the core. Along with the most common fissile materials, uranium-235 and plutonium-239, the isotopes uranium-233, neptunium-237, and americium-241 are able to sustain a chain reaction.

Nuclear Weapons

Nuclear weapons are either pure fission explosives, such as the Hiroshima and Nagasaki bombs, or two-stage thermonuclear weapons with a fission explosive as the first stage. The Hiroshima bomb contained about 60 kilograms of uranium enriched to about 80 percent in chain-reacting U-235. This was a "gun-type" device in which one subcritical piece of HEU was fired into another to make a super-critical mass (Figure A.2, left). Gun-type weapons are simple devices and have been built and stockpiled without a nuclear explosive test. The U.S. Department of Energy has warned that it might even be possible for intruders in a fissile-materials storage facility to use nuclear materials for onsite assembly of an improvised nuclear explosive device (IND) in the short time before guards could intervene.

The Nagasaki bomb operated using implosion, which has been incorporated into most modern weapons. Chemical explosives compress a subcritical mass of material into a high-density spherical mass. The compression reduces the spaces between the atomic nuclei and results in less leakage of neutrons out of the mass, with the result that it becomes super-critical (Figure A.2, right).

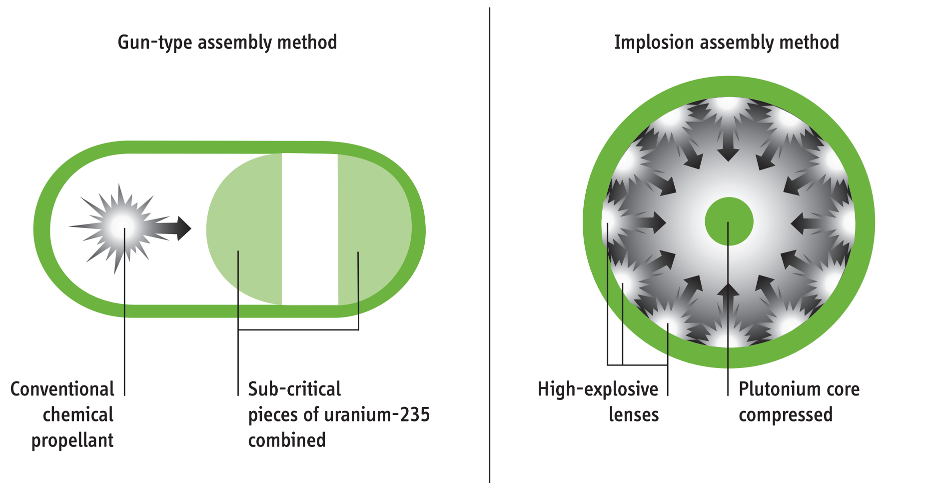

Figure A.2. Alternative methods for creating a supercritical mass in a nuclear weapon. In the technically less sophisticated "gun-type" method used in the Hiroshima bomb (left), a subcritical projectile of HEU is propelled towards a subcritical target of HEU. This assembly process is relatively slow. For plutonium, the faster "implosion" method used in the Nagasaki bomb is required. This involves compression of a mass of fissile material. Much less material is needed for the implosion method because the fissile material is compressed beyond its normal metallic density. For an increase in density by a factor of two, the critical mass is reduced to one quarter of its normal-density value.

For either design, the maximum yield is achieved when the chain reaction is initiated in the fissile mass at the moment when it will grow most rapidly, i.e., when the mass is most supercritical. HEU can be used in either gun-type or implosion weapons. As is explained below, plutonium cannot be used in a gun-type device to achieve a high-yield fission explosion.

Because both implosion and neutron-reflecting material around it can transform a subcritical into a supercritical mass, the actual amounts of fissile material in the pits of modern implosion-type nuclear weapons are considerably smaller than a bare or unreflected critical mass. Experts advising the IAEA have estimated "significant quantities" of fissile material, defined to be the amount required to make a first-generation implosion bomb of the Nagasaki-type (see Figure A.2, right), including production losses. The significant quantities are 8 kg for plutonium and 25 kg of uranum-235 contained in HEU, including losses during production. The Nagasaki bomb contained 6 kg of plutonium, of which about 1 kg fissioned. A similar uranium-based first generation implosion weapon could contain about 20 kg of HEU (enriched to 90% uranium-235, i.e. 18 kg of uranium-235 in HEU).

