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# The 2012 Seoul Nuclear Security Summit and HEU Minimization

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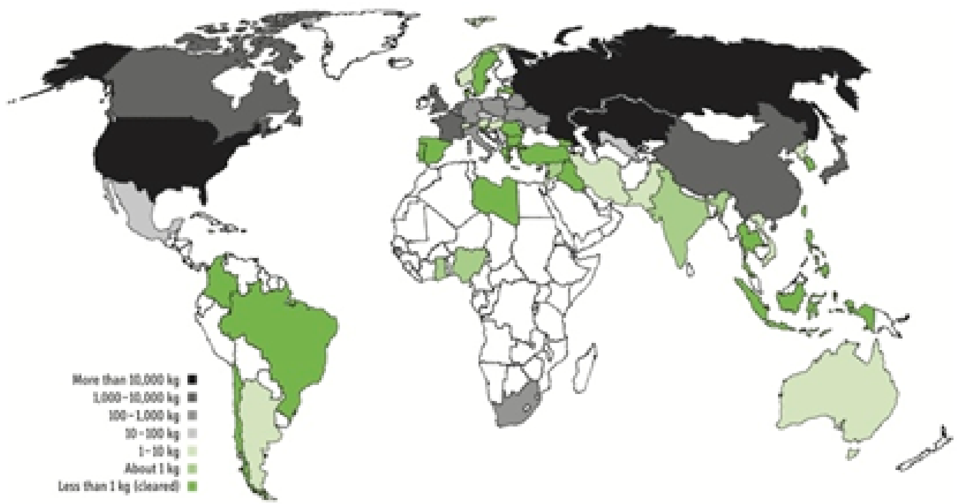
## BACKGROUND

Highly enriched uranium (HEU) is one of the most dangerous materials in the world, thanks to the ease with which it can be utilized in a nuclear explosive device. Unlike plutonium, highly enriched uranium is suitable for use in the simplest kind of nuclear weapon, a so-called gun-type bomb. In gun-type devices, one subcritical piece of fissile material is fired at another subcritical target, which together form a critical mass and spark a chain reaction. The process is so simple and well understood that such a device does not need to be explosively tested; even the first such bomb, which was dropped on Hiroshima in 1945, was not tested prior to its use. In addition, HEU's weak radioactivity makes it relatively easy to handle and hard to detect.[1] Terrorists who acquire a sufficient quantity of HEU[2] would not need to be backed by the scientific and financial resources of a state to construct a nuclear device.

HEU differs from natural uranium or the low enriched uranium (LEU) used in nuclear power reactors in the concentration of the uranium-235 (U-235) isotope relative to other uranium isotopes. Natural uranium includes less than one percent U-235, while LEU contains less than 20 percent U-235, and HEU contains more than 20 percent U-235. The higher enrichment level of the HEU, the less is needed for a nuclear weapon with concentrations of 80 percent or more traditionally used in state nuclear weapons programs. Various industrial techniques are employed to separate and concentrate the U-235 found in natural uranium to higher enrichment levels.

Massive amounts of HEU continue to be set aside for nuclear weapons and for powering nuclear vessels such as submarines and aircraft carriers. The primary civilian use of HEU has been in research reactors and other test facilities, where it has been employed because it generates a high flow of U-235 neutrons (neutron flux), useful for research and a number of specialized tasks. It has also been used in the process of producing medical isotopes and in civilian propulsion reactors. A half century ago, the Soviet Union and the United States started shipping HEU abroad as part of their peaceful nuclear cooperation programs ("Atoms for Peace" in the U.S. case) and the material ended up scattered widely around the globe (see Figure 1). But by the late 1970s, India's "peaceful nuclear explosion" and the rise of international terrorism had convinced the two superpowers to launch efforts to phase out research reactor use of HEU (particularly overseas) and replace it with LEU. These efforts were accelerated following the September 2001 terrorist attacks in the United States and have made significant gains.

