DOI: 10.2968/065001005

Bulletin of the Atomic Scientists

Fissile material stocks and production, 2008

Civilian and military stockpiles of materials that can be used to make nuclear weapons continue to pose global risks.

BY ALEXANDER GLASER & ZIA MIAN

Fissile materials are those that can sustain an explosive fission chain reaction. They are essential in all nuclear explosives, from first-generation fission weapons to advanced thermonuclear weapons. The most common fissile materials in use are highly enriched uranium (HEU) and plutonium. The production of kilogram quantities of these materials was the key challenge for the U.S. effort more than 60 years ago to build the world's first nuclear weapons and remains the major obstacle for any state seeking nuclear weapons today. Control of these materials is crucial to nuclear disarmament, to halting the proliferation of nuclear weapons, and to ensuring that terrorists do not acquire nuclear weapons.

The International Panel on Fissile Materials produces an annual Global Fissile Material Report, which includes a review of worldwide stocks, production, and disposition of HEU and plutonium. What follows is adapted from the 2008 assessment.[1]

Fissile materials and nuclear weapons. The International Atomic Energy Agency (IAEA) defines uranium enriched to more than 20 percent uranium 235 as "highly enriched uranium" and considers it to be a weapons-usable material. Increased enrichment allows for smaller amounts of material to be used for a weapon, with "weapon-grade" uranium typically concentrated to more than 90 percent uranium 235. The Hiroshima bomb was made from highly enriched uranium.

Plutonium is produced as a by-product in a nuclear reactor, usually as a mixture of several plutonium isotopes (determined by how long the uranium fuel fissions in the reactor), and needs to be separated from the spent nuclear fuel to be usable in a weapon. According to the U.S. Energy Department, "Virtually any combination of plutonium isotopes . . . can be used to make a nuclear weapon." The Nagasaki bomb was made from plutonium.

The IAEA defines a "significant quantity" of fissile material to be the amount required to make a first-generation implosion bomb, including production losses. The significant quantities are respectively 25 kilograms of uranium 235 contained in HEU and 8 kilograms of plutonium. Modern two-stage thermonuclear weapons typically contain both HEU and plutonium, with an estimated average of 4 kilograms of plutonium in the fission primary stage and 25 kilograms of HEU in the thermonuclear secondary stage.

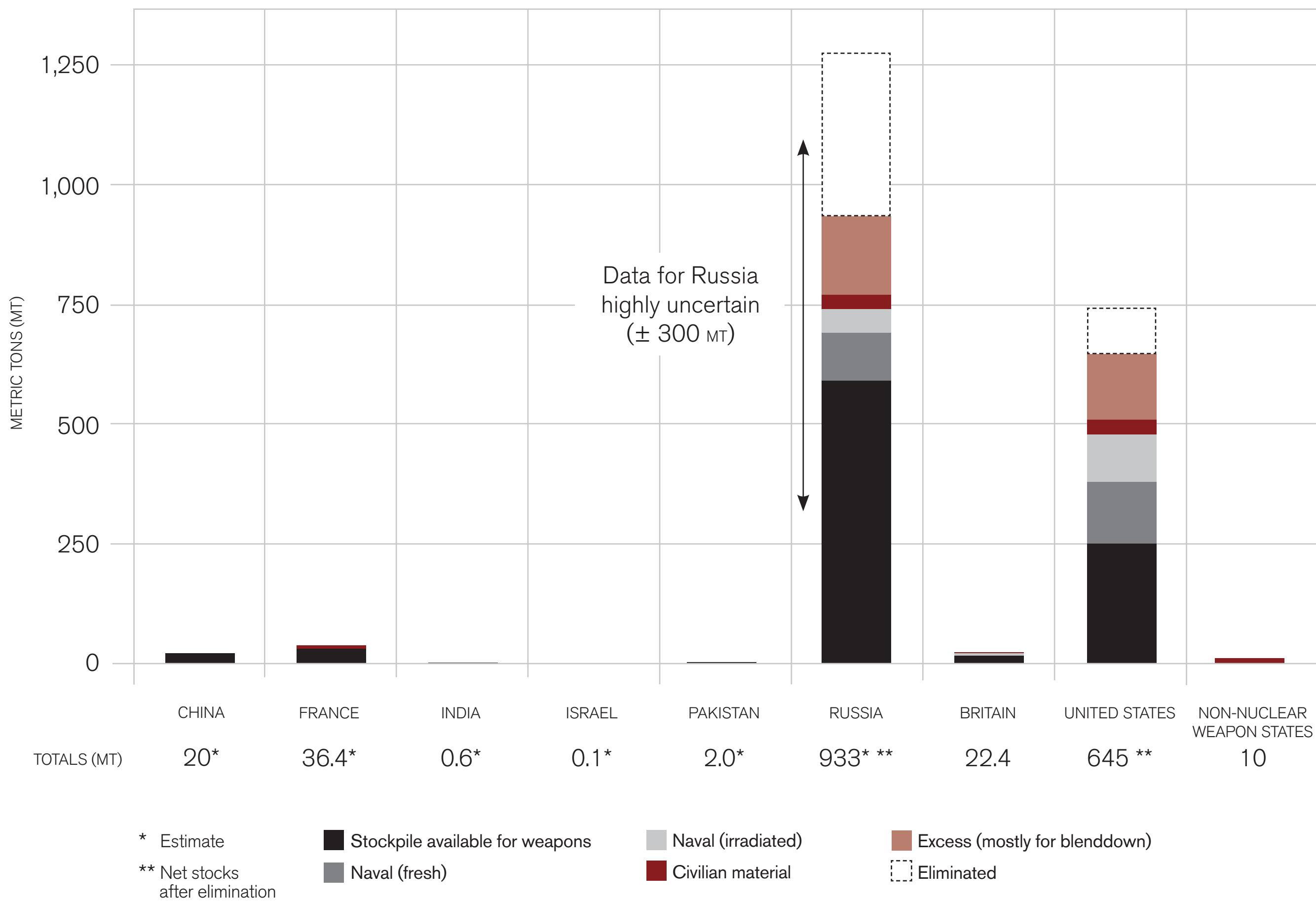
The nine nuclear weapon states are, in historical order, the United States and Russia with roughly 10,000 nuclear warheads a piece (5,000 U.S. warheads are awaiting dismantlement, the number to be dismantled in Russia is highly uncertain); Britain with 185; France with fewer than 300; China with about 240; Israel with between 100 and 200; India with 60–70; Pakistan with about 60; and North Korea with fewer than 5. Estimates of their current nuclear weapon stockpiles are based on the Nuclear Notebooks published in the *Bulletin of the Atomic Scientists*. The U.S. and Russian stockpiles peaked at approximately 30,000 warheads for the United States (around 1965) and 40,000 for Russia (around 1985).