The United States has declassified the fact that 4 kg of plutonium is sufficient to make a more modern nuclear explosive device. As the IAEA significant quantities recognize, an implosion fission weapon requires about three times as much fissile material if it is based on HEU rather than plutonium. This suggests a modern HEU fission weapon could contain only about 12 kg of HEU.

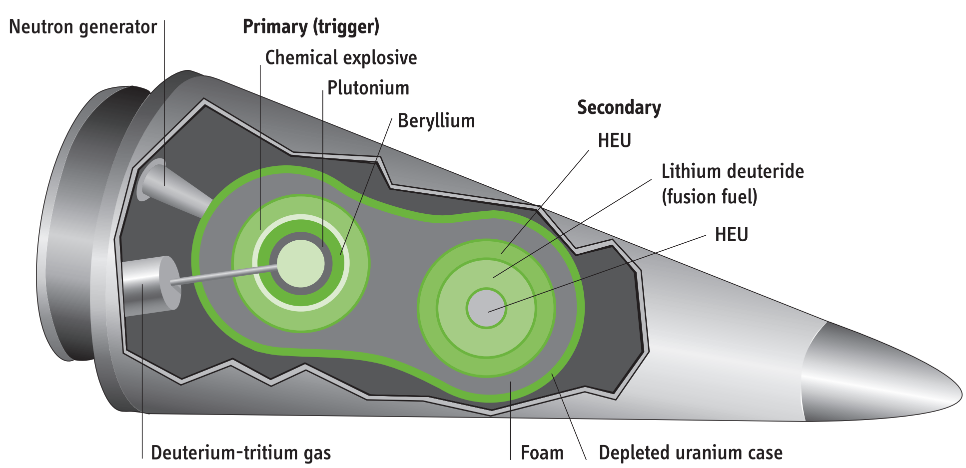

Figure A.3. A modern thermonuclear weapon usually contains both plutonium and highly enriched uranium. Typically, these warheads have a mass of about 200–300 kg and a yield of hundreds of kilotons of chemical explosive, which corresponds to about one kilogram per kiloton of explosive yield. For comparison, the nuclear weapons that destroyed Hiroshima and Nagasaki weighed 300 kg per kiloton.[162]

In modern nuclear weapons, the yield of the fission explosion is typically "boosted" by a factor of about ten by introducing a mixed gas of two heavy isotopes of hydrogen, deuterium and tritium, into a hollow shell of fissile material (the "pit") just before it is imploded. When the temperature of the fissioning material inside the pit reaches about 100 million degrees, it ignites the fusion of tritium with deuterium, which produces a burst of neutrons that increases the fraction of fissile material fissioned and thereby the power of the explosion.

In a thermonuclear weapon, the nuclear explosion of a fission "primary" generates X-rays that compress and ignite a "secondary" containing thermonuclear fuel, where much of the energy is created by the fusion of the light nuclei, deuterium and tritium The tritium in the secondary is made during the explosion by neutrons splitting lithium-6 into tritium and helium.

Modern nuclear weapons generally contain both plutonium and HEU (Figure A.3). The primary fission stage of a thermonuclear weapon can contain either plutonium or HEU or both (the last is known as a composite core or pit). HEU also is often added to the secondary stage as a 'spark-plug' to generate neutrons from a fission chain reaction to begin the conversion of the lithium-6 to tritium and to increase its yield. Natural or depleted uranium is also used in the outer radiation case, which confines the X-rays from the primary while they compress the thermonuclear secondary. Neutrons from the thermonuclear reaction also induce fission in the uranium, which can contribute one-half of the energy yield of the secondary.

