Civil HEU Watch

Tracking Inventories of Civil Highly Enriched Uranium[1]

National and Global Stocks, as of End 2014[2]

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Highly enriched uranium (HEU) is a key ingredient in nuclear weapons, making it one of the most dangerous materials in existence. As a result, governments take extraordinary measures to secure HEU against theft or diversion and to reduce the inventories of HEU in the world.

To that end, it is important to track how much civil HEU exists and where it is. However, national civil HEU stocks are difficult to estimate, with transparency policies varying by country and few countries providing official declarations of their stocks. As a result, this report contains the few official civil HEU declarations and estimates civil HEU stocks in countries that do not provide public declarations. This study relies on open source information to derive these estimates. It is an update of a report published in 2005.

Table 1 shows that 132-137 tonnes of HEU were in civil stocks as of the end of 2014, with a central estimate of 134 tonnes. At that time, 29 countries had HEU stocks with about one kilogram or more of HEU, the standard measure of a country being HEU free. As of October 2015, this number had dropped to 26 countries, as three more countries had become HEU free in the meantime. In practice, becoming HEU free entails countries sending their HEU to the United States or Russia, blending it down to low enriched uranium, or selling it to other HEU users.

Although the five acknowledged nuclear weapon states possess most of the world's civil HEU, many non-nuclear weapon states also possess HEU inventories. Starting in the 1950s, many countries bought research and test reactors to pursue peaceful nuclear activities, and many of these reactors were fueled with HEU. At the peak of HEU use, almost 60 countries used HEU fuels and tonnes of HEU were in international commerce. Since the late 1970s, the United States and other countries have worked to convert these reactors from HEU to low enriched uranium

[1] This report is part of a series on national and global stocks of nuclear explosive materials in both civil and military nuclear programs. This work was generously funded by a grant from the Nuclear Threat Initiative (NTI). This work builds on earlier work done at ISIS by one of the authors.
[2] With updates of countries reaching zero stocks by October 2015.

(LEU) fuels and discouraged the construction of new reactors that require HEU fuel. Both the United States and Russia also launched "take-back" programs to retrieve HEU they provided to these countries for use in their nuclear programs. A sign of the success of these programs is that the number of countries possessing HEU has more than halved.

The number of countries with a kilogram or more of HEU is expected to decrease further as Russia is set to take back more of the HEU that it provided to other countries and to reprocess and blend down the recovered HEU. The United States also will continue seeking to repatriate U.S.-origin HEU and accept additional priority stocks during the next several years.

HEU production for civil purposes largely stopped years ago. However, Russia decided to resume producing HEU for a Chinese fast reactor that reached criticality in 2010. Russia is known to have produced about 240 kg of HEU, enriched to 64 percent in the isotope uranium 235, for this reactor (see endnote (f)). Instead of producing more HEU, the United States maintains a reserve of HEU that can be sold to foreign and domestic civil research reactors if needed, such as for making molybdenum 99 (Mo 99 or "Moly 99") for medical purposes. Russia is believed to also maintain an HEU reserve for civil purposes, although it decided not to use this reserve stock to provide HEU to the new Chinese reactor.

HEU Holdings by Country, end of 2014

Table 2 lists the eleven largest stocks of HEU in NNWS, several of which are priorities of U.S. and Russian take-back programs. Table 3 shows civil HEU holdings in all countries at the end of 2014.

Non-Nuclear Weapon States (NNWS)

The largest stock of HEU in a NNWS is in Kazakhstan, which has slightly over 10 tonnes of HEU. However, 10 tonnes of this stock is enriched to only 26 percent and is contained in spent fuel from a shutdown fast reactor. This HEU is located in a long-term, secure storage site. Kazakhstan's other HEU is a target of the United States and Russia for removal.

Canada has a large stock of HEU used in reactor fuel and to make medical isotopes. Much of this stock will be sent to the United States for storage or blending down to low enriched uranium.

South Africa's HEU was produced in its defunct nuclear weapons program and subsequently all was allocated to peaceful uses. Much of this stock is expected to be sent to the United States, although shipments have been delayed.

Belarus has an estimated 280 kg of HEU of various enrichments between 21 and 90 percent. Tensions with the government of Belarus have delayed the removal of this HEU.

Belgium and Netherlands have research reactors that use HEU. In the case of the Netherlands, HEU spent fuel is being stored pending geological disposal. Belgium has signed contracts with a French reprocessing company to chemically separate the HEU from spent fuel and blend it down to low enriched uranium. Both countries also use HEU to make medical isotopes and store the HEU waste.

Germany and Japan have large HEU inventories resulting from substantial nuclear programs involving several research reactors and critical facilities. Japan will send to the United States several hundred kilograms of unirradiated weapon-grade uranium from a critical facility. The ultimate fate of the German HEU is currently unknown.

Italy's stock of HEU will likely be disposed as nuclear waste in Italy.

Poland's last batch of fuel assemblies containing HEU enriched to 36 percent is scheduled to be sent to Russia in 2016.

North Korea's stock of civil HEU is in spent fuel discharged from a Soviet-supplied research reactor. Efforts to remove this stock to Russia have stalled.

