NTI Paper

MAY 2015

A Roadmap to Minimize and Eliminate Highly Enriched Uranium

SUMMARY

Highly enriched uranium (HEU)—one of the key ingredients for nuclear weapons—is one of the most dangerous materials on the planet. Since 1992, the international community removed and eliminated thousands of kilograms of HEU, converted HEU-fueled reactors to use low-enriched uranium (LEU), and promoted the adoption of LEU alternatives for medical isotope production. Despite significant progress, the work to reduce—and ultimately eliminate—HEU is far from finished. This paper lays out a roadmap with five pathways to ending civilian HEU use and to beginning the necessary research and development to minimize and ultimately eliminate HEU for naval use, with specific recommendations that countries can undertake prior to the 2016 Nuclear Security Summit.

Andrew J. Bieniawski and Miles A. Pomper

NTI BUILDING A SAFER WORLD

CNS

FMWG fissile materials working group

This roadmap was developed by a working group on "A Path to the Elimination of Highly Enriched Uranium in Civil Applications," which is a project of the Fissile Materials Working Group (FMWG). The FMWG is a coalition of 80 civil society organizations from around the world that are committed to improving fissile materials security.

Andrew J. Bieniawski and **Miles A. Pomper** are members of the working group and co-authors of the paper. Bieniawski is a vice president at the Nuclear Threat Initiative for Material Security and Minimization and is a member of the FMWG Steering Committee. Pomper is a senior research associate of the James Martin Center for Nonproliferation Studies at the Middlebury Institute of International Studies at Monterey, California, and is co-chair of the FMWG.

About the Nuclear Threat Initiative

The Nuclear Threat Initiative (NTI) is a non-profit, non-partisan organization with a mission to strengthen global security by reducing the risk of use and preventing the spread of nuclear, biological, and chemical weapons and to work to build the trust, transparency, and security that are preconditions to the ultimate fulfillment of the Non-Proliferation Treaty's goals and ambitions. Founded in 2001 by former U.S. Senator Sam Nunn and CNN founder Ted Turner, NTI is guided by a prestigious, international board of directors. Joan Rohlfing serves as president.

About the James Martin Center for Nonproliferation Studies

The James Martin Center for Nonproliferation Studies (CNS) strives to combat the spread of weapons of mass destruction (WMD) by training the next generation of non-proliferation specialists and disseminating timely information and analysis. CNS at the Middlebury Institute of International Studies at Monterey is the largest non-governmental organization in the United States devoted exclusively to research and training on non-proliferation issues.

Introduction

Highly enriched uranium (HEU) is one of the most dangerous materials on the planet.[1] Enough HEU to fill a five-pound bag of sugar is all that is needed to construct a nuclear device with the potential to kill hundreds of thousands of people and to inflict billions of dollars in damage. Unlike plutonium, HEU can be used in a simpler "gun-type" nuclear weapon, making it potentially more attractive for a terrorist organization that is seeking to acquire a nuclear capability.

In 1992, more than 50 countries possessed HEU. Today, that number has been cut by more than half. This accomplishment is the result of international HEU minimization efforts, particularly those spearheaded since 2004 by the Global Threat Reduction Initiative (GTRI), a U.S. Department of Energy (DOE) program to remove and eliminate thousands of kilograms of HEU, to convert HEU-fueled reactors to low-enriched uranium (LEU) use, and to promote the adoption of LEU alternatives for medical isotope production.

On April 5, 2009, President Barack Obama gave a historic speech in Prague and launched "an international effort to secure all vulnerable material around the world within four years." This was followed by three high-level Presidential Nuclear Security Summits (NSS) in 2010, 2012, and 2014. Together, these efforts significantly boosted efforts to secure nuclear material around the world. In fact, since the President's 2009 Prague speech, all HEU has been removed from an additional 11 countries plus Taiwan.[2] This required more than 60 shipments from 21 different countries and involved the removal of enough material to make approximately 70 nuclear weapons.

However, the work to reduce—and ultimately eliminate—HEU is far from finished. Although most HEU is designated for nuclear weapons purposes, significant amounts remain in civilian programs and non-weapons applications (see Table 1). Today, approximately 61 metric tons of civilian HEU are spread across more than 100 facilities in 25 countries.[3]

Table 1. 25 Countries with Civilian HEU Stockpiles (as of January 2015)*

> 10,000 kilograms	1,000–10,000 kilograms	100–1,000 kilograms	10–100 kilograms	1–10 kilograms
Russia	Canada	Belarus	Italy	Argentina
United States	China	Belgium	Israel	Australia
	France	Germany	North Korea	India
	Japan	Netherlands	Pakistan	Iran
	Kazakhstan	South Africa	Poland	Norway
	United Kingdom			Switzerland
				Uzbekistan
2 countries	6 countries	5 countries	5 countries	7 countries

*Table includes only countries with one kilogram or more of HEU; data are from the International Panel on Fissile Materials.

1 HEU is uranium containing 20 percent or more of the isotope U-235.

2 Since the President's Prague April 2009 speech, all HEU has been removed from the following 11 countries plus Taiwan: Austria, Chile, the Czech Republic, Hungary, Libya, Mexico, Romania, Serbia, Turkey, Ukraine, and Vietnam.