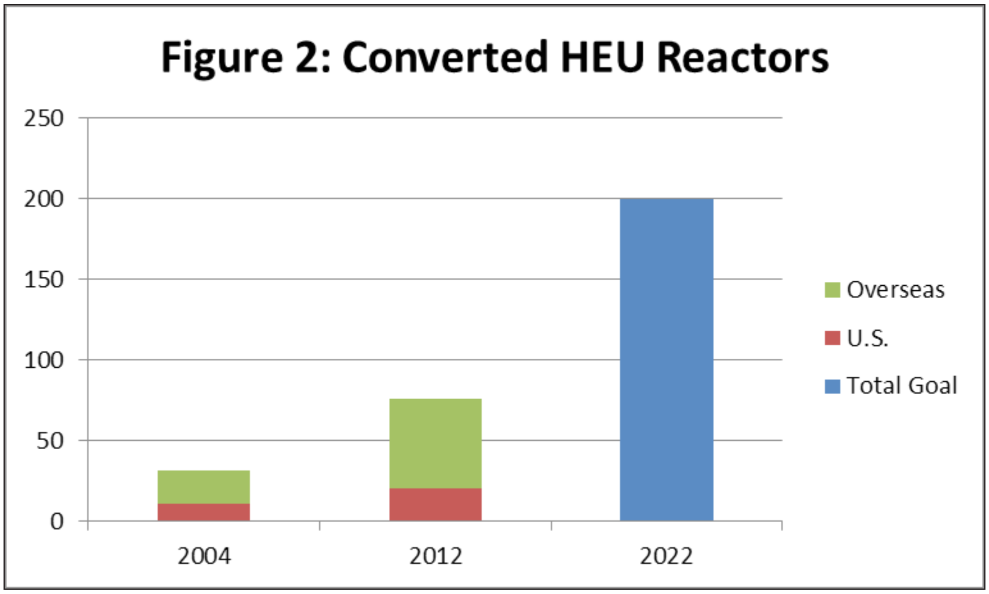
## Figure 1: Global HEU Stocks




*Global Fissile Material Report 2010: Balancing the Books*, Fifth Annual Report, International Panel on Fissile Materials

Source: Global Fissile Material Report 2010: Balancing the Books, Fifth Annual Report, International Panel on Fissile Materials.

Nonetheless, a tremendous amount of work remains to be done to minimize and ultimately eliminate the use of HEU in the civilian sector, let alone tackle the broader task of preventing terrorist access to any such material. The U.S. Department of Energy's National Nuclear Security Administration (NNSA), which leads U.S. HEU minimization efforts, assesses that after decades of efforts by the United States and Russia only one-third of the research facilities worldwide that use HEU have been converted to using LEU or shut down. NNSA estimates that at a minimum it will take more than another decade for these reactors to be entirely weaned off of HEU (see Figure 2). Moreover, the civilian facilities that use the most HEU have not been converted, with nine reactors in the United States and Europe alone consuming nearly 400 kg of HEU annually.[3] As much as 70 tons of HEU are said to remain in the civilian sector, enough perhaps for several thousand nuclear weapons.




Source: Jordi Roglans-Ribas, Argonne National Laboratory.

Fortunately, an international consensus has emerged in recent years—as demonstrated in international forums such as Nuclear Nonproliferation Treaty Review Conferences and UN Security Council Resolution 1887—that, given the security risks, the use of HEU outside military technologies should be minimized to the extent that it is technically and economically feasible. The 2010 Nuclear Security Summit also endorsed this consensus and several countries took individual steps to minimize or eliminate civil HEU.

Nonetheless, the world still lacks a common and comprehensive strategy to minimize and ultimately eliminate this danger. As a result, the United States, France, South Korea and industry leaders have sought to use the 2012 Seoul Nuclear Security Summit to accelerate efforts to minimize HEU in the civilian sector.

## REDUCING RESEARCH REACTOR USE OF HEU

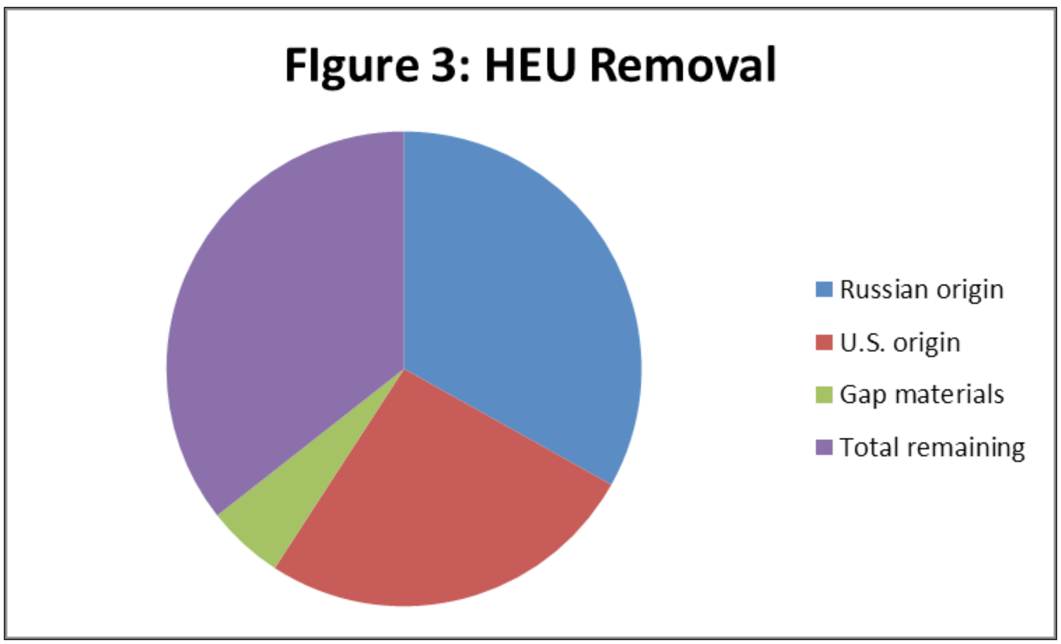
In the late 1970s and early 1980s, the United States and the Soviet Union launched programs to eliminate weapon-grade HEU use in research reactors abroad. In the United States, the effort fell under the Reduced Enrichment for Research and Test Reactors (RERTR) program, which spearheaded the conversion of 76 reactors to LEU by late 2011.[4] The Soviet/Russian programs did not necessarily shift to material that was LEU, i.e. where less than 20 percent of the uranium is the fissile isotope U-235. However, the enrichment level was sufficiently low (in the Soviet case, 36 percent U-235) that it would be more difficult to build a workable device given the relatively large total amount of uranium required to have a sufficient quantity of U-235.