Nuclear Weapon States

By far the largest stock of civil HEU is in the United States. Virtually all of this stock was originally dedicated to nuclear weapons and other military purposes. After the end of the Cold War, it was declared excess to defense requirements and dedicated to civil purposes. Once transferred, most of these stocks have been slated for downblending into low enriched uranium to fuel civil reactors; others are to be disposed permanently. For example, through early 2015, out of a total declared excess stock of about 239 tonnes of HEU, the United States has downblended about 146 tonnes of this HEU to low enriched uranium, leaving a stock of about 93 tonnes (see endnote (b)).

Russia also has a large stock of civil HEU but this material is in civil research and power reactor programs. Russia provides little information about its HEU stocks, and the estimate of 15-20 tonnes is highly uncertain. In early 1990s, Russia declared 500 tonnes of HEU excess to defense requirements and in twenty year partnership with the United States downblended it into LEU for sale to nuclear power reactors.

Britain and France (and Germany) officially declare their stocks of civil HEU each year.[3] Their declarations are a model for all countries and contain information on both irradiated and unirradiated HEU stored at enrichment plants, fuel fabrication or processing plants, and reactor and other sites, such as laboratories or research centers.

[3] See "Annual Holdings of Civil Plutonium from INFCIRC/549 Declarations," ISIS Report, (to be published).

Table 1. Civil HEU (initial mass) in NWS and NNWS, end 2014		
	HEU(tonnes)	**HEU(kg)**
Nuclear Weapon States (NWS)	115.051-120.051	115,051-120,051
Non-Nuclear Weapon States (NNWS)	16.513-16.775	16,513-16,775
TOTAL HEU	**131.564-136.807**	**131,564-136,807**

Table 2. Largest Civil HEU Stocks in NNWS, end 2014		
Country	**HEU(tonnes)**	**HEU(kg)**
Belarus	0.280	280
Belgium	0.555-0.605	555-605
Canada	1.035	1,035
Germany	1.260	1,260
Italy	0.115-0.130	115-130
Japan	1.8	1,800
Kazakhstan*	0.043-0.058	43-58
Netherlands	0.55-0.65	550-650
North Korea	0.042	42
Poland	0.060	60
South Africa	0.7-0.75	700-750
TOTAL HEU	**6.44-6.67**	**6,440-6,670**

***** This table only accounts for Kazakhstan's HEU used for R&D purposes; this value excludes ten tonnes of HEU in spent fuel from its breeder reactor.

Table 3. Civil HEU (initial mass) per country, end 2014		
Country	**HEU(tonnes) end of 2014, initial mass[a]**	
Nuclear Weapon States (NWS)		
United States	93[b]	
Russia	15-20[c]	
Britain	1.398[d]	
France	4.653[e]	
China	1[f]	
Subtotal	**115.051-120.051 tonnes (115,051-120,051 kg)**	
Non-Nuclear Weapon States (NNWS) that received US-origin HEU		
Argentina	0.002-0.006[g]	
Australia	0.002[h]	
Belgium	0.555-0.605[i]	
Canada	1.035[j]	
Germany	1.26[k]	
Indonesia	0.003[l]	
Iran	0.006[m]	
Israel	0.022[n]	
Italy	0.115-0.130[o]	
Jamaica	0.0008[p] (All removed in 2015)	
Japan	1.8[q]	
Netherlands	0.55-0.65[r]	
Norway	0.004[s]	
Pakistan	0.016[t]	
South Africa	0.7-0.75[u]	
Switzerland	0.002-0.010[v] (All removed in 2015)	
Others	0.0004-0.001[w]	
	Countries that received US-origin HEU that reached "Zero" HEU through DOE's GTRI Program[x]	Austria, Brazil, Chile, Colombia, Denmark, Greece, Mexico, Philippines, Portugal, Rep. of Korea, Romania, Slovenia, Spain, Sweden, Taiwan, Thailand, Turkey (and Iraq)[y]
Subtotal	**6.073-6.300 tonnes (6,073-6,300 kg)**	
Non-Nuclear Weapon States (NNWS) that received Russian-origin HEU		
Belarus	0.280[z]	
China[aa]		
DPRK	0.042[bb]	
Germany[cc]		
India	0.005[dd]	
Kazakhstan	10 (BN-350) + (0.043-0.058) (R&D)[ee]	
Poland	0.0604[ff]	
Uzbekistan	0.005[gg] (All removed in 2015)	

	Countries that received Russian-origin HEU that reached "Zero" HEU	Bulgaria, Czech Republic, Georgia, Hungary, Iraq, Latvia, Libya, Romania, Serbia, Ukraine, Vietnam[hh]
Subtotal	**10.435-10.450 tonnes (10,435-10,450 kg)**	
Countries with Chinese Supplied Research Reactors		
Ghana	0.001[ii]	
Syria	0.001[jj]	
Iran	0.001	
Nigeria	0.001[kk]	
Pakistan	0.001	
Subtotal	**0.005 tonnes (5 kg)**	

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[a] The values in this table are derived from open sources, including official declarations, country- and facility-specific information, interviews with knowledgeable officials and experts, public documents, and public records of U.S. and Russian HEU exports, retransfers, and returns. The highly enriched uranium (HEU) inventories in France, the United Kingdom, and Germany are official declarations of the actual masses of the HEU provided to the International Atomic Energy Agency (IAEA). Except where specifically noted, the inventories of the other countries are given in terms of the initial mass of the HEU, defined as the mass of HEU before it was inserted into a reactor and irradiated, a process which reduces the amount of contained uranium 235. This convention is adapted to permit comparisons and be consistent with other available estimates.