The United States, Russia, Britain, France, and China have each declared (China informally) that they have ended or suspended production of fissile materials for weapons. North Korea has also declared an end to production of plutonium for weapons and opened its facilities to international inspection. Only India, Pakistan, and possibly Israel continue to produce fissile materials for nuclear weapons use.

Highly enriched uranium stocks. The global inventory of HEU currently totals 1,670 metric tons (plus or minus 300 tons). More than 99 percent of this stockpile is in the possession of the nuclear weapon states. Only Britain and the United States have made public the sizes of their HEU stockpiles. Estimates of the remaining national holdings are generally uncertain. The main uncertainty in estimating the global total is due to a lack of information on the Russian stockpile. (See chart, "Estimated national stocks of HEU as of mid-2008," p. 3.)

The global HEU stock is decreasing due to the ongoing downblend activities in Russia and the United States, in which HEU that has been declared excess to military needs is diluted to produce low-enriched uranium (LEU), typically 3–5 percent enriched, for use as power reactor fuel. Together, the two countries have been eliminating about 40 tons of HEU a year. As of June 2008, Russia had eliminated 337 tons of weapon-grade HEU, out of a total of 500 tons that it had agreed to downblend as part of its 1993 deal with the United States. The deal is to be completed in 2013. As of mid-2008,