3 International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2013: Increasing Transparency of Nuclear Warhead and Fissile Material Stocks as a Step Toward Disarmament*, http://www.fissilematerials.org/library/gfmr13.pdf.

HEU is also used in reactors on certain naval vessels, including icebreakers, submarines, and aircraft carriers, in India, Russia, the United Kingdom, and the United States. Approximately 290 metric tons of HEU remain in global naval inventories, which is enough material for thousands of nuclear weapons.[4]

Considering the fact that nearly all civilian and naval applications of HEU fuel have proven LEU alternatives, the international community must take steps now to accelerate efforts to minimize—and ultimately eliminate—HEU in the civilian and naval spheres.[5]

By eliminating those stocks, countries also eliminate the risk that terrorists could acquire HEU in their country, "representing, in a real sense, bombs that will never go off."[6] Therefore, countries should view HEU elimination as a form of permanent threat reduction and as an essential component of the global effort to combat the threat of nuclear terrorism.

[4] Harold A. Feiveson, Alexander Glaser, Zia Mian, and Frank N. von Hippel, "Unmaking the Bomb: A Fissile Material Approach to Nuclear Disarmament and Nonproliferation," October 14, 2014, http://fissilematerials.org/library/ipfm14.pdf.

[5] Corey Hinderstein, Andrew Newman, and Ole Reistad, "From HEU Minimization to Elimination: Time to Change the Vocabulary," *Bulletin of the Atomic Scientists*, 68, no. 4 (2012): 83–85.

[6] Matthew Bunn, *Securing the Bomb*, 2010 (Cambridge, MA and Washington, DC: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, April 2010), 23.

A Global Roadmap for HEU Elimination

Governments should adopt a roadmap for ending civilian HEU use and for beginning the necessary research and development to minimize and ultimately eliminate HEU for naval use within a clear time period. This roadmap should incorporate the following measures:

- Clear commitments to convert or shut down all HEU-using civilian reactors, with particular attention to critical assemblies, pulsed reactors, and fast reactors. The majority of countries, including the United States, should pledge to meet this goal by 2035. In the case of Russia, because of its vast reactor fleet, a longer deadline may be required.
- A firm commitment that all future research facilities and fast reactors will not use HEU, given the advancement in high-density LEU-based fuels.
- A commitment by countries using HEU in naval vessels to accelerate research, analysis, testing, and prototyping for LEU fuels and reactor designs that meet key operational requirements for naval reactors and that could offer a pathway for conversion in India, Russia, the United Kingdom, and the United States.
- A commitment from the U.S. Administration to minimize and ultimately eliminate HEU for naval use. A key initial step would be to ensure that the Naval Nuclear Propulsion Program has adequate funding to begin research and development of a replacement core for an LEU fuel reactor in FY 2017.
- Clear commitments and demonstrated actions by the end of 2016 either to convert molybdenum-99 (Mo-99) medical isotope production to use LEU targets or to verify the shutdown of the remaining HEU-based Mo-99 medical isotope production facilities in Belgium, Canada, the Netherlands, Russia, and South Africa.
- A commitment to end subsidized production of Mo-99 by many market participants, as called for by the Organisation for Economic Co-Operation and Development's Nuclear Energy Agency (OECD-NEA). The lack of such "full-cost recovery" thus far has held back the entry of new firms that could stabilize supplies in this commercial market.[7]
- Concerted efforts globally—and particularly in Europe—to expedite approval of non-HEU-based Mo-99 and its daughter product technetium-99m (Tc-99m).
- Conversion of Chinese-origin Miniature Neutron Source Reactors (MNSRs) from the use of HEU to LEU fuel, including (a) continued domestic Chinese conversions, (b) completion of the first foreign MNSR conversion in Ghana by the end of 2016, and (c) initiation of a new Chinese-origin HEU take-back program (similar to the Russian and U.S. HEU fuel return programs).
- A firm commitment that any exports of HEU will be tied to a pledge from the facility receiving the HEU for demonstrated actions to convert to use of LEU. To this end, a bilateral U.S.–Russian commitment to stop HEU exports would be very useful.
- Continued commitment by the United States and Russia to repatriate and downblend HEU fuel provided to countries around the world decades ago under the auspices of U.S. and Russian HEU export programs.
- The United States and Russia should continue to downblend HEU declared excess from military stocks, to pledge additional amounts of their military HEU stocks as excess, and to designate them for downblending.
- Identify pathways for so-called "gap material" (material that is currently not covered under either the U.S. or Russia fuel removal programs) to be removed and downblended.

7 OECD NEA, "Medical Isotope Supply in the Future: Production Capacity and Demand Forecast for the ^{99}Mo/^{99m}Tc Market, 2015–2020," April 14, 2014, 20–21, https://www.oecd-nea.org/med-radio/reports/sen-hlgmr2014-2.pdf.