[b] As of early 2015, the United States had slated about 239 tonnes of HEU excess to defense requirements for downblending and use in civilian reactors or for disposal. See Robert M. George, "U.S. Disposition Program," Office of Fissile Material Disposition, INMM Annual Meeting Presentation, July 2009 and email to David Albright from the Department of Energy (DOE), April 9, 2015. According to the DOE, as of early 2015, about 146 tonnes of this HEU had been downblended into LEU. See email to David Albright from DOE April 9, 2015. That leaves 93 tonnes of excess HEU. The United States has accepted foreign HEU of U.S.-origin. This quantity of HEU was included in the 1994 and 2005 HEU declared inventories and should be included in the figure of 239 tonnes declared as excess. In any case, it a relatively small quantity. Similarly, the same is true for HEU from U.S. Nuclear Regulatory Commission (NRC)-licensed research reactors. Spent fuel from DOE research reactors should be included in the above numbers.

[c] The value for Russia is highly uncertain. See *Global Fissile Material Report 2010*, Fifth Annual Report of the International Panel on Fissile Materials, 2010, http://fissilematerials.org/library/gfmr10.pdf, and David Albright and Kimberly Kramer, *Civil HEU Watch: Tracking Inventories of Civil Highly Enriched Uranium*, February 2005, Revised August 2005, http://isis-online.org/uploads/isis-reports/documents/civil_heu_watch2005.pdf.

[d] *Communication Received from the United Kingdom of Great Britain and Northern Ireland Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.8/18, October 8, 2015.

[e] *Communication Received from France Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.5/19, August 28, 2015.

[f] China is believed to possess about 1 ton of HEU dedicated to civil purposes. See Albright and Kramer (op. cit). A small amount of this HEU, about 240 kg, is Russian-origin. Russia supplied the HEU in order to fuel China's Experimental Fast Reactor (CEFR). This reactor reached criticality in 2010 and used HEU enriched at 64.4 percent. See Hui Zhang, "Approaches to Strengthening China's Nuclear Security," Project on Managing the Atom, Harvard University, p. 2, http://belfercenter.ksg.harvard.edu/files/ChinaNuclearSecurity-hzhang.pdf. As of early 2014, it does not appear that China reprocessed and recycled spent research reactor fuel.

[g] Of the total amount of HEU sent to Argentina, only about 2-6 kg remain today. Since 2001, Argentina repatriated about 50 kg of HEU and down blended the remaining 1.4 kg of fresh HEU. Additionally, the RA-6 reactor was converted to LEU in 2008. See "The Four-Year Effort and the Global Threat Reduction Initiative," U.S. Department of Energy, NNSA, December 2013, http://nnsa.energy.gov/sites/default/files/nnsa/12-13-inlinefiles/2013-12-12%204%20Year%20Effort.pdf; "NNSA Cooperates With Argentina, South Africa and Ukraine To Convert Research Reactors," NNSA Press Release, October 13, 2008, http://nnsa.energy.gov/mediaroom/pressreleases/nnsa-cooperates-argentina-south-africa-and-ukraine-convert-research-reactors; and "U.S.-Origin Nuclear Fuel Safely Returned from Argentina," NNSA Press Release, July 19, 2006, http://nnsa.energy.gov/mediaroom/pressreleases/u.s.-origin-nuclear-fuel-safely-returned-argentina, and "DOE Made Progress to Secure Vulnerable Nuclear Materials Worldwide, but Opportunities Exist to Improve Its Efforts," GAO Report to Congressional Requesters, September 2015, http://www.gao.gov/assets/680/672703.pdf#page21.

[h] Less than 2 kg of HEU remain in Australia. This number was confirmed via private communications with knowledgeable officials dated December 21, 2014. All strictly U.S.-origin HEU has been removed from Australia. See "Final U.S.-Origin HEU Shipment from Australia Completed," *NNSA Press Release*, May 21 2009, http://www.nnsa.energy.gov/mediaroom/pressreleases/05.21.09.

[i] As of December 2014, about 550-600 kg of HEU remained in Belgium. This estimate, however, does not include some recent returns (see below). This estimate is based on a wide variety of information collected by ISIS regarding Belgium's imports, repatriations, reprocessing and downblending of HEU. As of December 2003, ISIS estimated that Belgium had between 700 kg and 750 kg of HEU. Since then, Belgium has received about 424 kg of HEU for the refueling of the BR-2 reactor and target material. Belgium had also sent an estimated 425 kg of HEU to France to be reprocessed and the recovered HEU blended down into low enriched uranium (LEU). Given that these reprocessing activities were scheduled to start in 2005, this estimate assumes that this amount of HEU has been reprocessed and the recovered HEU down blended. Additionally, in March 2014 Belgium announced the successful removal of all excess fresh HEU and plutonium at the 2014 Nuclear Security Summit. This fuel was returned because

it could not be used for fuel or targets. See "Belgium Highly Enriched Uranium and Plutonium Removals," White House Fact Sheet, March 24, 2014, http://www.whitehouse.gov/the-press-office/2014/03/24/fact-sheet-belgium-highly-enriched-uranium-and-plutonium-removals. The amount of HEU in these returns could not be determined. It is worth noting that in December 2014 the NRC received a request for a new license to export 132 kg of HEU as reload fuel for the BR-2 reactor in Belgium. As of early 2015, the NRC had not approved this license. This amount of HEU in this pending license is not reflected in the above estimate because the license has not been approved and thus no shipments have taken place by the end of 2014. While the BR-2 reactor is not expected to convert to LEU fuel until 2026, it will start using LEU instead of HEU in targets to make molybdenum 99 in 2015.