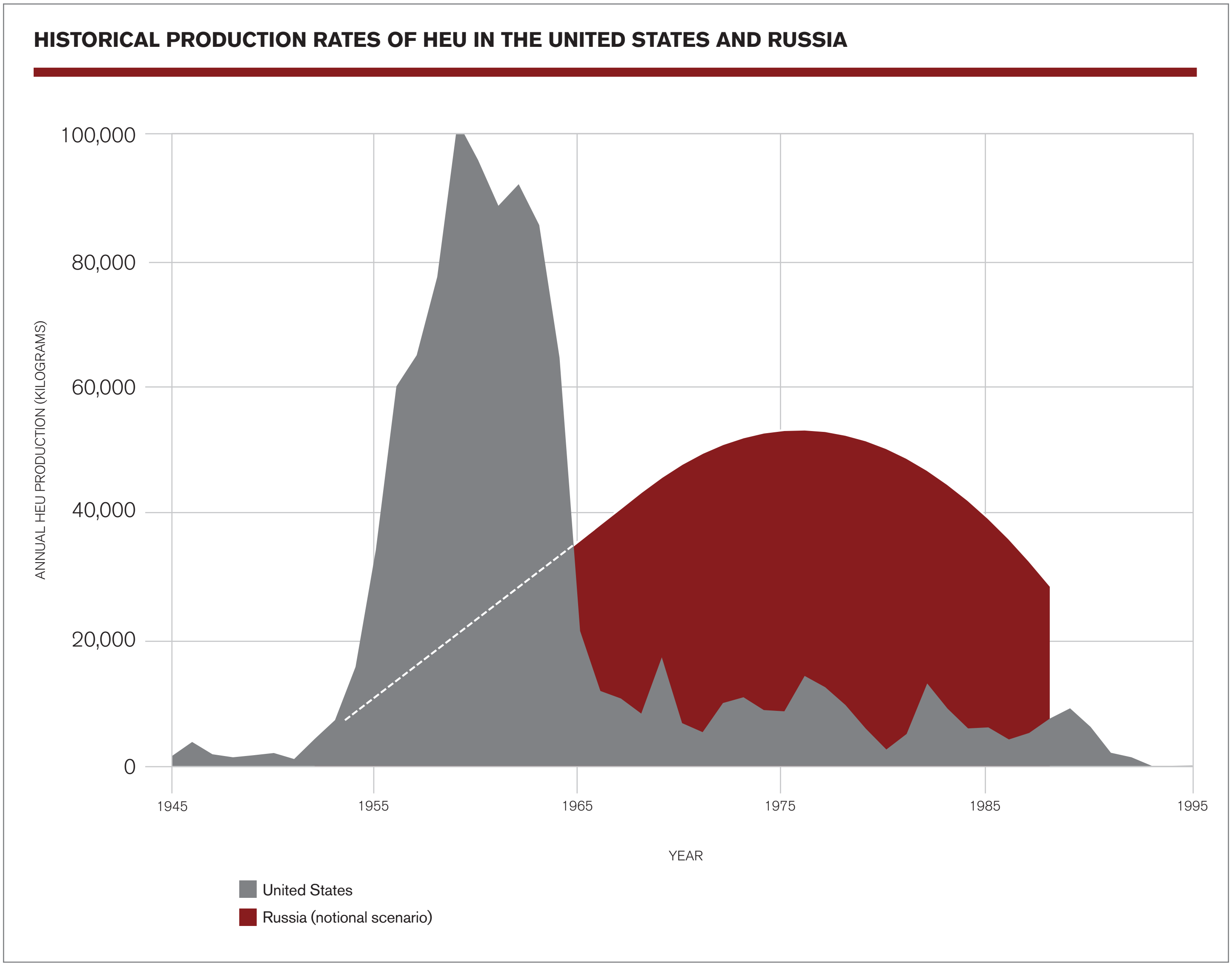
ESTIMATED NATIONAL STOCKS OF HEU AS OF MID-2008



the United States had downblended about 96 tons of HEU, but little if any of this material was weapon-grade.

Production of HEU for weapons. Pakistan may be the only country still producing HEU for weapons today. (India is producing HEU for naval fuel—but probably at less than weapon-grade levels of enrichment.) Pakistan is believed to have first achieved the capacity to produce significant quantities of HEU in the early 1980s and to have built up its enrichment capacity using P-2 centrifuges. More recently, Pakistan may have phased in more powerful P-3 and P-4 centrifuges, with estimated separative capacities two and four times that of the P-2, respectively. The country may be producing on the order of 100–200 kilograms of HEU per year.

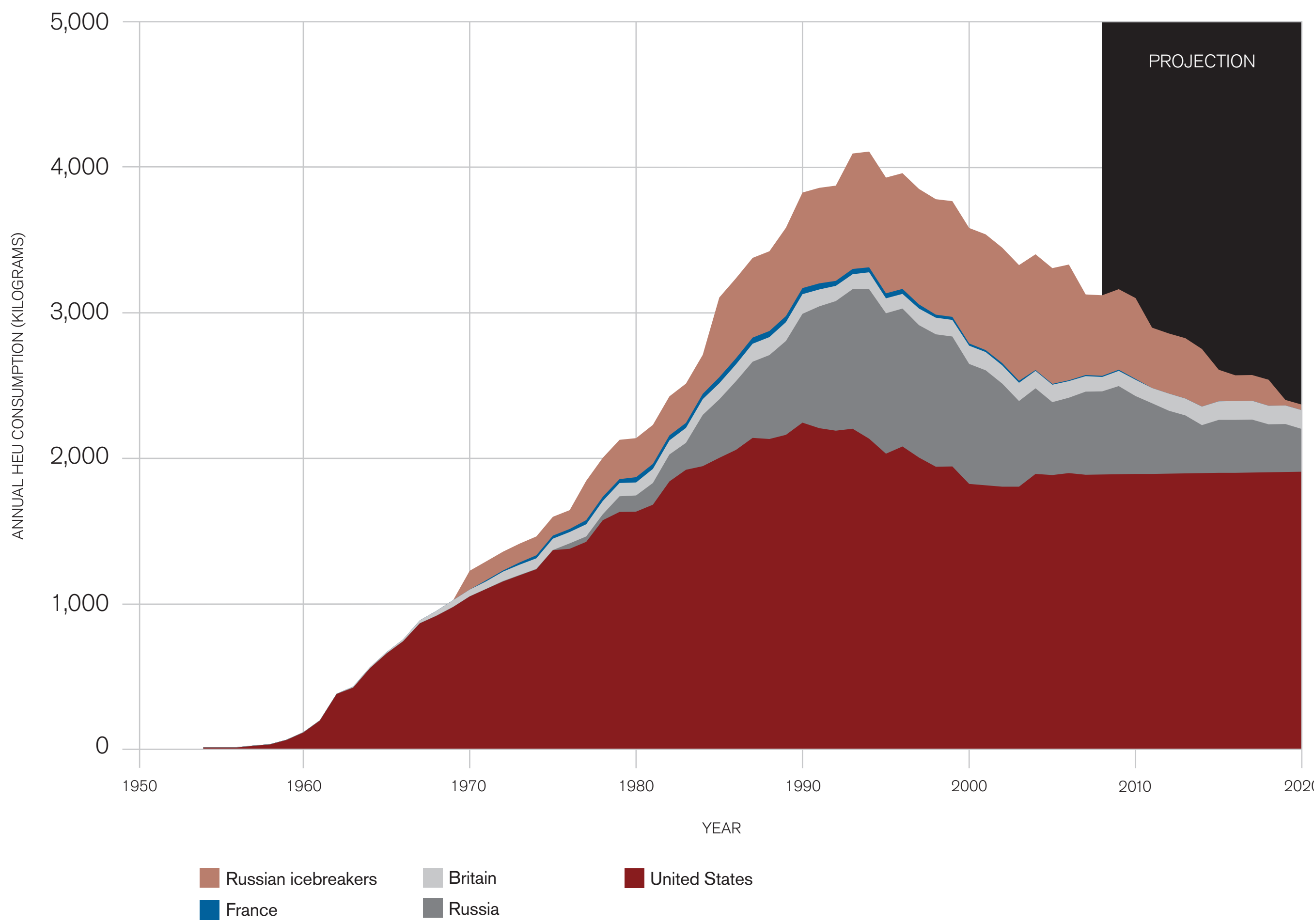
Over the long term, Pakistan's annual HEU production capacity will be constrained by the need to also fuel its plutonium production program from its limited domestic production of natural uranium (currently about 40 tons per year). Pakistan's Khushab plutonium production reactor requires about 13 tons of natural uranium as fuel per year. Two new production reactors are now