Many of those commitments should be codified at the 2016 NSS through explicit statements regarding civilian HEU elimination in the NSS Communiqué, through an HEU elimination "gift basket" statement by the NSS countries, through individual national statements and commitments, or through a combination of these. After the 2016 NSS, such steps could be supported through HEU-free zones, as well as through initiatives by institutions such as the International Atomic Energy Agency (IAEA) or the G8 Global Partnership.

To implement these commitments, countries should focus on **five pathways** (outlined in Table 2) toward the elimination of HEU for civilian use and the minimization of HEU for naval use.

Table 2. Five Pathways toward the Elimination and Minimization of HEU

Pathway	Objectives
HEU Reactor Conversions and/or Shutdowns	• Develop conversion pathways for the remaining six civilian HEU reactors in the United States. • Accelerate reactor conversions in Africa, Asia, Canada, Europe, and the Middle East. Develop a conversion, shutdown, and replacement plan or a combination of these for Russia's 63 HEU facilities.
HEU Fuel Removals	• Continue HEU fuel repatriation to the United States and Russia, particularly from Belarus, Canada, Japan, and Poland. • Build international momentum for development of HEU-free zones, particularly in Africa, Europe, Latin America, the Middle East, and Southeast Asia.
LEU Alternatives for Medical Isotope Production	• Convert to LEU targets, or verify the shutdown of remaining HEU-based Mo-99 production facilities in Belgium, Canada, the Netherlands, Russia, and South Africa. • End subsidies for Mo-99 production that create barriers for new firms getting into the market. • Accelerate medical approval for non-HEU-based Mo-99 in Europe.
Naval Reactors	• Address gaps in the current system that allow states to produce weapons-grade HEU for naval reactors or to lease HEU-fueled vessels. • Accelerate research, analysis, testing, and prototyping for LEU naval fuels and reactor designs that meet key operational requirements.
HEU Downblending	• Accelerate efforts to downblend HEU stocks already declared excess, and continue to identify additional HEU stocks to be declared excess and downblended. • Encourage countries to establish national timetables for HEU downblending and to create a reporting mechanism to track progress.

HEU Research Reactor Conversions

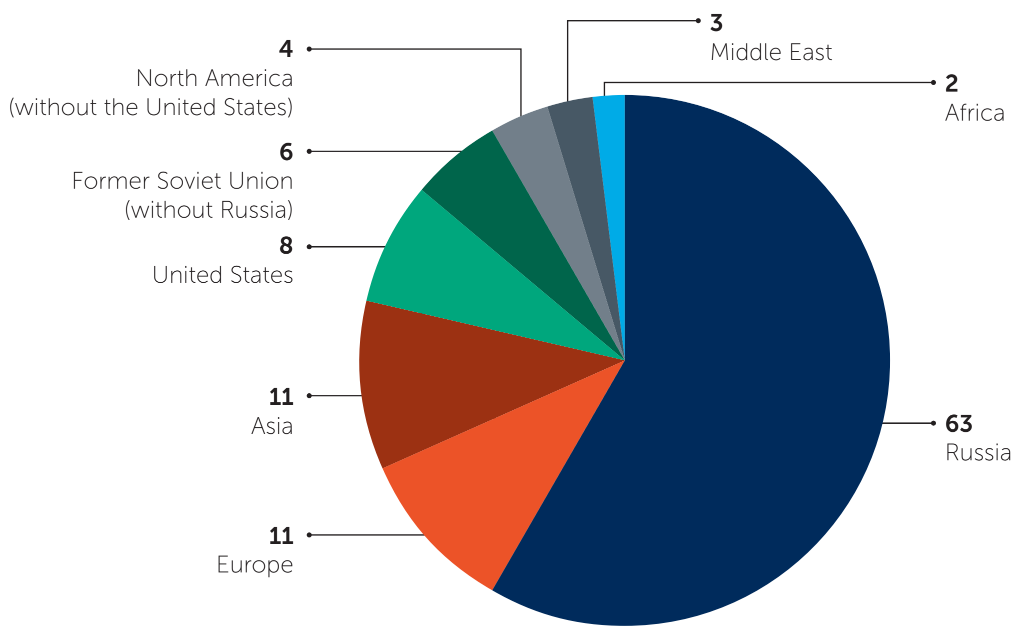
To eliminate the need for HEU, governments should continue to accelerate efforts to convert research and test reactors as well as radioisotope production facilities to the use of LEU or non-HEU-based technologies.

Since its inception in 2004, DOE's GTRI, along with the Reduced Enrichment for Research and Test Reactors (RERTR) Program, has been responsible for converting or verifying the shutdown of 92 HEU research reactors and medical isotope production facilities; 20 of them were in the United States, and 72 were in other countries.[8] The goal is to complete the conversion or to verify the shutdown of approximately 200 HEU-fueled research reactors and medical isotope production facilities by 2035.[9] DOE continues to make progress toward achieving this goal. Most recently, DOE completed installation of a pilot high-density LEU fuel fabrication line at the Babcock and Wilcox Company (B&W) and began rolling of material at this facility in the United States.