[j] Canada treats information about its HEU stock as sensitive and was only willing to state in discussions with the authors that its HEU inventory was less than 1,500 kilograms. Author inquiries to Canadian officials about whether they could state that the inventory is less than 1,000 kilograms were declined. This estimate assesses Canada's inventory from public information which includes U.S. export licenses for HEU, returns of HEU to the United States, and official statements. It leads to an estimate that as of the end of December 2014, about 1.035 tonnes of HEU remained in Canada. Because this estimate rests on export authorizations, it is possible that Canada did not import the total amount of HEU authorized for export. As a result, to help determine the feasibility of this estimate, below is also an accounting of the fate of the known imported HEU.

With regard to deriving an estimate of 1,035 kg at the end of 2014, the starting point is the 1993 NRC value for the amount of HEU Canada had been authorized to import, export, and return to the United States, or a net of 1,184 kg of HEU. The actual exports are rarely provided, but this estimate assumes that the amount approved was exported. See *The United States Nuclear Regulatory Commission's Report to Congress on the Disposition of Highly Enriched Uranium Previously Exported from the United States*, January 1993, http://pbadupws.nrc.gov/docs/ML0924/ML092430345.pdf. Since then, the United States exported 167 kg between 1994 and 2003 and 123.5 kg between 2004 and 2014, for a total of 290.5 kilograms. Since 1996, Canada has retuned 249 kg of HEU in spent fuel, 1.6 kg contained in two slowpoke cores, and 189 kg of fresh HEU through the Global Threat Reduction Initiative (GTRI) program. According to a 2013 NNSA publication, the 189 kg of fresh HEU were scheduled to be shipped back to the U.S. by early 2014. Therefore, this estimate assumes that, as of the end of 2014, all 189 kg of fresh HEU have been returned. See "The Four Year Effort," NNSA Publication on GTRI Contributions as of December 2013, http://nnsa.energy.gov/sites/default/files/nnsa/12-13-inlinefiles/2013-12-12%204%20Year%20Effort.pdf; David B. Rose, Used Nuclear Fuel Management at Savannah River Site (SRS), http://www.inmm.org/AM/Template.cfm?Section=29th_Spent_Fuel_Seminar&Template=/CM/ContentDisplay.cfm&ContentID=4375. It is important to note that about 45 kg of this fresh HEU was originally sent to the Maple Reactor for use in targets while the reactor was under construction but the reactor project was cancelled before it was finished (private communication with Alan Kuperman, January 23, 2015).

At the 2014 Nuclear Security Summit, Canada restated its commitment to return U.S.-origin HEU in spent fuel by the end of 2018. It also has committed to return the HEU left over from Mo-99 production that is contained in about 23,000 liters of liquid high-level waste in the Fissile Solution Storage Tank (FISST) at Chalk River Laboratories (CRL). See Tom Clements, "Re: May 29 Federal Register Notice for Application for a License to Export High-Enriched Uranium to Canada, by National Nuclear Security Administration," SRS Watch, June 9, 2014, http://pbadupws.nrc.gov/docs/ML1416/ML14161A697.pdf. See also "Canadian Liquid Highly Enriched Uranium Return," U.S. Department of Energy Presentation, April 10, 2014, http://www.energy.sc.gov/files/gnac/GNACPresAECLLiquid.pdf. No shipments of this HEU had occurred by the end of 2014. Shipments are expected to begin in 2015 or 2016. See "NAC-LWT Package Design for Transport and Highly Enriched Uranyl Nitrate Liquid," Canadian Nuclear Safety Commission, December 2014, http://www.nuclearsafety.gc.ca/eng/pdfs/chalk-river/HEU-Technical-Assessment-and-Environmental-Report_ENG.pdf

In May 2013, the DOE prioritized about 750 kg of HEU in Canada for return to the United States, according to a knowledgeable source. This amount did not represent all the HEU in Canada at that time. Our understanding is that it represented research reactor spent fuel and much of the HEU waste from moly 99 production eligible for return.

To understand better Canada's inventory of HEU, the following is an assessment of the public information about the use and fate of the remaining Canadian HEU. Canada's main reason for importing HEU was to fuel research reactors and "boost" the reactivity of certain power reactors. Although both of these needs ended long ago, Canada has increased its use of HEU to make molybdenum 99, a key medical isotope.