under construction at Khushab. When all three reactors are online, they will require virtually all of the natural uranium that Pakistan currently produces.

Israel is often assumed not to have produced HEU for nuclear weapons.[2] Recently, however, two former U.S. government officials highlighted that Israel may have covertly acquired about 100 kilograms of weapon-grade HEU from the United States. In October 2007, former congressional staffer Henry Myers wrote, "Senior officials in the U.S. government concluded in the late-1960s that weapon-size quantities of HEU had probably been diverted from [the Nuclear Materials and Equipment Corporation] to Israel."[3] Victor Gilinsky, a former U.S. Nuclear Regulatory Commissioner, has revealed that "the CIA believed that the nuclear explosives in Israel's first several bombs, about 100 kilograms of bomb-grade uranium in all, came from material that was missing at a U.S. naval nuclear fuel plant."[4] There have been several classified investigations into this case.

ESTIMATED ANNUAL HEU CONSUMPTION IN NAVAL VESSELS



Nuclear navies. France, Russia, Britain, and the United States use HEU to fuel submarine and ship propulsion reactors, and India is preparing to do so. France has almost completed a switch to low-enriched fuel for its nuclear navy. Information on China's naval fuel is very limited, but it is reportedly based on low- or nearly low-enriched uranium. Brazil is the only non-nuclear weapon state to be developing a nuclear submarine, and it is expected to use LEU fuel.

The United States is the world's largest user of HEU as naval fuel. Toward the end of the Cold War, the Soviet Union and the United States each used about 2 tons of HEU annually for this purpose (see chart, "Estimated annual HEU consumption in naval vessels," above).[5] Today, the United States still consumes 2 tons of weapon-grade HEU per year as naval fuel. Russia uses about 1 ton (not all weapon-grade) a year, with its nuclear-powered icebreaker fleet accounting for a significant fraction of this HEU consumption.

The United States appears to be committed to maintaining its reliance on nuclear propulsion for its aircraft carriers and submarines, and possibly expanding it to include nuclear-powered cruisers. We estimate that the 128 tons of HEU (sufficient for more than 5,000 nuclear weapons) that the United States has reserved for its nuclear navy could fuel its surface ships and submarines for 40–60 years. In 2008, the U.S. Senate instructed the navy to study the possibility of moving to LEU fuel for future ships.

India is not included in our naval-HEU consumption projections, but it has been producing HEU to fuel its planned nuclear-powered ballistic missile submarine, the Advanced Technology Vessel. Construction on the vessel is reported to be near completion, with plans to begin sea trials in early-2009. Reports suggest India intends to deploy three nuclear submarines, each with 12 nuclear-armed ballistic missiles, by 2015.

By the end of 2007, India would have needed to produce an estimated 400 kilograms of HEU (enriched perhaps to 45 percent uranium 235) to supply fuel for the land-based prototype naval reactor and the first submarine core. To have fuel ready in time for the additional planned submarines, India will require another 400 kilograms of HEU over the next 5–6 years. To reach this production rate, India will need to increase its uranium enrichment capacity.