Conversion of a reactor from HEU to LEU is a complex process that involves determining a suitable LEU fuel design and core configuration for each individual reactor. Technical expertise obtained through the GTRI and RERTR, in collaboration with the IAEA and other international partners, should be fully considered in such conversion efforts.

Today, there are still approximately 108 civilian facilities that continue to use HEU, the majority of which are located in Russia[10] (see Figure 1). Although the United States and Russia had previously agreed to collaborate on reactor conversions inside Russia (through an agreement signed in 2010 to conduct feasibility studies on the conversion of six reactors), progress has been hampered by political constraints. Only one conversion effort has been completed to date—the ARGUS reactor at the Kurchatov Institute in Moscow.[11] The United States and Russia should, therefore, restart a dialogue to complete and expand the initial set of feasibility studies for the conversion of six reactors.

Figure 1. Worldwide Numbers of HEU Research Reactors & Medical Isotope Facilities Left to Convert



[8] Jordi Roglans, "GTRI Reactor Conversion Program Scope and Status," presentation to the National Academy of Sciences, Washington, D.C., October 23, 2014, by Argonne National Laboratory, http://dels.nas.edu/resources/static-assets/nrsb/miscellaneous/Roglans.pdf.

[9] Ibid.

[10] IPFM, *Global Fissile Material Report. 2013*, 14.

[11] IPFM, "Russia Completed Conversion of Argus Research Reactor," November 30, 2014, http://fissilematerials.org/blog/2014/11/russia_completed_conversi.html.

Russia is currently implementing a major program of removing "spent" (irradiated) fuel from research reactors located outside of Russia that have Russian-supplied HEU. Removing spent fuel is a prerequisite for decommissioning these reactors and will consolidate spent HEU fuel at fewer sites. As Anton Khlopkov of Russia's Center for Energy and Security Studies recently wrote in a March 2015 working paper for the Stanley Foundation, "The tasks facing Russian specialists as part of this [spent fuel removal] program are similar to those that had to be addressed during the repatriation of fuel under the RRRFR [Russian Research Reactor Fuel Removal] program."[12] Therefore, the United States—which continues to support the RRRFR program—should now consider partnering with Russia on this spent fuel removal program inside Russia, as well as on joint research and development work with Russian technical institutes concerning issues such as decommissioning, fuel removal, and high-density fuel development.

Given the fact that Russia currently operates 63 HEU-fueled facilities, it is unlikely Russia will be able to meet the 2035 deadline for HEU phase-out that is within the reach of other countries. Nonetheless, Russia is capable of converting its facilities soon thereafter if it develops a national plan for the use, conversion, shutdown, and decommissioning of its HEU research reactors. Thus, Russia should be encouraged to develop its own plan and its own HEU phase-out date.

Critical Assemblies, Pulsed Reactors, and Breeder Reactors

Although much international attention has been placed on converting "standard" HEU research reactors, two other types of research facilities—pulsed reactors and critical assemblies (which hold the most HEU by far)—have largely been left out of cooperative efforts.[13] Pulsed reactors provide huge bursts of neutrons that can be used in many types of nuclear physics research, including nuclear weapons development. Critical and subcritical assemblies are test beds where different core configurations and fuel types are tested before deployment.

Nearly all pulsed reactors are located in Russia, where 16 known HEU-fueled pulsed reactors remain in operation.[14] Thanks to the large physics dataset already gathered throughout the world, as well as advances in computing, pulsed reactors are becoming increasingly unnecessary, especially for civilian use—a conclusion that many in Russia's scientific community have already come to recognize.[15] Moreover, thanks to advances in reactor design, a scientific team from the Russian Federal Nuclear Center VNIIEF (the All-Russian Research Institute of Experimental Physics) has concluded that modern LEU-fueled replacement reactors are able to match or surpass the performance of old HEU-fueled pulsed reactors.[16]

There are also approximately 40 critical and subcritical assemblies around the world, with Russia housing 38 of them. As with pulsed reactors, a debate currently surrounds the continued use of critical assemblies versus using computer simulations based on benchmark experiments. A comprehensive approach is needed for diminishing HEU use in critical and subcritical assemblies and pulsed reactors. This approach would include decommissioning both unnecessary reactors and those that are impossible to convert, consolidating workloads toward remaining reactors, and—if needed—deploying new LEU-powered replacement reactors for niche applications.[17]

12 "Russia's Nuclear Security Policy: Priorities and Potential Areas for Cooperation" (Washington, D.C., March 18, 2015).

13 Critical assemblies hold approximately 10 metric tons of HEU in lifetime cores and approximately two metric tons in pulsed reactors. Research reactors use 750 kilograms of HEU annually, with only hundreds of kilograms of HEU in lifetime cores. See Alan J. Kuperman, "Global HEU Phase-Out: Prospects and Challenges," in *Nuclear Terrorism and Global Security: The Challenge of Phasing Out Highly Enriched Uranium*, ed. Alan J. Kuperman, (New York: Routledge, 2013), 9.

14 Paul Osborne, "Russia: Critical Assemblies and Pulsed Reactors," in *Nuclear Terrorism and Global Security: The Challenge of Phasing Out Highly Enriched Uranium*, ed. Alan J. Kuperman, (New York: Routledge, 2013), 165–66.