As of 1996, Argonne National Laboratory data show that 625 kg of HEU (initial mass) remained in spent Canadian research reactor fuel or in the core of the reactors. By 1996, Canada had stopped using HEU fuel; thus, this amount of HEU in irradiated fuel did not increase afterwards. With the return of an estimated 249 kg HEU in spent fuel and 1.6 kg of HEU in Slowpoke cores through 2014, the amount of HEU in spent fuel amounts to 374.4 kg of HEU. Earlier, the Bruce CANDU reactor imported about 160 kg of HEU as "booster" rods; it is likely that these rods remain in Canada since they do not qualify for return to the United States.

Canada has also accumulated a considerable amount of HEU in waste generated during medical isotope production, essentially all moly-99 production. After irradiation, targets are dissolved and the desirable isotopes removed, leaving HEU and other highly radioactive fission products as high-level nuclear waste. In total, the amount of HEU in target material is relatively large. One indication of its size is a 1996 projection by the U.S. DOE in an Environmental Impact Statement which stated that Canada would have 525 kg of HEU in target waste material by 2006. See *Final Environmental Impact Statement on Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel*, February 1996, volume 1, DOE/EI-0218F, p 4-72. Of this total projected amount, DOE considered accepting less than 40 percent of this HEU target material, and this HEU had to be in solid form. The rest was evidently in liquid form. Thus, according to the DOE, Canada was projected to have a total stock of about 525 kg by 2006, of which less than about 210 kg was considered for shipment to the United States. At the time, although the DOE considered accepting this HEU, it decided not to do so. Thus, at that time over 300 kg of the HEU was projected to be in liquid form. The United States changed its regulations later and now accepts HEU liquid waste from Canada, as discussed above, but it is unclear if the United States will accept solid moly-99 HEU waste.

There are three periods of interest to this study of HEU used in moly 99 production: up to 1986, from 1986-2003 (when the HEU liquid was stored in FISST), and after 2003 to the end of 2014 (when liquid HEU waste was solidified).

Prior to 1986, Canada used HEU to make moly-99 but we found few records or documents of the amounts of HEU involved. This amount is not believed to have been returned to the United States but its fate and quantity is unknown.

In the period from 1986 to 2003, the liquid HEU waste was stored in FISST. The tank became full in 2003, ending its use to store more liquid HEU. The amount of HEU in FISST is not public. One public estimate, citing the *Ottawa Citizen*, is that the tank contains an estimated 175 kg of HEU, although the methodology of the calculation is not provided. See Global Security Newswire, produced by National Journal, "Concerns Linger Over Canadian HEU Waste," Dec. 20, 2011. Another estimate is based on Canada's HEU export authorizations from 1996 to 2003, which totaled 167 kg and were only for target irradiation. Subtracting out the amount slated for the planned Maple reactors, leaves about 120 kg for NRU irradiation, or about 13.6 kg per year. Extrapolating this annual estimate to the period 1986 to 2003, gives an upper bound estimate of 230 kg. We use the range of 175-230 kg of HEU in FISST.

Since 2003, according to the Canadian Nuclear Safety Commission (CNSC), no HEU liquid waste has been produced at CRL; the process was changed so that liquid HEU has been solidified and stored onsite at Chalk River. See *Consultation Report, Technical Assessment Report: NAC-LWT Package Design for Transport of Highly Enriched Uranyl Nitrate Liquid*, undated. http://www.nuclearsafety.gc.ca/eng/pdfs/chalk-river/NAC-LWT-HEUNL-Technical-Assessment-Consultation-Report-bil.pdf. From 2003 to the end of 2014, U.S. authorities approved the export of a total of about 120 kilograms of HEU to Canada for use in NRU targets. This value can represent roughly the amount of HEU in solid waste, which to the best of our knowledge is not yet slated for return to the United States.

The table summarizes our findings. The results do not account for all of the estimated HEU in Canada, namely 1035 kg, but about 80-86 percent of it.

Estimated HEU Inventories in Canada, as of end 2014			
Type or Form		**HEU (kg)**	**Return to USA**
Spent Fuel	Research Reactors	374	Yes
	Bruce booster rods	160	No
	Other Research Reactors	-	
Targets	Pre-1986	-	
	FISST	175-230	Yes
	Post-2003	120	No
Other Forms		-	
HEU Total (partial)		829-884	

[k] *Communication Received from Germany Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.2/18, August 28, 2015. Germany has received HEU from the United States and Russia.

[l] "DOE Made Progress to Secure Vulnerable Nuclear Materials Worldwide, but Opportunities Exist to Improve its Efforts," United States Government Accountability Office, September 2015, http://www.gao.gov/assets/680/672703.pdf#page21.

[m] Iran received 6 kg of U.S.-origin HEU (see NRC Report to Congress, 1993). None of this HEU has been returned as of December 2014. It is stored at the Tehran Research Reactor

(TRR). In recent years, Iran has further irradiated some of this fuel in the TRR as part of a research project, although this fuel was fully irradiated years ago.

[n] Israel received a shipment of 34 kg of HEU from the United States (see NRC Report to Congress, 1993). Since 2002, Israel has returned about 12 kg of this HEU, leaving 22 kg in Israel.