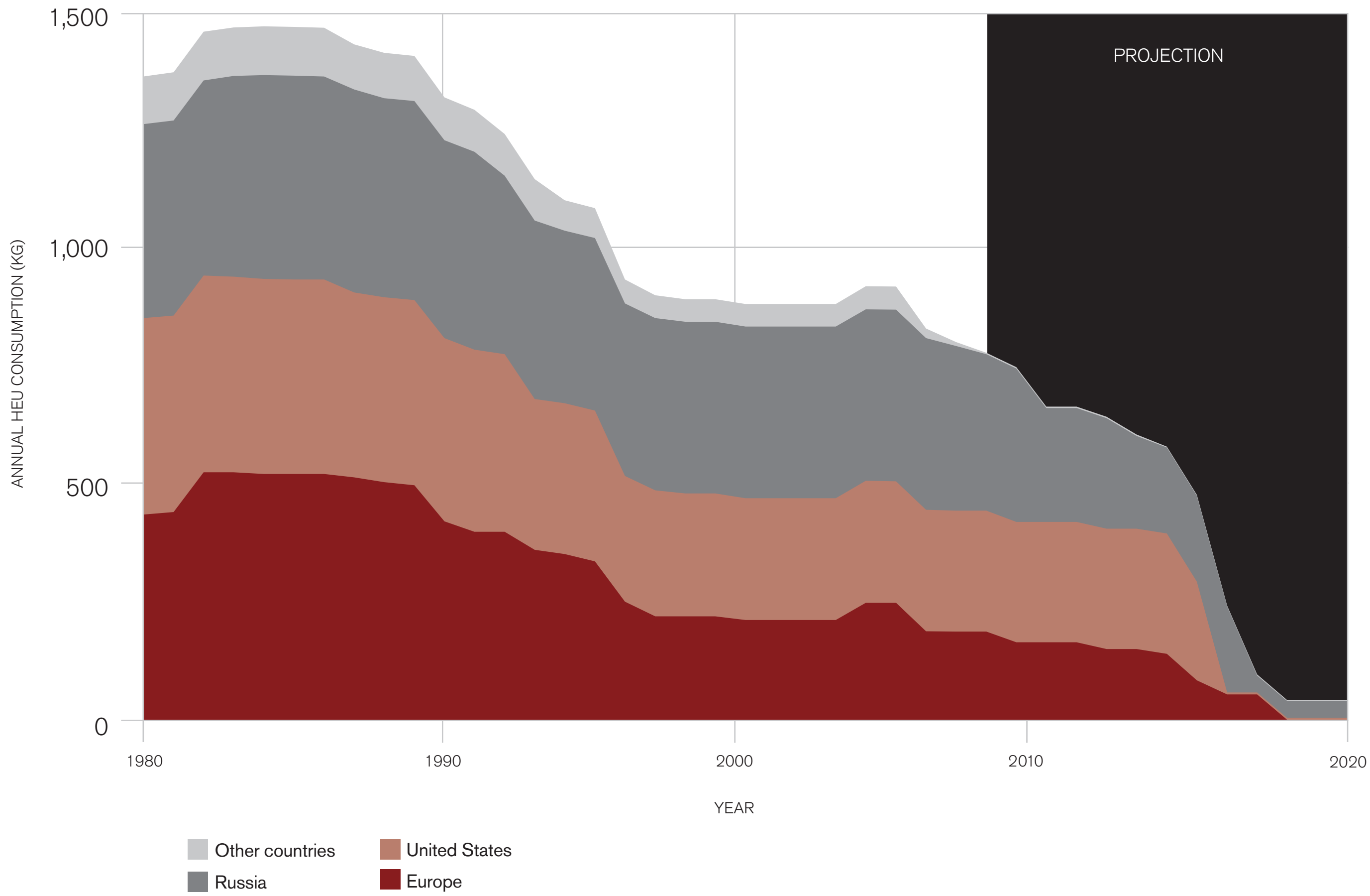
Civilian use and management of HEU. HEU is used today as a research-reactor fuel in about 130 civilian and military reactors worldwide. In addition, HEU remains at sites of many shut down, but not yet decommissioned reactors. These reactors are a legacy of competing U.S. and Soviet Atoms for Peace programs from the 1950s and 1960s. Taken together, the global inventory of fresh and irradiated HEU reactor fuel is very roughly 100 metric tons.

Since 1978, an international Reduced Enrichment for Research and Test Reactor (RERTR) program has sought to convert HEU-fueled civilian research reactors to low-enriched fuel. Almost all new reactors designed since that time use LEU fuel. By the end of 2007, the RERTR program had converted or partially converted 56 reactors.

The world's research reactors now consume about 800 kilograms of HEU per year—a significant reduction from the more than 1,400 kilograms that were needed annually in the early 1980s (see chart, "Estimated annual HEU use in research reactors, 1980–2000," p. 7).[6]

In 2004, the United States merged its reactor-conversion and spent HEU-fuel take back efforts into the Global Threat Reduction Initiative. If this program achieves its ambitious objectives, annual HEU demand could drop to very low levels by 2020. Critical assemblies and pulsed reactors with lifetime cores do not require regular refueling (and are therefore not shown in the respective chart)—but they can contain ton-level quantities of barely irradiated uranium and are not yet formally being targeted by any of these conversion and consolidation efforts.

ESTIMATED ANNUAL HEU USE IN RESEARCH REACTORS, 1980–2000



Separated plutonium. The global stockpile of separated plutonium is about 500 tons, and it is increasing. The stockpile is divided now almost equally between civilian and military stocks, with civilian stocks growing much faster than military ones. All the nuclear weapon states hold stocks of separated plutonium, but Japan and Germany also have significant amounts. (See chart, "National stocks of separated plutonium," p. 10.)

Russia and the United States possess by far the largest stocks of military plutonium, 120–170 tons and 92 tons, respectively. Russia has declared 34 tons, and potentially up to 50 tons, of its weapon-grade plutonium excess for weapon purposes. The United States has declared as excess 54 tons of separated government-owned plutonium. Despite the U.S.-Russian Plutonium Management and Disposition Agreement of 2000, which committed each country to the transparent and monitored disposition of 34 metric tons of weapon-grade plutonium, virtually none has so far been disposed of.

Plutonium production for weapons. India, Pakistan, and possibly Israel are believed to be currently producing plutonium for weapons. North Korea has recently ended its plutonium production.

India. India continues to produce weapons plutonium in its two production reactors, Cirus and Dhruva, at a combined rate of about 30 kilograms per year. It separates much more reactor-grade, but still weapons-usable, plutonium from the spent fuel of its unsafeguarded pressurized heavy water power reactors. It may have separated about 6.4 tons of this power-reactor plutonium as of 2008. This plutonium is intended to fuel the Prototype Fast Breeder Reactor (PFBR), expected to be completed in 2010. The PFBR would consume reactor-grade plutonium but, in doing so, could produce more than 140 kilograms a year of weapon-grade plutonium in the "blanket" of natural uranium surrounding the core.