15 Anatoli S. Diakov, "On Conversion of Research Reactors in Russia," Center for Arms Control, Energy, and Environmental Studies, August 2013, 1, http://www.armscontrol.ru/pubs/en/on-conversion-of-research-reactors-in-russia-en-corr.pdf.

16 Osborne, "Russia," 164.

17 Pulsed reactors with neutron moderators may already be potential conversion targets with existing fuels. See Osborne, "Russia," 164, 166.

Recent experience also indicates that many facilities are no longer carrying out the applications for which they acquired fissile materials in the first place. As an important first step toward conversion, it would be valuable to investigate the nature of the work currently being conducted at such facilities and to determine whether or not fissile materials are indeed necessary.

One of the reasons Japan was able to agree last year to remove HEU from its Fast Critical Assembly was that Japanese and U.S. officials concluded that facility scientists were no longer carrying out research on fast neutron reactors that had previously required such materials. Similar conclusions can likely be made at Russian facilities by Russian technical experts.

Finally, special types of experimental power reactors—fast breeder reactors—used HEU in the past. New models are transitioning to a plutonium–uranium fuel mixture called MOX (mixed oxide fuel), and experimental efforts are under way to see if both can be replaced with LEU fuel. Therefore, there is no technical rationale for new HEU-fueled fast breeder reactors anywhere in the world, and this conclusion should be acknowledged at the political level.

Objectives for HEU Research Reactor Conversion and /or Shutdown Pathway

1. Develop conversion plans for the remaining six civilian HEU research reactors in the United States—the Advanced Test Reactor (ATR) and ATR critical assembly at Idaho National Laboratory, the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory, the Massachusetts Institute of Technology Reactor (MITR), the University of Missouri Research Reactor (MURR), and the National Institute of Standards and Technology (NIST) Neutron Beam Split-Core Reactor (NBSR).
2. Accelerate HEU research reactor conversions in Africa, Asia, Canada, Europe, and the Middle East.
3. Restart a high-level U.S.-Russian dialogue on reactor conversion.
4. Encourage Russia to develop a national plan for HEU phase-out with a realistic completion date for elimination.
5. Examine possible U.S.-Russian activities related to removal of spent HEU fuel, HEU reactor decommissioning, development of high-density LEU fuel, and development of commercial incentives for conversion and consolidation of remaining HEU reactors.
6. Assess current uses of critical assemblies and pulsed reactors, particularly in Russia, and determine whether those facilities are still used for purposes requiring fissile materials.
    a. For facilities that still use HEU, determine whether results could be achieved instead through computer simulations or non-HEU alternatives.
    b. Encourage Russia to implement a plan to shut down all HEU facilities that are no longer required to meet scientific objectives and that are impossible to convert. Consolidate workloads toward remaining facilities, and—if needed—deploy new LEU-powered replacement reactors for niche applications.
7. Pledge not to build or operate any new HEU-fueled fast reactors.
8. Encourage countries to develop their own national plans for HEU elimination (which could be announced as a deliverable at the 2016 NSS) with specific timelines for their efforts.

HEU Fuel Removals

Once reactors are converted or decommissioned, countries should continue to take measures—with international assistance, if needed—to remove all HEU from those sites, including spent HEU fuel and unirradiated (or "fresh") HEU fuel. The material can then be removed safely to another country, where it can be placed in secure storage or downblended into LEU.

In the decade after the launch of the Atoms for Peace program, the United States, the Soviet Union, and other nuclear-weapon states exported research reactors fueled with HEU to approximately 40 countries. Since then, a number of high-profile initiatives, particularly DOE's GTRI, have led the way to repatriate this U.S.-origin and Soviet/Russian-origin HEU fuel back to the United States and Russia, respectively.