These efforts sped up after the September 2001 terrorist attacks and the launch of the Bush administration's Global Threat Reduction Initiative in 2004 which grouped together RERTR with several other related initiatives and which received substantially increased funding from Congress.

U.S. efforts have been supported by an important policy lever: the Schumer Amendment to the 1992

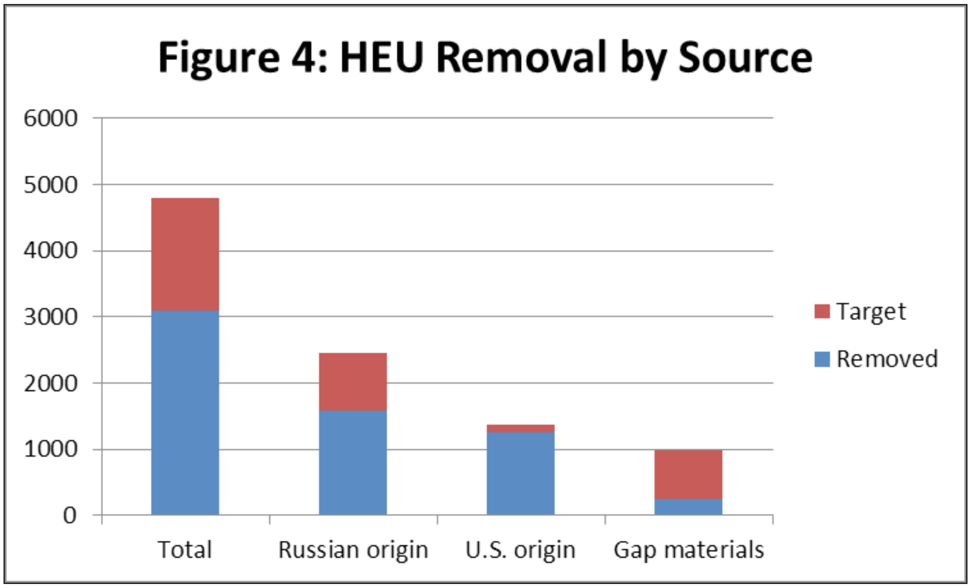
Energy Policy Act, a U.S. law which allows the issuance of an export license for HEU for use in research or test reactors only under certain conditions: if there is no fuel or target of LEU that could be used in the importing reactor; if the recipient commits to use a low-enriched substitute when it becomes available; and if the United States is actively developing alternative fuels or targets for the reactor.[5] As a result, from 1993 to 1999 there were "virtually no exports" of HEU,[6] compared to the nearly three tons exported by the United States annually in the late 1960s.[7] The effect of this law was diluted in 2005, unfortunately, when Congress passed the Burr Amendment to the 2005 Energy Policy Act which permitted exports of HEU to the largest producers of medical isotopes (Belgium, Canada, France, Germany and the Netherlands) without requiring a commitment to convert to the use of LEU targets. The Act does, however, still require that the receiving state either utilize LEU fuel in the reactor, or agree to convert to LEU fuel when such a substitute becomes available.

The Bush administration also fostered bilateral cooperation with Russia. In 2005, Presidents George W. Bush and Vladimir Putin agreed that their countries would cooperate in research reactor conversion by providing LEU for any U.S. or Russian designed research reactors operating with HEU. Spent HEU fuel is then returned to the country of origin.[8] In practice, this has largely meant that NNSA has paid Russia to help ship back HEU to Russia from countries such as Belarus, Poland, Serbia and Ukraine. This effort has yielded clear progress (see Figure 3): nearly all of the U.S. HEU abroad has been returned and much of the Soviet fuel has been returned to Russia.




Source: National Nuclear Security Administration.

Less success has been achieved in repatriating so called gap material that did not fall neatly into U.S. or Russian programs, such as material from third countries (see Figure 4).



Source: National Nuclear Security Administration.