[o] By 1993 the United States had sent Italy 315 kg of U.S.-origin HEU (see NRC Report to Congress, 1993). In 1994, 100 kg of HEU were sent to France (see *Nuclear Fuel*, June 20, 1994). Italy was, therefore, left with 215 kg of HEU. As of December 2014, according to the GTRI, about 40% of this HEU had been removed and repatriated to the United States via the GTRI Program, implying that Italy still possessed about 130 kg of HEU. The lower bound of the range was calculated using information relative to the status of the Elk River spent fuel at ITREC and Italy's Tapiro Reactor. According to the NNSA, none of the HEU contained in the Elk River spent fuel has been repatriated. The amount of HEU present in this spent fuel is about 90 kg. Additionally, Italy's RSV-Tapiro critical facility has about 25 kg of HEU in its core, bringing the total to 115 kg of HEU. Therefore, Italy still possesses between 115 and 130 kg of HEU by the end of 2014.

[p] At the end of 2014, about 1 kg of HEU enriched at 93% U235 was still present in the Jamaican SLOWPOKE-2 (JM-1) reactor, which was scheduled for conversion to LEU fuel. The conversion should be completed by September 2015. See H. Dennis, "Analysis of the Jamaican SLOWPOKE-2 Research Reactor for the Conversion from HEU to LEU Fuel," Paper presented at the 35th International Meeting on Reduced Enrichment for Research Reactors and Test Reactors, Vienna, Austria, October 12-16, 2014, http://www.rertr.anl.gov/RERTR35/pdfs/S1P4_Paper_Dennis.pdf. In fact, this HEU was removed from Jamaica on schedule. See "NNSA Removes U.S.-Origin HEU from Jamaica, Makes the Caribbean HEU Free," NNSA Press Release, September 22, 2015. http://fissilematerials.org/blog/2015/09/all_heu_removed_from_jama.html

[q] Japan's remaining stock of HEU is estimated to be about 1.8 tonnes. According to the NRC's *1993 Report to Congress*, Japan received 1,973 kg of HEU from the United States. It also received about 500 kg from the United Kingdom and France, according to officials who tracked U.S.-origin HEU in the 1990s and 2000s. Therefore, overall Japan received a total of 2,473 kg of HEU. Since 1997, Japan has returned about 656 kg of HEU. Also, Japan's UTR-KINKI research reactor is currently undergoing conversion to LEU fuel, and feasibility studies for the conversion of the two critical assemblies are underway. See G. Aliberti, J.A. Morman and J.G. Stevens, and H. Unesaki, "Conversion of the KUCA 'Type-A' Cores to LEU Fuel Preserving Reactivity and Central Flux Spectra," Paper presented at the 35th International Meeting on Reduced Enrichment for Research Reactors and Test Reactors, Vienna, Austria, October 12-16, 2014, http://www.rertr.anl.gov/RERTR35/pdfs/S5P5_Paper_Aliberti.pdf. At the 2014 Nuclear Security Summit, Japan stated it would return HEU in the Fast Critical Assembly (FCA). The shipment has not yet happened but is expected to involve several hundred kilograms of HEU.

[r] About 550-650 kg of HEU remain in the Netherlands as of December 2014. At the end of 2003, ISIS estimated that the Netherlands had an HEU stockpile of about 730-810 kg, based on a wide variety of information and sources. Since then about 45 kg of US-origin HEU have been

exported to the Netherlands and about 205 kg of HEU returned to the United States. This estimate derives from calculations made by ISIS based on information gathered through multiple sources.

[s] Norway continues to possess a small amount of HEU. According to the NRC's 1993 Report to Congress, Norway received 4 kg of US-origin HEU. The purpose and fate of this HEU has been difficult to determine. Some of this HEU may have been used to produce fuel rods for the IFA-652 experiment in the Halden HWBR. However, it is unclear if this experiment involved this HEU, how much HEU was used in the experiment, and what happened to the HEU in the rods after the experiment. See Calabrese, R., Vettraino, F., Tverberg T., *Comparative Study of Inert Matrix Fuels Concepts from IFA-652 Experiment*, Proceedings of the 17th International Conference on Nuclear Energy, Brussels, July 12-16, 2009.

[t] NRC Report to Congress, 1993 (op cit).

[u] "Highly Enriched Uranium (HEU) Inventories in South Africa, status as of end of 2014," ISIS Report, (to be published).

[v] Switzerland was estimated to possess about 2 to 10 kg of HEU at the end of 2014. It received 114 kg of U.S.-origin HEU, of which 20 kg were retransferred out, 12 kg were returned to the US, 56 kg of HEU in spent were returned as well, 16 kg sold as fresh fuel to the Dutch Petten reactor in 2000, and between 0 to 5 kg sold as fresh fuel. The end of 2014 estimate was derived from a calculation made by ISIS based on information gathered through multiple sources and personal communications with knowledgeable officials. In 2015, DOE/NNSA and Switzerland successfully negotiated to remove Switzerland's remaining excess HEU, sending the last 2.2 kilograms of HEU back to the United States. See "Last HEU Removed from Switzerland under NNSA Collaboration," NNSA Press Release, September 16, 2015. http://nnsa.energy.gov/mediaroom/pressreleases/last-heu-removed-switzerland-under-nnsa-collaboration