A rough estimate of average plutonium and HEU in deployed thermonuclear weapons can be obtained by dividing the estimated total stocks of weapon fissile materials possessed by Russia and the United States at the end of the Cold War by the numbers of nuclear weapons that each deployed during the 1980s: about 4 kg of plutonium and 25 kg of HEU. Many of the older U.S. and Russian strategic weapons had yields in excess of 1 MT and may have contained more than 25 kg HEU. The lower yield thermonuclear weapons deployed today (typically around 100–500 kt) could contain 10–20 kg of HEU.

	Plutonium	HEU	Yield	Example
IAEA Significant Quantity (SQ)	8 kg	25 kg*		
1st-generation gun-type weapon	n/a	50 – 60 kg	20 kt	Hiroshima
1st-generation implosion-type weapon	5 – 6 kg	15 – 18 kg	20 kt	Nagasaki (6 kg Pu)
2nd-generation single-stage weapon	4 – 5 kg	12 kg	40 – 80 kt	(levitated or boosted pit)
Two-stage low-yield weapon	3 – 4 kg Pu and 4 – 7 kg HEU		100 – 160 kt	W76
Two-stage medium-yield weapon	3 – 4 kg Pu and 15 – 25 kg HEU		300 – 500 kt	W87/W88
Two-stage high-yield weapon	3 – 4 kg Pu and 50+ kg HEU		1 – 10 MT	B83

Table A.1. Nuclear weapon generations and estimated respective fissile material quantities. Warhead types are U.S. warhead-designations. The estimates assume about 18 kt per kilogram of nuclear material fissioned, a fission-fraction of 50 % for a 2nd-generation and two-stage weapon, and a yield fraction of 50 % in the secondary from fission in the two-stage weapon. *The significant quantity specifies uranium-235 contained in highly enriched uranium.

Production of Fissile Materials

Fissile materials that can be directly used in a nuclear weapon do not occur in nature. They must be produced through complex physical and chemical processes. The difficulties associated with producing these materials remain the main technical barrier to the acquisition of nuclear weapons.

Highly enriched uranium (HEU). In nature, U-235 makes up only 0.7 percent of natural uranium. The remainder is almost entirely non-chain-reacting U-238. Although an infinite mass of uranium with a U-235 enrichment of 6 percent could, in principle, sustain an explosive chain reaction, weapons experts have advised the IAEA that uranium enriched to above 20 percent U-235 is required to make a fission weapon of practical size. The IAEA therefore considers uranium enriched to 20 per cent or above "direct use" weapon-material and defines it as highly enriched uranium. To minimize their masses, however, actual weapons typically use uranium enriched to 90-percent U-235 or higher. Such uranium is sometimes defined as "weapon-grade."

The isotopes U-235 and U-238 are chemically virtually identical and differ in weight by only one percent. To produce uranium enriched in U-235 therefore requires sophisticated isotope separation technology. The ability to do so on a scale sufficient to make nuclear weapons or enough low-enriched fuel to sustain a large power reactor is found in only a relatively small number of nations.

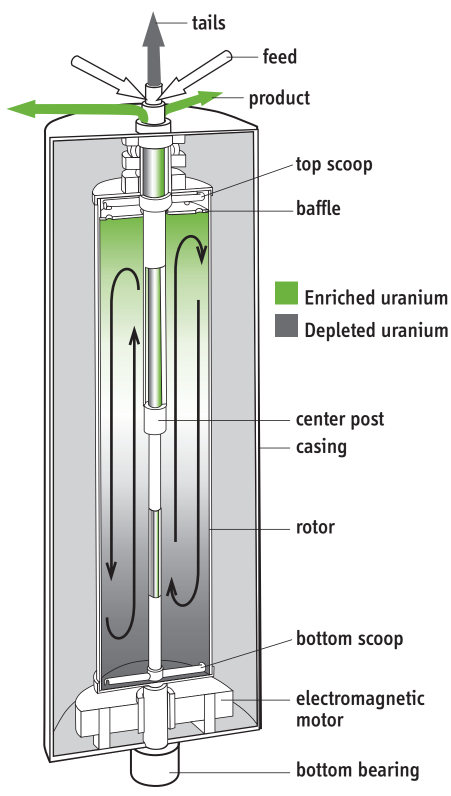

Figure A.4. The gas centrifuge for uranium enrichment. The possibility of using centrifuges to separate isotopes was raised shortly after isotopes were discovered in 1919. The first experiments using centrifuges to separate isotopes of uranium (and other elements) were successfully carried out on a small scale prior to and during World War II, but the technology only became economically competitive in the 1970s. Today, centrifuges are the most economic enrichment technology, but also the most proliferation-prone.