Presidents Barack Obama and Dmitry Medvedev emphasized their commitment to the 2005 agreements at their July 2009 summit in Moscow, and noted "the importance of HEU minimization in civilian applications" and to "support such efforts to the maximum extent possible, where feasible."[9] Those commitments were further extended in a September 2011 joint statement by the heads of the U.S. Department of Energy and the Russian state nuclear energy corporation Rosatom. It said that the two countries intended to "conduct joint efforts to convert research reactor cores in third countries from HEU fuel to LEU fuel, and examine the feasibility of converting U.S. and Russian HEU research reactors to LEU fuel in order to encourage other countries to take similar steps."[10]

Over the past decade, a broader international consensus has also begun to emerge regarding the need to minimize the use of HEU. The final document of the 2000 Nuclear Nonproliferation Treaty Review Conference "note[d] with appreciation that many research reactors are discontinuing the use of highly enriched uranium fuel in favor of low-enriched uranium fuel…"[11] The subject was further discussed in the 2005 review cycle, but that conference ended without a consensus final document.

At the 2010 Review Conference, less progress was made on the subject of HEU than many had hoped for in the face of the many other challenges and tensions that dominated the conference. Nonetheless, the consensus final document did, "encourage States concerned, on a voluntary basis, to further minimize highly enriched uranium in civilian stocks and use, where technically and economically feasible."[12]

Civilian HEU was also highlighted at the UN Security Council summit held in September 2009, chaired by President Obama. Resolution 1887, which was unanimously adopted at that meeting:

> *Calls upon* all States to manage responsibly and minimize to the greatest extent that is technically and economically feasible the use of highly enriched uranium for civilian purposes, including by working to convert research reactors and radioisotope production processes to the use of low enriched uranium fuels and targets.[13] [Emphasis in original.]

Finally, minimization of HEU was endorsed at the April 2010 Nuclear Security Summit in Washington, DC, which was attended by 38 heads of state or government, and 47 states in total. In the final communiqué of the summit, the gathered states, "encourage[d] the conversion of reactors from highly enriched to low enriched uranium fuel and minimization of use of highly enriched uranium, where technically and economically feasible."[14]

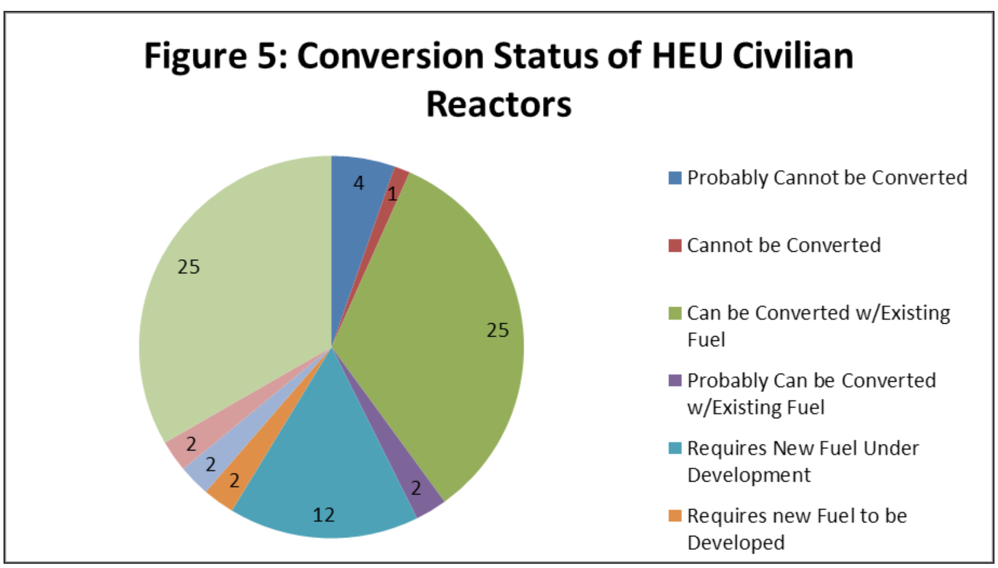
The summit's work plan further noted that participating states "will collaborate to research and develop new technologies that require neither highly enriched uranium fuels for reactor operation nor highly enriched uranium targets for producing medical or other isotopes…"[15]

In addition to the agreed work plan and communiqué, many of the participating states made national commitments to reduce the use of HEU in their own territories or contribute more generally to the cause of nuclear security. Canada, for example, agreed to return a large quantity of HEU to the United States and to fund HEU removals from Mexico and Vietnam. Ukraine committed to remove its entire stock of HEU, by the time of the next Nuclear Security Summit in 2012. In a significant step towards fulfilling this pledge, in May 2010, 56 kg of Russian-origin HEU spent fuel were removed from Ukraine. Later, in December 2010, a total of 50 kilograms of HEU fresh fuel was removed.[16] Laura Holgate, a White House official who has helped direct U.S. efforts in the summit process, said that since the summit, over 400 kg of HEU had been removed from more than 10 countries, which would be "enough for 16 nuclear bombs."[17]