[w] Many years ago, several other countries received a combined total of significantly less than 1 kg U.S.-origin HEU, including Bolivia (1 g), Czechoslovakia (8 g), India (98 g), Ireland (2 g), Malaysia (7 g), Uruguay (5 g), Venezuela (11 g), and Zaire (4 g). Also Vietnam received U.S.-origin HEU but this quantity was removed by the United States at the end of the Vietnam War. Shipments to the IAEA (300 g) are also included in this category. Indonesia received 18 g of HEU several decades ago. This HEU may have been used in targets. If so, however, GTRI has verified the cessation of the use of HEU targets for isotope production in Indonesia, and it is working to down blend the remaining amount of HEU, which it characterizes as a residue material. See "GTRI's Convert Program: Minimizing the Use of Highly Enriched Uranium," NNSA Fact Sheet, May 29, 2014, http://nnsa.energy.gov/mediaroom/factsheets/gtri-convert. Indonesia has also returned a total of 336 spent fuel assemblies to the United States between 2004 and 2009, but these assemblies did not contain HEU.

[x] Zero signifies a country that originally had a stock of civil HEU dedicated to its civil reactor programs but has eliminated it. However, when zero is used in this table, it is typically a rounded figure. HEU is used in gram quantities for standards, samples, fission chambers,

exempt materials and waste. Those amounts are not tracked in this table and are not typically eligible for return to the United States or Russia.

[y] "The Four Year Effort," NNSA Publication on GTRI Contributions as of December 2013, p. 4, http://nnsa.energy.gov/sites/default/files/nnsa/12-13-inlinefiles/2013-12-12%204%20Year%20Effort.pdf. Iraq is also included, although it became HEU-free as a result of a 1991 U.N. Security Council mandate. Iraq had tens of kilograms of HEU supplied by France and Russia.

[z] The estimate for Belarus derives from analysis by ISIS based on information gathered through multiple sources and personal communications with knowledgeable officials. However, it is worth noting that the enrichment level of the HEU in this estimate is highly uncertain. This uncertainty derives from the fact that the enrichment level of the fuel elements for the Giacint critical facility varied, with elements having enrichments of 21%, 36%, 75%, and 90%. Therefore, it is possible that a good portion of the HEU estimate has an enrichment level closer to 21% rather than 90%.

[aa] See above entry for China.

[bb] See David Albright and Kevin O'Neill, *Solving the North Korean Nuclear Puzzle*, Institute for Science and International Security, November 1, 2000.

[cc] See above entry for Germany.

[dd] This estimate covers civilian research reactors in India that used HEU fuel. One was the 1 MWth Apsara reactor. [*50 Glorious Years of Apsara*, BARC, 2006]. This source states that the Apsara reactor used a total of three cores, each containing about 5 kilograms of 93% enriched uranium. The first two cores were from Britain and the third was shipped by France in 1983. Apparently, the Aspara reactor did not use indigenously produced HEU. The first two cores were sent back to Britain for reprocessing. It is unclear if India owns the recovered HEU or if Britain took ownership, and what was the ultimate fate of the recovered HEU. Here, we assume that the HEU was not returned to India. The test breeder reactor, the Fast Breeder Test Reactor (FBTR), was slated to use HEU in its initial core but it is unclear if it did. India expected to receive the HEU from France. But there remains some uncertainty whether France supplied this HEU, which would have amounted to tens of kilograms of HEU.

[ee] Kazakhstan continues to possess about 10 tonnes of Russian-origin HEU used in the BN-350 breeder reactor. This value was provided to the IAEA by the government of Kazakhstan. It is unknown if this value represents an initial mass of HEU or one reflecting burn-up of the HEU fuel in the BN-350 fast reactor. The HEU used in the BN-350 was typically enriched to less than 26%. The HEU is in the form of spent fuel and was packaged and transported to a new secure long-term storage facility in Kazakhstan. See "Joint Statement by Co-Chairs of the U.S.-Kazakhstan Energy Partnership On Successful Completion of the U.S.-Kazakhstan BN-350 Spent Fuel Program," NNSA Press Release, November 17, 2010, http://nnsa.energy.gov/mediaroom/pressreleases/spentfuelstatement111710. Additionally, between 43 and 58 kg of HEU remain in Kazakhstan for research and development purposes. About 43 kg of HEU are present in Almaty. This HEU is contained in the core of the VVR-K

research reactor at Almaty and in spent fuel stored there. The VVR-K is still using HEU fuel. However, it is expected to convert to LEU fuel in 2016. This remaining spent fuel stored at Almaty is expected to be repatriated to Russia in mid-2016. Additionally, about 15 kg of HEU enriched at 90 percent may be present in the two Kurchatov reactors. About 5 kg of HEU enriched at 90 percent are believed to be in the core of the IVG.1M reactor and 10 kg of HEU with the same enrichment are loaded in the core of the IGR reactor. See Shaiakhmet Shiganakov, "BN-350 Reactor Spent Fuel Handling," Technical Meeting, Oskarshamn, Sweden, 26-28 April 2006, http://www.iaea.org/OurWork/ST/NE/NEFW/documents/NETWORK/Status/2005/MS/KAZAKHSTAN.pdf. These estimates are based on analyses by ISIS based on information gathered through multiple sources and personal communications with knowledgeable officials.