In a uranium enrichment facility, the process splits the feed (usually natural uranium) into two streams: a product stream enriched in U-235, and a waste (or "tails") stream depleted in U-235. Today, two enrichment technologies are used on a commercial scale: gaseous diffusion and centrifuges. All countries that have built new enrichment plants during the past three decades have chosen centrifuge technology. Gaseous diffusion plants still operate in the United States and France but both countries are switching to more economical gas centrifuge plants.

Gas centrifuges spin uranium hexafluoride (UF_6) gas at enormous speeds, so that the uranium is pressed against the wall with more than 100,000 times the force of gravity. The molecules containing the heavier U-238 atoms concentrate slightly more toward the wall relative to the molecules containing the lighter U-235. An axial circulation of the UF6 is induced within the centrifuge, which multiplies this separation along the length of the centrifuge, and increases the overall efficiency of the machine significantly (see Figure A.4 for an illustration).

Gaseous diffusion enrichment, invented during the Manhattan Project, exploits the fact that, in a uranium-containing gas, the lighter molecules containing U-235 move more quickly through the pores in a barrier than those containing U-238. The effect is only a few tenths of a percent, however, and the molecules have to be pumped through thousands of barriers before HEU is produced.

A third enrichment method, electromagnetic separation, involves introducing a beam of uranium-containing ions into a magnetic field and separating it into two beams by virtue of the fact that the path of the electrically charged ions containing the heavier U-238 atoms is bent less by the magnetic field. This method of enrichment was used by the United States during the World War II Manhattan Project and attempted by Iraq in the late 1980s.

Plutonium. Plutonium is an artificial isotope produced in nuclear reactors after uranium-238 (U-238) absorbs a neutron creating U-239 (see Figure A.5). The U-239 subsequently decays to plutonium-239 (Pu-239) via the intermediate short-lived isotope neptunium-239.

The longer an atom of Pu-239 stays in a reactor after it has been created, the greater the likelihood that it will absorb a second neutron and fission or become Pu-240—or absorb a third or fourth neutron and become Pu-241 or Pu-242. Plutonium therefore comes in a variety of isotopic mixtures.

The plutonium in typical power-reactor spent fuel (reactor-grade plutonium) contains 50–60% Pu-239, and about 25% Pu-240. Weapon designers prefer to work with a mixture that is as rich in Pu-239 as feasible, because of its relatively low rate of generation of radioactive heat and relatively low spontaneous emissions of neutrons and gamma rays (Table A.2). Weapon-grade plutonium contains more than 90% of the isotope Pu-239 and has a critical mass about three-quarters that of reactor grade plutonium.