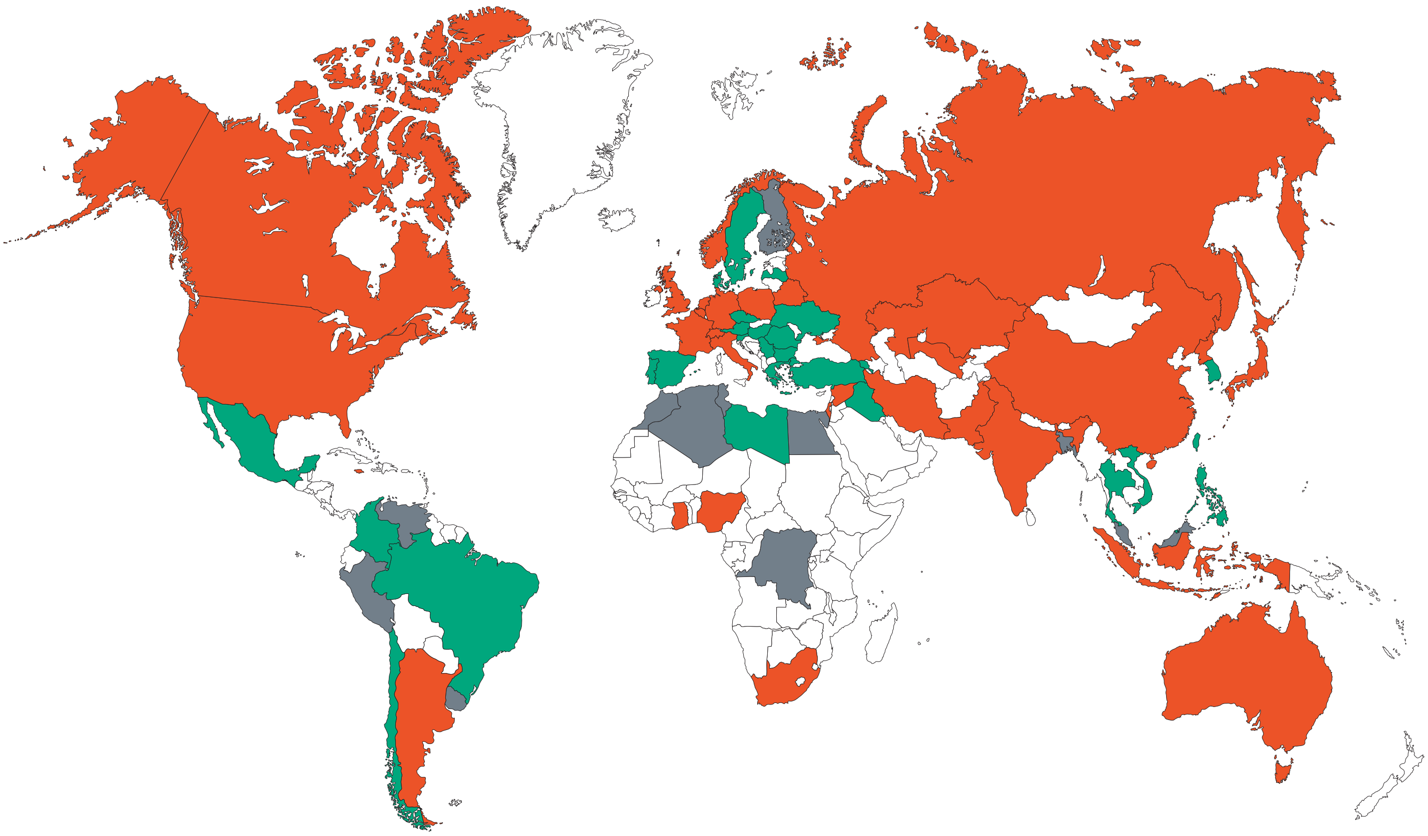
The map in Figure 2 on the following page shows countries that have already been cleared out of HEU, as well as countries that continue to possess HEU stocks.

The short- and medium-term objectives pertaining to this elimination pathway are as follows:

1. Continue HEU fuel repatriation to the United States and Russia, particularly from Belarus, Canada, Japan, and Poland. Eliminate by downblending in-country if repatriation is not feasible.
   a. Revitalize efforts to convince Belarus to eliminate its remaining HEU.
   b. Revitalize international efforts to discuss HEU disposition options with South Africa, including possible cooperation with South Africa to downblend its remaining HEU to LEU in-country.
   c. Accelerate efforts to remove more than 500 kilograms of HEU and plutonium from the Fast Critical Assembly Facility in Japan prior to the 2016 NSS.[18]
   d. Accelerate the final shipment of HEU from Poland in order to complete the Poland HEU clean-out prior to the 2016 NSS. With creative approaches to address both the time required to cool the spent HEU fuel and how to appropriately ship the spent HEU fuel, this shipment could be completed prior to the final NSS and could be highlighted to the international community as another example of Poland's leadership on HEU minimization.
2. Initiate a new Chinese-origin fuel removal program to address the five Chinese-supplied MNSRs located outside of China in Ghana, Iran, Nigeria, Pakistan, and Syria. Syria has recently requested IAEA assistance in converting its MNSR from the use of HEU to LEU fuel.
3. Build international momentum to support creation of HEU-free zones, particularly in Africa, Latin America, Europe, the Middle East, South America, and Southeast Asia.
   a. Regions such as South America and Southeast Asia, which have essentially been cleared of such materials, could pledge the establishment of such zones as "gift baskets" to the 2016 NSS.
   b. By encouraging the establishment of such zones, the United States and the international community could foster the development of regional champions to help drive the HEU elimination agenda forward after the end of the NSS process.

[18] White House Fact Sheet: U.S.-Japan Cooperation for a More Prosperous and Stable World, April 28, 2015, noted that the U.S. and Japan are "working together to remove all highly enriched uranium and plutonium fuel from the Fast Critical Assembly in Japan in 2016."