In March 2014, a White House Fact Sheet reported that "Once the final three research reactors are converted to LEU, DOE/NNSA will work with Kazakhstan to return the remaining 85 kg of HEU at these facilities to the Russian Federation for disposition." If ones subtracts the amount of HEU that was returned after March 2014 (47.5 kg), this leaves 37.5 kg of HEU. However, this number is inconsistent with information provided to ISIS by knowledgeable officials. One explanation for the lower value is that the DOE number may include some post-irradiation HEU masses and not initial masses of HEU, which is what is used above.

[ff] The Maria reactor originally ran on 80% enriched HEU fuel but subsequently converted to 36% in 1999. In September 2014, however, the reactor completed final conversion to LEU fuel. Since its first conversion, Poland has been sending spent HEU fuel back to Russia. The 80% enriched spent fuel assemblies were the first to be removed. The last batch of fuel assemblies containing about 60.4 kg of HEU are scheduled to be sent to Russia in 2016 and contain HEU enriched at 36%. This estimate derives from calculations made by ISIS based on information gathered through multiple sources and personal communications with knowledgeable officials. Maria has contracted to irradiate small amounts of U.S.-origin HEU in targets to make molybdenum 99. The irradiated target is sent to Belgium or Netherlands for processing and extraction of the molybdenum 99. The irradiated HEU is stored in the Netherlands or Belgium. Therefore, the HEU is accounted for in the processor's stock of HEU.

[gg] "Russia to Return all HEU from Uzbekistan," IPFM Blog, February, 3, 2014, http://fissilematerials.org/blog/2014/02/russia_to_return_all_heu_.html; S. Tozser, P. Adelfang, E. Bradley, J. Dix, "IAEA Cooperation with the RRRFR Programme – 2014 update," Paper presented at the 35th International Meeting on Reduced Enrichment for Research Reactors and Test Reactors, Vienna, Austria, October 12-16, 2014, http://www.rertr.anl.gov/RERTR35/pdfs/S2P4_Paper_Tozser.pdf; Sh. Alikulov, S. Baytelesov, F. Kungurov, U. Salikhbaev, Dj. Yusupov, "Successful Operation of WWR-SM Research Reactor after Conversion to LEU Fuel," Paper presented at the 35th International Meeting on Reduced Enrichment for Research Reactors and Test Reactors, Vienna, Austria, October 12-16, 2014, http://www.rertr.anl.gov/RERTR35/pdfs/S3P1_Paper_Alikulov.pdf. In September 20, 2015, NNSA announced that the last 5 kg of HEU were removed from Uzbekistan to Russia. See "NNSA Partnership Successfully Removes All Remaining HEU from Uzbekistan," Press Release, September 29, 2015, http://nnsa.energy.gov/mediaroom/pressreleases/nnsa-partnership-successfully-removes-all-remaining-heu-uzbekistan. This shipment was challenging since it was the first transport of liquid HEU spent fuel by air.

[hh] "The Four Year Effort" (op.cit). The Czech LVR-15 REZ reactor has contracted to irradiate small quantities of U.S.-origin HEU in targets for molybdenum 99 production. After irradiation in the reactor, the target is sent to Belgium, or possibly the Netherlands, for processing and extraction of the molybdenum 99. Therefore, the HEU is accounted for in the processor's stock of HEU.

[ii] About 1 kg of HEU enriched at 90.2% U235 is still present in the Ghana Research Reactor-1 (GHARR-1). This is a Miniature Neutron Source Reactor (MNSR) and the core has been scheduled for conversion to 13% enriched LEU in the form of UO_2. The spent HEU fuel is scheduled to be removed in March/April 2015 and shipped to China. See H. C. Odoi, J. K. Gbadago, R. G. Abrefah, S. A. Birikorang, R. B. M. Sogbadji and E. Ampomah-Amoako, "Efforts Made for the Conversion of Ghana's MNSR to LEU," Paper presented at the 35th International Meeting on Reduced Enrichment for Research Reactors and Test Reactors, Vienna, Austria, October 12-16, 2014, http://www.rertr.anl.gov/RERTR35/pdfs/S1P3_Paper_Odoi.pdf.

[jj] Fredrik Dahl, "U.S., Russia Clash over Syria Reactor at U.N. Meeting," Reuters. September 9, 2013, http://www.reuters.com/article/2013/09/09/us-syria-crisis-russia-nuclear-idUSBRE9880J520130909.

[kk] About 1 kg of HEU enriched at more than 90% U^{235} is still present in the Nigeria Research Reactor-1 (NIRR-1). This is a Miniature Neutron Source Reactor (MNSR) and all studies have been completed for the conversion to LEU fuel (12.5% U^{235}). Activities leading to the conversion, such as the approval by the Regulatory Agency in Nigeria (NNRA), will be invigorated. As of December 2014 the 1 kg of HEU remains in the NIRR-1 core. See S.A. Jonah, "Status Report of Activities for the Core Conversion of Nigeria MNSR to LEU," Paper presented at the 35th International Meeting on Reduced Enrichment for Research Reactors and Test Reactors, Vienna, Austria, October 12-16, 2014, http://www.rertr.anl.gov/RERTR35/pdfs/S5P3_Paper_Jonah.pdf.