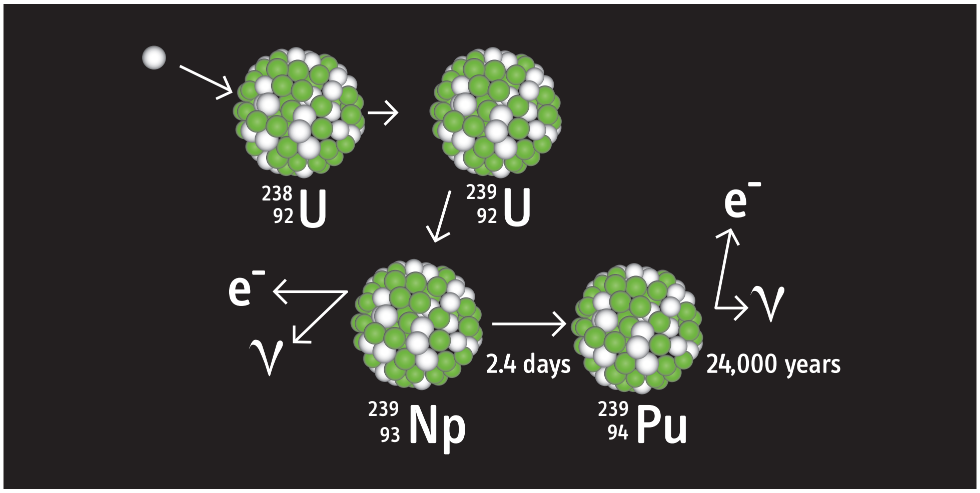

Figure A.5. Making plutonium in a nuclear reactor. A neutron released by the fissioning of a chain-reacting U-235 nucleus is absorbed by the nucleus of a U-238 atom. The resulting U-239 nucleus decays with a half-life of 24 minutes into neptunium, which in turn decays into Pu-239. Each decay is accompanied by the emission of an electron to balance the increase in charge of the nucleus and a neutrino.

For a time, many in the nuclear industry thought that the plutonium generated in power reactors could not be used for weapons. It was believed that the large fraction of Pu-240 in reactor-grade plutonium would reduce the explosive yield of a weapon to insignificance. Pu-240 fissions spontaneously, emitting neutrons. This increases the probability that a neutron would initiate a chain reaction before the bomb assembly reached its maximum supercritical state. This probability increases with the percentage of Pu-240.

For gun-type designs, such "pre-detonation" reduces the yield a thousand-fold, even for weapon-grade plutonium. The high neutron-production rate from reactor-grade plutonium similarly reduces the probable yield of a first-generation implosion design—but only about ten-fold, because of the much shorter time for the assembly of a supercritical mass. In a Nagasaki-type design, even the earliest possible pre-initiation of the chain reaction would not reduce the yield below about 1000 tons TNT equivalent. That would still be a devastating weapon.

More modern nuclear weapon designs are insensitive to the isotopic mix in the plutonium. As summarized in a 1997 U.S. Department of Energy report:[163] "Virtually any combination of plutonium isotopes … can be used to make a nuclear weapon." The report recognizes that "not all combinations, however, are equally convenient or efficient," but concludes that "reactor-grade plutonium is weapons-usable, whether by unsophisticated proliferators or by advanced nuclear weapon states."

For use in a nuclear weapon, the plutonium must be separated from the irradiated uranium and the highly radioactive fission products that it contains. Separation of the plutonium is done in a chemical "reprocessing" operation. With the current PUREX technology, the spent fuel is chopped into small pieces and dissolved in hot nitric acid. The plutonium is extracted in an organic solvent that is mixed with the nitric acid using blenders and pulse columns, and then separated with centrifuge extractors. Because all of this has to be done behind heavy shielding and with remote handling, reprocessing requires both resources and technical expertise. Detailed descriptions of the process have been available in the published technical literature, however, since the 1950s.

Spent fuel can only be handled remotely, due to the very intense radiation field. This makes its diversion or theft a rather unrealistic scenario. Separated plutonium can be handled without radiation shielding, but is dangerous when inhaled or ingested.

Isotope	**Bare Critical Mass** [kg]	**Half Life** [years]	**Decay Heat** [watts/kg]	**Neutron Generation** [neutrons/g-sec]
Pu-238	10	88	560	2600
Pu-239	10	24,000	1.9	0.02
Pu-240	40	6,600	6.8	900
Pu-241	13	14	4.2	0.05
Pu-242	80	380,000	0.1	1700
Am-241	60	430	110	1.2
WPu (94% Pu-239)	10.7		2.3	50
RPu (55% Pu-239)	14.4		20	460