## CHALLENGES

*Technical*

Converting reactors is a time consuming and technically demanding process akin to using a new kind of fuel in a car engine while seeking to maintain the car's performance and safety and not altering its basic dimensions or operating costs. The challenge is particularly difficult given that research reactors are even less standardized than power reactors. As a result, almost every conversion of a reactor requires a lengthy study to determine what changes can be made safely even before undertaking the conversion process, which can take years. A very few reactors are seen as particularly difficult to convert either because of their individual dimensions or their high performance levels (see Figure 5).

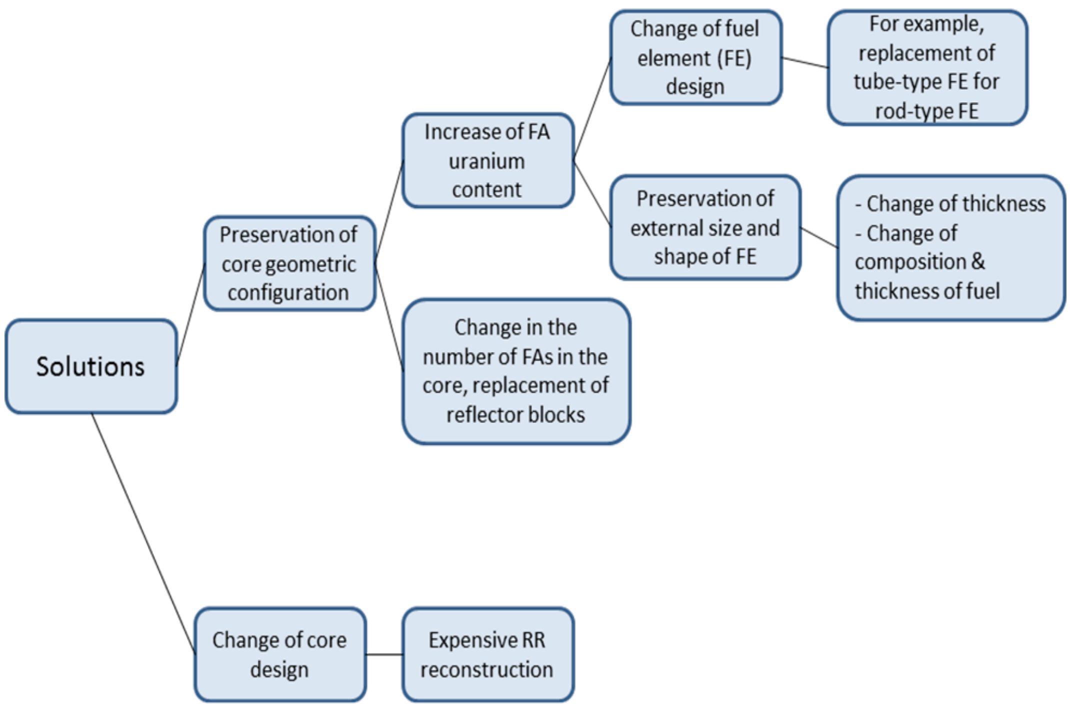



Source: Pablo Adelfang, International Atomic Energy Agency, conference presentation 8-10 June 2011.

These numbers do not include 50 defense and icebreaker reactors.

Converting the reactor without altering its basic configuration generally involves finding ways to increase the amount of uranium in the core enough to make up for the fact that LEU has far less U-235 than HEU (18 percent LEU, for example, would have only one-fifth as much U-235 as 90 percent HEU). Reactor operators can increase the number of fuel assemblies relative to reflectors or "neutron poisons;" increase the amount of uranium in fuel assemblies by changing the basic design of fuel elements; change the thickness of the zirconium or aluminum metal cladding that wraps around the uranium fuel; or increase the density or alter the composition of the fuel within the elements (see Figure 6).

**Figure 6: Conversion of Operating RR from HEU to LEU Fuel: Solutions to the Problem**




Source: Tetiyakov, I.T., ROSATOM Company, JSC "NIKIET," conference presentation 8-10 June 2011.

A number of different techniques have been advanced to accomplish these goals, some more successful than others. Nonetheless, the primary obstacles to conversion have been economic and political—insufficient funding, determined political objections or a lack of political will to alter the facilities or change the practices of established institutions. In a few cases, such as with South Africa and Belarus, the lack of action has reflected the desire of those countries to leverage their stocks for other political goals. But more commonly, little action has occurred because of low threat perceptions, bureaucratic inertia and the resistance of reactor operators. Some institutions have feared losing capabilities needed for research or to produce sufficient quantities of medical isotopes as well as a loss of prestige that has sometimes accompanied the use of HEU.