India's annual domestic uranium production has been falling short of the combined demand from its growing number of nuclear power, naval-propulsion, and plutonium-production reactors. In September 2008, under U.S. pressure, the 45-nation Nuclear Suppliers Group, which manages international nuclear trade, exempted India from the normal requirement of full-scope IAEA safeguards as a condition of access to the international market for uranium and nuclear technology. This will allow India to import uranium to make up the shortfall in supply and expand its nuclear energy program by purchasing reactors, while expanding its production of fissile material for nuclear weapons.[7]

Pakistan. Pakistan continues to produce almost 12 kilograms of plutonium per year for weapons at its Khushab production reactor. Work appears to have started on two additional production reactors at this site in 2001 and 2005, respectively. Pakistan's first plutonium-production reactor took about a decade to build. If the second and third reactors take as long, then they may be expected to begin operating between 2011 and 2014. If these three production reactors each have the same capacity, Pakistan could produce almost 40 kilograms of uranium annually. A new reprocessing plant is reportedly being built as well.

Israel. Information about Israel's plutonium production is very limited. Based on information from former Israeli nuclear technician Mordecai Vanunu, Frank Barnaby (author of *The Invisible Bomb: The Nuclear Arms Race in the Middle East*) estimated that Israel had produced 400–800 kilograms of plutonium in its Dimona reactor by the mid-1980s. But such a high estimate is based on the assumption that the thermal power of the reactor had been increased from its initial 26 megawatts to 70 megawatts and later to 150–200 megawatts. If Dimona's power level never exceeded 70 megawatts, which is equivalent to a plutonium production rate of about 14–17 kilograms per year, Israel's inventory of separated plutonium would have been 280–340 kilograms by the mid-1980s. By now, the reactor could have produced 560–680 kilograms. Assuming an average of 4 kilograms of plutonium per warhead (typical for an advanced design), this inventory would be sufficient for a stockpile of about 150 weapons.

North Korea. In June 2008, North Korea submitted a 60-page declaration of information on its plutonium-production program backed up by 18,000 pages of documentation. This declaration has not been made public. Reportedly, North Korea declared a plutonium inventory of 30.8 kilograms, not including about 6 kilograms that might still be in the irradiated fuel from the Yongbyon reactor. The U.S. government and independent analysts had previously estimated North Korea's plutonium stock to be 30–50 kilograms.

Civilian plutonium. A number of countries are pursuing large-scale reprocessing and recovery of plutonium from power-reactor spent fuel in their civilian nuclear energy programs. This plutonium is usable for nuclear weapons.

Britain.[8] Britain began reprocessing in 1952 to separate plutonium for weapons. By the end of 2007, it also had separated a total of more than 100 tons of civilian plutonium from domestic and foreign spent fuel. This amount will increase to 133 tons if existing contracts are fulfilled, with commercial operations expected to end by 2020. These activities have left a large environmental and cleanup problem at the Sellafield site, with cleanup costs now estimated at about $92 billion.

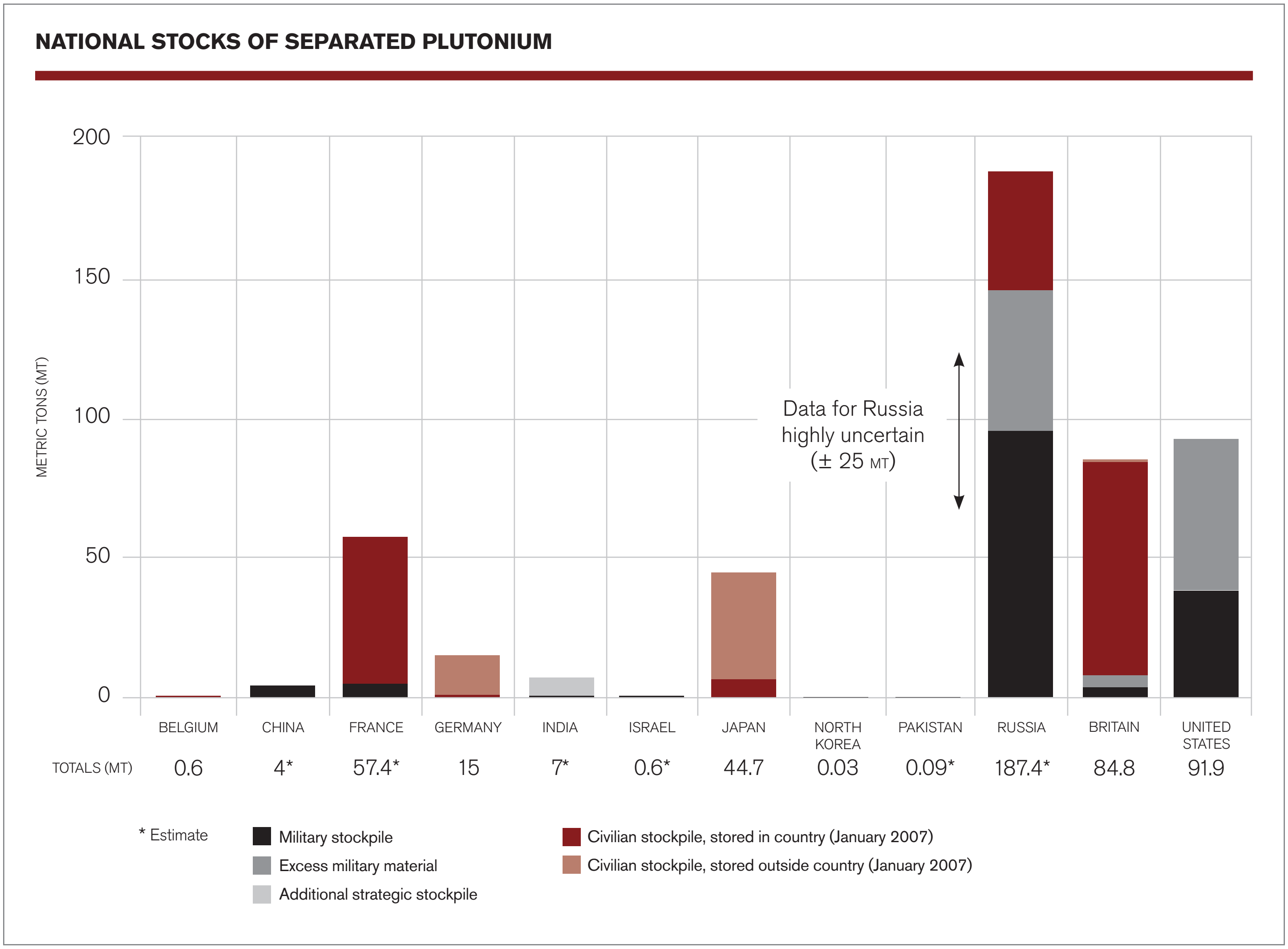
The plutonium from foreign spent fuel, or equivalent British plutonium, will be returned to foreign clients as mixed oxide (MOX) fuel. Britain has not yet determined a strategy for disposition of the approximately 100 tons of plutonium that it will have separated from its domestic spent fuel.