Table A.2. Key properties of plutonium isotopes and Am-241 into which Pu-241 decays. Data from: U.S. Department of Energy, "Annex: Attributes of Proliferation Resistance for Civilian Nuclear Power Systems," in *Technological Opportunities to Increase the Proliferation Resistance of Global Nuclear Power Systems*, TOPS, Washington, DC, U.S. Department of Energy, Nuclear Energy Research Advisory Committee, 2000, www.ipfmlibrary.org/doe00b.pdf, p. 4; see also, J. Kang et al., "Limited Proliferation-Resistance Benefits from Recycling Unseparated Transuranics and Lanthanides from Light-Water Reactor Spent Fuel," *Science & Global Security*, Vol. 13, 2005, p. 169. WPu is typical weapon-grade plutonium, and RPu is typical reactor-grade plutonium.

Appendix 2
Uranium Enrichment Plants

Facility	Type	Operational Status	Safeguards Status	Capacity [tSWU/yr]
Argentina				
Pilcaniyeu	Civilian	Resuming operation	yes	20–3000
Brazil				
Resende	Civilian	Being commissioned	yes	115–200
China				
Shaanxi	Civilian	Operating	(yes)	1000
Lanzhou II	Civilian	Operating	offered	500
Lanzhou (new)	Civilian	Operating	no	500
France				
George Besse I	Civilian	Scheduled for shutdown	yes	10800
George Besse II	Civilian	Operating	yes	7500–11000
Germany				
Gronau	Civilian	Operating	yes	2200–4500
India				
Ratehalli	Military	Operating	no	15–30
Iran				
Natanz	Civilian	Under construction	yes	120
Qom	Civilian	Under construction	yes	5–10
Japan				
Rokkasho	Civilian	Temporary shutdown	yes	(1500)
Netherlands				
Almelo	Civilian	Operating	yes	5000–6000
North Korea				
Yongbyon	?	?	no	(8)
Pakistan				
Kahuta	Military	Operating	no	15–45
Gadwal	Military	Operating	no	Unknown
Russia				
Angarsk	Civilian	Operating	offered	2200–5000
Novouralsk	Civilian	Operating	no	13300
Zelenogorsk	Civilian	Operating	no	7900
Seversk	Civilian	Operating	no	3800
United Kingdom				
Capenhurst	Civilian	Operating	yes	5000
United States				
Paducah, Kentucky	Civilian	Shutdown postponed	offered	11300
Piketon, Ohio	Civilian	Planned	offered	3800
Eunice, NM	Civilian	Operating	offered	5900
Areva Eagle Rock, Idaho	Civilian	Planned	(offered)	3300–6600
GLE, Wilmington, NC	Civilian	Planned	?	3500–6000

Appendix 3
Reprocessing Plants

Facility	Type	Operational Status	Safeguards Status	Capacity (tHM/yr)
China				
Pilot Plant	Civilian	Operating	(no)	50–100
France				
UP2	Civilian	Operating	yes	1000
UP3	Civilian	Operating	yes	1000
India				
Trombay	Military	Operating	no	50
Tarapur-I	Dual	Operating	no	100
Tarapur-II	Dual	Operating	no	100
Kalpakkam	Dual	Operating	no	100
Israel				
Dimona	Military	Operating	no	40–100
Japan				
Rokkasho	Civilian	Starting up	yes	800
Tokai	Civilian	Temporarily shut down	yes	200
North Korea				
Yongbyon	Military	On standby	no	100–150
Pakistan				
Nilore	Military	Operating	no	20–40
Chashma	Military	Under construction	no	50–100
Russia				
RT-1	Dual	Operating	no	200–400
Seversk	Dual	To be shutdown after cleanup	no	6000
Zheleznogorsk	Dual	To be shutdown after cleanup	no	3500
United Kingdom				
B205	Civilian	To be shutdown after cleanup	yes	1500
THORP	Civilian	Operating	yes	1200
United States				
H-canyon, SRP	Converted	Special Operations	no	15