*Russia*

Nowhere has this been more evident than in Russia. Although Russia has played an important role in taking back HEU that it previously supplied to other countries, it has done little to tackle its own use of civil HEU. Russia has as much as 30 tons of civil HEU, and more than half of the research reactors and test facilities worldwide that use the material. At the 2009 Obama-Medvedev summit, Russia agreed for the first time to conduct feasibility studies "to explore possibilities for conversion" of research reactor cores.[18] The six feasibility studies are expected to be completed by the end of 2011. At that point, Russian officials will have to make a political decision whether to move forward with conversion, something they have long resisted. [19]

In addition to standard research reactors, Russia has the world's highest number of critical and subcritical assemblies facilities that involve very large amounts of HEU.[20] These facilities, which are used for basic physics experimentation or to model reactor cores, represent difficult challenges both for proliferation and conversion. They have highly unique cores and fuel (i.e., sometimes without cladding). Not only does their fresh fuel present a danger, but their spent fuel is lightly irradiated and lies in easy-to-transport discs, similarly making it potentially attractive to terrorists. Moreover, these facilities consume HEU so slowly that they essentially have lifetime cores and there is little economic incentive to convert them since they can operate using their current HEU stocks.[21]

Russia has 30 of these facilities, while European countries have only one. This difference, in part, reflects a Russian preference for hands-on experimentation instead of the computer simulations preferred by its European counterparts. (Similar problems surround pulse reactors that fall within the defense sector and so would not likely be subject to a civilian ban). One positive recent development in this regard is that Kazakhstan has been working with the United States to convert a Soviet-era critical assembly in Almaty. The researchers at the Kazakhstan Institute of Nuclear Physics are anticipating that conversion may begin this summer.[22]

Like counterparts in the Russian and U.S. nuclear navies, Russia's civilian icebreakers use HEU for naval propulsion with some ships carrying up to 200 kg of U-235.

Russia is also looming as a potential obstacle to the specific goal of minimizing the use of HEU in medical isotope production. Formerly only a bit player in the global market, Russia is revving up its medical isotope production and planning to use both HEU fuel and targets to do so—at least until it grabs a sizeable market share.

## HEU AND MEDICAL ISOTOPE PRODUCTION

Russia is only one of the obstacles to progress in converting medical isotope facilities to LEU. Others have included the technical difficulty of converting reactors to operate with less-enriched fuel; the economic costs of conversion; the disincentives for LEU-based medical isotope production and the construction of new LEU-based isotope production reactors; anxieties that conversion will exacerbate real and potential shortages of such isotopes; and political difficulties created by licensing requirements and by states and industries seeking market advantage.

Such isotopes are an important feature of modern medicine, particularly in the fields of medical imaging and diagnostics. The major medical isotope is the very short-lived technetium-99m, which can be chemically incorporated into small molecule ligands and proteins that concentrate in specific organs or tissues when injected into the body, allowing doctors to use them in medical scans that examine particular areas of the body (see Table 1).[23]

**Table 1: Selected Examples of Tc-99m Kits for Nuclear Medicine Diagnostic Imaging[24]**

| Kit Name | Imaging Procedure |
|---|---|
| Technetium Tc-99m Medronate (MDP) | Bone Scan |
| Technetium Tc-99m Albumin Aggregated (MAA) | Lung Perfusion |
| Technetium Tc-99m Pentetate (DTPA) | Kidney Scan and Function |
| Technetium Tc-99m Sulfur Colloid | Liver Scan |
| | Sentinel Lymph Node Localization |
| Technetium Tc-99m Sestamibi | Cardiac Perfusion |
| Technetium Tc-99m Exametazime | Brain Perfusion |
| Technetium Tc-99m Mebrofenin | Gall Bladder Function |
| Technetium Tc-99m Etidronate | Bone Scan |
| Technetium Tc-99m Disofenin | Gall Bladder Function |
| Technetium Tc-99m Succimer (DMSA) | Kidney Scan and Function |
| Technetium Tc-99m Tetrofosmin | Cardiac Perfusion |
| Technetium Tc-99m Bicisate | Brain Perfusion |
| Technetium Tc-99m Red Blood Cell | Blood Pool Imaging |
| Technetium Tc-99m Sodium Pertechnetate | Thyroid, Salivary Gland, Meckel's Scan |
| Technetium Tc-99m Lidofenin | Gall Bladder Function |
| Technetium Tc-99m Mertiatide (MAG3) | Kidney Scan and Function |
| Technetium Tc-99m Oxidronate (HDP) | Bone Scan |