Figure 2. HEU Elimination Efforts to Date



Cleared of HEU (27)		Currently possesses HEU (30)		Has a research reactor that has *never used* HEU (11)
Austria	Philippines	Argentina	Japan	Algeria
Brazil	Portugal	Australia	Kazakhstan	Bangladesh
Bulgaria	Romania	Belarus	Netherlands	Democratic Republic of Congo
Chile	Serbia	Belgium	Nigeria*	Egypt
Colombia	Slovenia	Canada	North Korea	Finland
Czech Republic	South Korea	China	Norway	Malaysia
Denmark	Spain	France	Pakistan	Morocco
Georgia	Sweden	Germany	Poland	Peru
Greece	Taiwan	Ghana*	Russia	Tunisia
Hungary	Thailand	India	South Africa	Uruguay
Iraq	Turkey	Indonesia*	Switzerland	Venezuela
Latvia	Ukraine	Iran	Syria*	
Libya	Vietnam	Israel	United Kingdom	
Mexico		Italy	United States	
		Jamaica*	Uzbekistan	

*Indicates a country with less than one kilogram of HEU.

Source: Data collected from various sources including *NTI Nuclear Materials Security Index, Building a Framework for Assurance, Accountability, and Action*, Second Edition (Washington, D.C.: NTI, January 2014), http://ntiindex.org/wp-content/uploads/2014/01/2014-NTI-Index-Report1.pdf; International Panel on Fissile Materials, *Global Fissile Material Report 2013: Increasing Transparency of Nuclear Warhead and Fissile Material Stocks as a Step Toward Disarmament* (Princeton, N.J.: 2013); and documents from the 2010, 2012, and 2014 NSS. Map created by Alexandra Van Dine, NTI.

LEU Alternatives for Medical Isotope Production

At the 2016 NSS, countries could be near an important milestone: the end of the use of HEU in medical isotope production. Reactors are used to produce the vital isotope Mo-99 by irradiating uranium "target" plates. Furthermore, Mo-99 decays into the even shorter-lived Tc-99m, which is used as a tracer in more than 30 million medical procedures each year.[19] Historically, those reactors have been powered with HEU and used HEU in the uranium targets. Production of Tc-99m is heavily concentrated; in fact, eight reactors produce the vast majority of Mo-99 in the world.[20]

The United States has pushed for the conversion of both reactors and targets to LEU. Nearly all of the major Mo-99 producers now run on LEU fuel or are slated to be shut down in the next few years.[21] Those producers have also begun the process of converting to LEU targets. However, conversion efforts may face a major hurdle within the next few years because of a potential shortage in the supply of LEU until non-HEU-based Mo-99 production facilities become fully operational. Older HEU-fueled reactors have had their capital costs effectively subsidized, making it difficult for new LEU-based competitors to enter the market and compete successfully.

A high-level group convened by the OECD-NEA has repeatedly stressed the importance of ending the subsidies for the older HEU-based reactors (full-cost recovery).[22] In December 2014, 11 countries made a joint declaration to the OECD-NEA to move to unsubsidized production by the beginning of 2015 or as soon as previous contracts expire or technical restrictions allow.[23]

One remaining obstacle is the need to ensure sufficient demand for non-HEU-based production to encourage new producers. Although the United States has both expedited medical approvals of such isotopes and taken policy steps to boost supply and demand, medical approvals have been slower elsewhere—most notably in Europe. Recently, European officials have said they are working on steps to accelerate action in this arena.

Other countries should consider similar measures. Ideally, the transition away from HEU-based production should be completed and codified in time for the 2016 NSS. Should this transition not be possible for technical reasons, states should ensure that it takes place as soon as possible after the summit.[24]

The short- and medium-term objectives pertaining to this elimination pathway are as follows:

1. Convert to LEU targets, or verify shutdown of the remaining HEU-based Mo-99 in Belgium, Canada, the Netherlands, Russia, and South Africa.
2. End subsidies for existing Mo-99 production that create barriers for new firms entering the market.
3. Accelerate medical approvals for non-HEU-based Mo-99 in Europe.

[19] Anya Loukianova, "What the Doctor Ordered: Eliminating Weapons-Grade Uranium from Medical Isotope Production," Nuclear Threat Initiative, September 5, 2012, http://www.nti.org/analysis/articles/what-doctor-ordered-eliminating-weapons-grade-uranium-medical-isotope-production/.

[20] Anton Khlopkov and Miles Pomper, with contributions by Valeriya Chekina, *Ending HEU Use in Medical Isotope Production: Options for U.S.-Russian Cooperation*, Nuclear Threat Initiative, February 2014, 3, http://www.nti.org/media/pdfs/Ending_HEU_Use_in_Medical_Isotope_Production.pdf?_=1393952246.

[21] Ibid, 6.

[22] OECD Nuclear Energy Agency, "Medical Isotope Supply," 20–21. Additional reports can be found at http://www.oecd-nea.org/med-radio/docs/.

[23] The countries were Australia, Canada, Germany, Japan, the Netherlands, Poland, Russia, South Korea, Spain, the United Kingdom, and the United States. OECD-NEA, "Joint Declaration on the Security of Supply of Medical Radioisotopes," December 2014, http://www.oecd-nea.org/med-radio/jointdeclaration.html.

[24] European countries had pledged to convert by 2015, assuming regulatory approval, but failure to start this effort in a timely manner by the Dutch producer Mallinckrodt may delay a full Dutch shift to LEU until 2017 or later.