China. China is developing a civilian plutonium complex. Its long-delayed pilot reprocessing plant at the Yumenzhen site in Gansu Province, with a design capacity of 50 tons per year, is reported to have been completed and to be undergoing testing prior to start-up. China's National Nuclear Corporation has also agreed with the French company AREVA on feasibility studies for the construction of a large commercial reprocessing and MOX-fuel fabrication complex in the country.

France.[9] Reprocessing for weapons started in 1958 and ended in 1993. Since then it has been a civilian program, with both domestic and foreign customers. France has accumulated more than 80 tons of separated plutonium, 30 tons of which is foreign owned.

Almost all of the foreign spent fuel under contract has been reprocessed, and only minor new contracts have been signed. The economic burden of reprocessing is increasingly of concern to *Électricité de France*, the national electric utility. As in Britain, reprocessing has left a large environmental and cleanup legacy.

Germany. Germany abandoned its reprocessing program and sent spent nuclear fuel to be reprocessed in France and Britain, be-



fore deciding to phase out its use of nuclear energy altogether. It will have consumed all of its separated plutonium as MOX fuel by 2013.

Japan. Japan's Rokkasho reprocessing plant, which began active testing in 2006, continues to experience problems and delays. These tests were to be completed by February 2008 but were extended to July and then again to November. As a result of the tests, however, the facility had separated about 2.7 tons of plutonium by May, which is stored mixed with an equal amount of uranium. In the mid-term future, Japan will become a major contributor to the growth of the global plutonium stockpile, until it is able to recycle its stock into MOX fuel as rapidly as it separates it from spent fuel.[10]

Status of production facilities worldwide. Aging and no longer operating fissile material production facilities in the nuclear weapon states continue to be closed down and in some cases, dismantled.

Britain. The eight dual-purpose British Calder Hall and Chapelcross reactors were used for both electric-power production and sporadically for military plutonium production, which ended in 1989. The two groups of reactors were closed in 2003 and 2004, respectively, and their cooling towers were demolished in 2007.

France. France closed both the military reprocessing plant at Marcoule and its gaseous diffusion enrichment plant for production of HEU for weapons at Pierrelatte in 1996. The two plants had been in operation since 1958 and 1967, respectively. Decontamination and decommissioning of these facilities is expected to take several decades. In 2008, as a transparency measure, French President Nicolas Sarkozy invited international experts to observe the dismantlement of the military fissile material production facilities.[11]

North Korea. In October 2007, North Korea committed to end its nuclear weapons program; declare all of its nuclear activities; and disable its Yongbyon plutonium-production reactor and the associated fuel-fabrication and reprocessing plants by the end of 2007. The cooling tower of the Yongbyon reactor was demolished in June 2008.

Russia. In April and June 2008, Russia shut down its last two operating plutonium-production reactors at the Seversk/Tomsk-7 site. These reactors had been operating since 1965 and 1968, respectively, each producing about 0.5 tons of weapons plutonium per year as well as electricity and steam for local district heating. Russia's last remaining plutonium-production reactor, at the Zheleznogorsk/Krasnoyarsk-26 site, is expected to shut down in 2010 when a replacement coal-fired plant is completed.

The continuing effort to eliminate stockpiles. Even 20 years after the end of the Cold War, considerable uncertainty remains about total fissile material stocks. An uncertainty of plus or minus 325 tons is the equivalent of about 20,000 nuclear weapons. Only the United States and Britain have so far declared their fissile material holdings. This lack of transparency may become a serious obstacle to the reduction and elimination of nuclear weapons and fissile material stocks—objectives that have lately received renewed international attention.