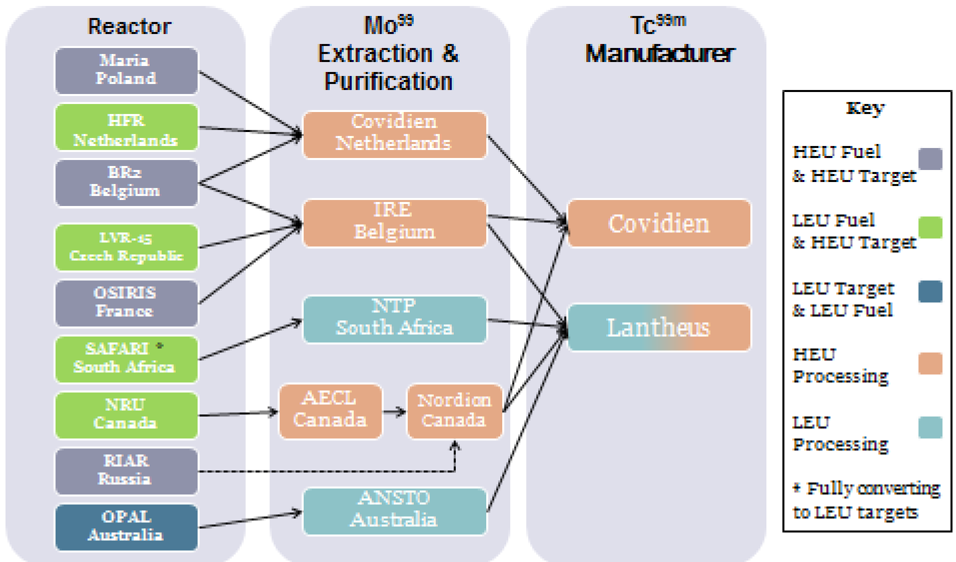
Note: MAA = methacrylic acid, MDP = methylene diphosphonate, DTPA = diethylene triamine Pentaacetic acid, DMSA = dimercaptosuccinic acid, MAG3 = mercapto acetyl triglycine, HDP = hydroxymethylene diphosphonate.
Source: National Academy of Sciences.

More than 30 million such examinations take place around the world each year, with the United States alone accounting for 14 million procedures annually.[25]

Because technetium-99m has a half-life of only about six hours[26] it must be produced continuously rather than stockpiled. Historically, it has been produced from the decay of the isotope molybdenum-99. That isotope has been produced by irradiating an HEU target inside a research reactor (with the reactor, in turn, traditionally fueled by HEU). Neutrons from the reactor split the uranium-235 atoms in the HEU target. Some of the fragments created by these splits are molybdenum-99 (henceforth "Mo-99"). In order to maximize the production of Mo-99, which has a half-life of 66 hours, the target is irradiated only briefly—five to seven days in most cases.[27] The target is then purified to produce bulk Mo-99, which is then placed in generators to produce technetium-99m. Only around three percent of the uranium is used up in this process, leaving tens of kilograms of HEU left over each year as lightly-irradiated and proliferation-sensitive waste.[28]

In addition, HEU has often been used as fuel in the reactors. The total annual world demand for HEU for the production of medical isotopes is 40-50 kg,[29] nearly enough to produce two bombs each year with considerably more fresh and spent HEU fuel stockpiled around the globe. Production of such isotopes has been governed by a highly concentrated and unusually structured industry in which more than 90 percent of Mo-99 has been produced by irradiation in five largely government-run research reactors and then processed largely by four predominantly commercial Mo-99 processors (see Figure 7). [30]

Figure 7: **Medical Isotopes- Current U.S. $Mo^{99}$ / $TC^{99m}$ Supply Matrix**




Source: Ira Goldman, "Toward a More Secure Future? Mo-99 Supply," Sept. 2011.

For the last few years, NNSA has used a two-pronged strategy to establish a reliable supply of Mo-99 that does not utilize HEU. Domestically, NNSA has reached cost-sharing agreements ("Cooperative Agreements") with four U.S. based producers to pursue nontraditional approaches to Mo-99 production that do not involve irradiating targets in traditional research reactors. The idea is to eventually use these technologies to replace HEU-based production from countries such as Canada, which have traditionally provided the bulk of U.S. medical isotopes. The United States, in turn, provides nearly half of the world market for isotopes.

Meanwhile, the U.S and the IAEA have sought to both expand the number of small scale regional Mo-99 producers in areas like Latin America or Eastern Europe and to help the major overseas producers convert to LEU. The toughest development challenges have involved the development of higher uranium density fuels and targets. As described, the increased density for fuel is needed to ensure that there is sufficient uranium-235 in the fuel to ensure a sufficient uranium flux. For the target, the challenge is to maximize the yield of Mo-99, while minimizing waste from the additional uranium needed for LEU targets and seeking to ensure, to the extent possible, compatibility with existing processes for target dissolution and Mo-99 recovery.[31] To date, all but one of the five reactors that have traditionally been used for large-scale production of Mo-99 (and more than 90 percent of the market supply) have been converted to use LEU fuel and the lone holdout, the BR-2 reactor in Belgium, is in the process of being converted although facing some technical difficulties in doing so.[32]

The major reactors producing medical isotopes are spread across three continents: three in Europe including the BR-2 in Belgium, HFR in Netherlands and OSIRIS in France; the NRU in Canada; and the SAFARI-1 in South Africa (see Table 2).