Naval Reactors

The use of HEU in naval reactors has been largely exempt from international efforts aimed at securing, minimizing, and ultimately eliminating the use of HEU. Yet it represents the largest use of fresh HEU for non-weapons purposes and is a core challenge to HEU minimization efforts.

Approximately 290 metric tons of HEU remain in global naval inventories, enough material for more than 11,000 nuclear weapons.[25] The United States alone has more than 250 metric tons of HEU in its inventory of fresh and spent naval fuel. India, Russia, the United Kingdom, and the United States all use HEU in their nuclear propulsion programs—in part because current HEU cores can generate more energy by volume, conserve space, and require less refueling. For submarines and aircraft carriers, these attributes have historically been major advantages.

However, other navies use, or plan to use, LEU cores in their naval reactors. The French Navy successfully converted its fleet to LEU in 2008, and China is believed to use LEU in its submarines. Although it is still in development, the reactor that Brazil has designed for its nuclear-powered attack submarine is believed to be fueled with 18–19 percent enriched uranium.[26] Russia has designed an LEU-fueled reactor for its next-generation nuclear-powered icebreaker submarine. These experiences in converting nuclear fleets from HEU and into operating LEU-fueled naval reactors could provide valuable insight into the technical, operational, and financial issues that India, Russia, the United Kingdom, and the United States would need to address.

But naval reactor conversion is controversial and complex. In practice, conversion in many cases will require the development of new reactors, new fuels, or both for future generations of naval vessels. Moreover, there are currently no international restrictions that would prevent additional states from using HEU in naval reactors in the future. Under the Nuclear Non-Proliferation Treaty, states can legally produce weapons-grade HEU and withdraw that material from IAEA safeguards if it is intended for non-explosive military purposes. This loophole presents a major proliferation risk. A state could produce weapons-grade HEU and use it for a covert weapons program—all the while claiming it is for a naval propulsion program. Even a potential Fissile Material Cut-off Treaty, which is aimed at permanently halting the production of fissile material for weapons purposes, would likely permit the continued production of HEU for naval reactors.

To start to deal with those challenges and to minimize the use of HEU in naval reactors, countries should pursue several short- and medium-term objectives:

1. Assess naval inventory needs, and downblend excess material.
2. Address gaps in the current system that allow states to produce weapons-grade HEU for naval reactors or to lease HEU-fueled vessels.[27]
3. Facilitate information exchanges between navies that are currently using LEU-fueled naval reactors and those using HEU-fueled reactors.
4. Explore the possibility of placing some naval HEU under IAEA safeguards as an interim confidence-building measure.
5. Accelerate research, analysis, testing, and prototyping for LEU fuels and reactor designs that meet key operational requirements and could offer a pathway for conversion in India, Russia, the United Kingdom, and the United States.
6. A commitment from the U.S. Administration to minimize and ultimately eliminate HEU for naval use. A key initial step would be to ensure that the Naval Nuclear Propulsion Program has adequate funding to begin research and development of a replacement core for an LEU fuel reactor in FY 2017.[28]

[25] Harold A. Feiveson et al., "Unmaking the Bomb."

[26] George M. Moore, Cervando A. Banuelos, and Thomas T. Gray, "Potential for Elimination of the Use of Highly Enriched Uranium (HEU) in Propulsion Reactors," publication forthcoming.

[27] Ibid.

[28] Federation of American Scientists Task Force, "Naval Nuclear Propulsion: Assessing Benefits and Risks," March 2015, http://fas.org/pub-reports/naval-nuclear-propulsion-assessing-benefits-risks/.

HEU Downblending

Both Russia and the United States have declared large sums of HEU as "excess" or "surplus" to military needs and have slated this HEU for downblending to LEU.

Since 1996, the United States has declared 186 metric tons of surplus HEU and has designated this HEU for downblending. According to DOE's website, "More than 143 [metric tons] of HEU [have] already been downblended to LEU or delivered for near-term downblending. The remaining balance of HEU slated for downblending is expected to be completed as additional nuclear warheads are dismantled."

Russia's participation in the historic 1993 HEU Purchase Agreement resulted in 500 metric tons of its surplus HEU being downblended at Russian facilities and sold to the United States as fuel for commercial reactors. Furthermore, the U.S. National Nuclear Security Administration's Material Conversion and Consolidation project in Russia resulted in the conversion of more than 16 metric tons of non-weapons HEU into LEU.

To continue to make progress on HEU downblending, countries—particularly the United States and Russia—should take the following steps:

1. Accelerate efforts to downblend HEU stocks already declared excess, and continue to identify additional HEU stocks to be declared excess and slated for downblending.
2. Establish national timetables for HEU downblending, and create a binational (U.S.-Russian) or international reporting mechanism to track countries' progress on downblending. This reporting mechanism could be unveiled on the sidelines of the 2016 NSS or at the 2016 IAEA Conference on Nuclear Security.

BUILDING A SAFER WORLD

1747 Pennsylvania Avenue, NW | Seventh Floor | Washington, DC 20006 | @NTI_WMD | www.nti.org