The United States and Russia have declared a fraction of their stocks as excess to their weapons requirements, but they still hold the bulk of the world's stock of both HEU and plutonium. Even with arsenals of 5,000 weapons each, the two countries could declare even more material excess. If they were to reduce their total warheads to 1,000 on either side, their fissile material stocks would be reduced about tenfold from current levels.

Large stocks of fissile materials, sufficient for many thousands of nuclear weapons, are currently designated for civilian or naval reactor use, and kept outside international safeguards. These stocks too may hamper prospects for deeper cuts, to levels of a few hundred warheads each, in U.S. and Russian arsenals, and be an obstacle to bringing states with smaller nuclear arsenals into the disarmament process.

The reduction and elimination of current fissile material stocks will also need an accompanying verifiable worldwide ban on the production of fissile materials for weapons.[12] Many military fissile material production facilities have been shut down and some have been dismantled, others have been converted to civilian use. But new civilian uranium enrichment and plutonium separation facilities are being built in several states. The enrichment of uranium and the separation and use of plutonium, even under safeguarded civilian nuclear energy programs, provide states with a virtual nuclear weapons capacity and pose a major challenge for efforts to control fissile materials and for nuclear disarmament. ■

Alexander Glaser and Zia Mian are with the Program on Science and Global Security at Princeton University, which provides administrative and research support for the International Panel on Fissile Materials (IPFM). IPFM is an independent group of scientists and analysts from 17 countries. Its mission is to analyze the technical basis for practical and achievable policy initiatives to secure, consolidate, and reduce stockpiles of highly enriched uranium and plutonium.

NOTES

1. International Panel on Fissile Material (IPFM), "Global Fissile Material Report 2008," September 2008, www.ipfmlibrary.org/gfmr08.pdf. Some of the stockpile estimates have been derived from previous estimates published in: David Albright, Frans Berkhout, and William Walker, "Plutonium and Highly Enriched Uranium 1996," Stockholm International Peace Research Institute, Oxford University Press, 1997.

2. According to Mordecai Vanunu, Israel may have produced enriched uranium in limited quantities starting in 1979–1980, but information on this program is very limited. Frank Barnaby, *The Invisible Bomb: The Nuclear Arms Race in the Middle East*, (London: I. B. Tauris, 1989), p. 40.

3. Henry Myers, "The Real Source of Israel's First Fissile Material," *Arms Control Today*, October 2007, p. 56. Myers was on the staff of the House of Representatives Interior Committee that had the responsibility for overseeing the Nuclear Regulatory Commission when it investigated the Nuclear Materials and Equipment Corporation (NUMEC) matter in the late-1970s.

4. Victor Gilinsky, "Israel's Bomb," *New York Review of Books*, vol. 51, no. 8, May 13, 2004. From the same author, see also "Time For More NUMEC Information," *Arms Control Today*, June 2008.

5. Ole Reistad and Styrkaar Hustveit, "HEU Fuel Cycle Inventories and Progress on Global Minimization," *Nonproliferation Review*, vol. 15, no. 2, July 2008.

6. Ibid.

7. Zia Mian, A. H. Nayyar, and R. Rajaraman, "Fissile Materials in South Asia and the Implications of the U.S.-India Nuclear Deal," IPFM Research Report No. 1, September 2006, www.ipfmlibrary.org/rr01.pdf.

8. The history and legacy of Britain's reprocessing program is reviewed in a recent IPFM research report: Martin Forwood, "The Legacy of Reprocessing in the United Kingdom," IPFM Research Report No. 5, July 2008, www.ipfmlibrary.org/rr05.pdf.

9. The experience of France's reprocessing program is summarized in: Mycle Schneider and Yves Marignac, "Spent Nuclear Fuel Reprocessing in France," IPFM Research Report No. 4, May 2008, www.ipfmlibrary.org/rr04.pdf.

10. Data from INFCIRC/549 declarations to the International Atomic Energy Agency. Projection for Germany from: M. Weis et al., *atw*, vol. 51, no. 12, 2006, pp. 793–796. Projection for Japan from: Tadahiro Katsuta and Tatsujiro Suzuki, "Japan's Spent Fuel and Plutonium Management Challenges," IPFM Research Report No. 2, September 2006, www.ipfmlibrary.org/rr02.pdf.

11. Speech by French President Nicolas Sarkozy, Presentation of *Le Terrible* in Cherbourg, France, March 21, 2008, www.ipfmlibrary.org/sar08.pdf.

12. In the *Global Fissile Material Report 2008*, the IPFM has proposed key elements for a verifiable Fissile Material Cutoff Treaty and provided technical arguments for how such a treaty could be verified by the IAEA. A companion volume, "Banning the Production of Fissile Materials for Nuclear Weapons: Country Perspectives on the Challenges to a Fissile Material (Cutoff) Treaty," provides a country-by-country analysis of the concerns of key states to different aspects of a prospective Fissile Material Cutoff Treaty and proposes specific policy initiatives and compromises that states could make to break the logjam preventing negotiation on a treaty.

Alexander Glaser & Zia Mian, "Fissile material stocks and production, 2008," *Bulletin of the Atomic Scientists*, January/February 2009, vol. 65, no. 1, pp. 35-47.

DOI: 10.2968/065001005