Appendix 4
Civilian Plutonium Stockpile Declarations

	France (Addendum 5)		Japan (Addendum 1)		Russia (Addendum 9)		United Kingdom (Addendum 8)		United States (Addendum 6)	
1996	65.4	30.0	5.0	0.0	28.2	0.0	54.8	6.1	45.0	0.0
		0.2		15.1		0.0		0.9		0.0
1997	72.3	33.6	5.0	0.0	29.2	0.0	60.1	6.1	45.0	0.0
		<0.05		19.1		0.0		0.9		0.0
1998	75.9	35.6	4.9	0.0	30.3	0.0	69.1	10.2	45.0	0.0
		<0.05		24.4		0.0		0.9		0.0
1999	81.2	37.7	5.2	0.0	32.0	0.0	72.5	11.8	45.0	0.0
		<0.05		27.6		0.0		0.9		0.0
2000	82.7	38.5	5.3	0.0	33.4	0.0	78.1	16.6	45.0	0.0
		<0.05		32.1		0.0		0.9		0.0
2001	80.5	33.5	5.6	0.0	35.2	0.0	82.4	17.1	45.0	0.0
		<0.05		32.4		0.0		0.9		0.0
2002	79.9	32.0	5.3	0.0	37.2	0.0	90.8	20.9	45.0	0.0
		<0.05		33.3		0.0		0.9		0.0
2003	78.6	30.5	5.4	0.0	38.2	0.0	96.2	22.5	45.0	0.0
		<0.05		35.2		0.0		0.9		0.0
2004	78.5	29.7	5.6	0.0	39.7	0.0	102.6	25.9	44.9	0.0
		<0.05		37.1		0.0		0.9		0.1
2005	81.2	30.3	5.9	0.0	41.2	0.0	104.9	26.5	45.0	0.0
		<0.05		37.9		0.0		0.9		0.0
2006	82.1	29.7	6.7	0.0	42.4	0.0	106.9	26.5	44.9	0.0
		<0.05		38.0		0.0		0.9		0.0
2007	82.2	27.3	8.7	0.0	44.9	0.0	108.0	26.8	53.9	0.0
		<0.05		37.9		0.0		0.9		0.0
2008	83.8	28.3	9.6	0.0	46.5	0.0	109.1	27.0	53.9	0.0
		<0.05		37.8		0.0		0.9		0.0
2009	81.8	25.9	10.0	0.0	47.7	0.0	112.1	27.7	53.9	0.0
		<0.05		36.15		0.0		0.9		0.0
2010	80.2	24.2	9.9	0.0	48.4	0.0	114.8	28.0	53.9	0.0
		<0.05		35.0		0.0		0.9		0.0

Inventory held in country
Foreign-owned (included in local inventory)
Stored outside the country (not included in local inventory)

Since 1997, nine countries (Belgium, China, France, Germany, Japan, Russia, Switzerland, the United Kingdom and United States) have been declaring annually and publicly their stocks of civilian plutonium to the IAEA (INFCIRC/549). Russia does not include in its declaration excess weapons plutonium, whereas the United States does. The annual inventories (as of December 31st of the respective year) listed in the table are in metric tons. The declarations give the fissile material stocks at reprocessing plants, fuel-fabrication plants, reactors, and elsewhere, divided into non-irradiated forms and irradiated fuel.

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Over the past six decades, our understanding of the nuclear danger has expanded from the threat posed by the vast nuclear arsenals created by the superpowers in the Cold War to encompass the proliferation of nuclear weapons to additional states and now also to terrorist groups. To reduce this danger, it is essential to secure and to sharply reduce all stocks of highly enriched uranium and separated plutonium, the key materials in nuclear weapons, and to limit any further production. These measures also would be an important step on the path to achieving and sustaining a world free of nuclear weapons.

The mission of the IPFM is to advance the technical basis for cooperative international policy initiatives to achieve these goals. This report provides revised estimates of fissile material production and stocks worldwide.

A report published by
The International Panel on Fissile Materials (IPFM)
www.fissilematerials.org

Program on Science and Global Security
Princeton University
221 Nassau Street, 2nd Floor
Princeton, NJ 08542, USA

January 2012

ISBN 978-0-9839411-0-1

9 780983941101