**Table 2: Major Current Mo-99 Producing Reactors[33]**

| Reactor name | Location | Annual operating days | Normal production per week | Weekly % of world demand | Fuel/targets | Date of first commissioning |
|---|---|---|---|---|---|---|
| BR-2 | Belgium | 140 | 5200 | 25-65 | HEU/HEU | 1961 |
| HFR | Netherlands | 300 | 4680 | 35-70 | LEU/HEU | 1961 |
| LVR-15 | Czech Republic | — | >600 | — | LEU/HEU | 1957 |
| MARIA | Poland | — | 700-1500 | — | HEU/HEU | 1974 |
| NRU | Canada | 300 | 4680 | 35-70 | LEU/HEU | 1957 |
| OPAL | Australia | 290 | 1000 – 1500 | — | LEU/LEU | 2006 |
| SAFARI-1 | South Africa | 305 | 2500 | 10-30 | LEU/LEU* | 1965 |
| RA-3 | Argentina | 230 | 240 | <2 | LEU/LEU | 1967 |

**Full conversion awaiting approval from foreign regulators.*
Source: OECD Nuclear Energy Agency; National Nuclear Security Administration.

The conversion of LEU targets has proven an economic challenge as much as a technical one. A 2009 National Academies of Science study commissioned by Congress to consider the production of medical isotopes without HEU found that there are "no technical reasons that adequate quantities [of medical isotopes] cannot be produced from LEU targets in the future."[34] Indeed, LEU targets, in many cases, could simply be substituted in reactors, but this simple change would require reactor and Mo-99 processors to process about five times as many targets and an equivalent increase in waste. Some processors have claimed that their facilities might not be able to accommodate these higher throughput requirements without substantial modification, although some other process changes could mitigate this need. The increased reactor irradiation capacity that would be required could also be limited.[35] Other alternatives in substituting LEU targets for the HEU variety include those similar to the changes in fuel elements and assemblies: making targets larger, or with a greater uranium density, or with more uranium meat and less cladding. All of these options would enable irradiating and processing fewer targets than simply substituting LEU fuel into existing targets, but could require new processes for producing Mo-99. In any case, production costs would likely rise marginally compared to the existing HEU targets and process, but without significantly increasing the cost of diagnostic imaging.[36]

One of the four major Mo-99 producers, the South African company NECSA, has committed to operating its medical isotope production facilities solely on the basis of LEU, with financial support from NNSA. In June 2009, the company announced that it had fueled the reactor itself with LEU. In October 2010, the United States signed a $25 million contract with a consortium led by NECSA (and also including ANSTO of Australia, a smaller all LEU producer) to import a significant quantity of isotopes produced completely with LEU. The first FDA-approved shipment of bulk Mo-99 was provided in December to a Boston-based company that provides technecium-99m generators and for a time in June 2011 the consortium was supplying one-third of the U.S. demand for Mo-99. [37] The targets have almost twice the uranium density of the previous HEU targets with South Africa hoping to start development in soon of new targets, perhaps with even higher density.[38] European processors and reactors are planning to convert to using LEU targets by 2015.[39] Australia and Argentina, have utilized LEU for several years and Australia would like to substantially increase production and processing of LEU isotopes if market conditions permit.[40]

**Table 3: Potential New projects for Mo-99 production**

| REACTOR | Six-day ci EOP/yr | Six day ci EOP/wk | Weeks/yr | Potential first year |
|---|---|---|---|---|
| **PROJECTS WITH PROCESSING FACILITIES AS PART OF PROJECT** | | | | |
| ROSATOM*/** | 52 000 | 1 000 | 52.0 | 2013 |
| ROSATOM*/** -TOTAL | 130 000 | 2 500 | 52.0 | 2013 |
| Babcock and Wilcox | 144 000 | 3 000 | 48.0 | 2014 |
| China advanced RR*** | 25 710 | 1 000 | 25.7 | 2015 |
| CNEA, Argentina | - | - | - | 2018 |
| SAFARI - 2 | 108 930 | 2 500 | 43.5 | 2020 |
| **PROJECTS REQUIRING ADDITIONAL PROCESSING FACILITIES****** | | | | |
| MURR** | 156 000 | 3 000 | 52.0 | 2012 |
| FRM - II** | 102 860 | 3 000 | 34.3 | 2015 |
| GE - Hitachi | 144 000 | 3 000 | 48.0 | 2014 |
| US - LEU target technology | 144 000 | 3 000 | 48.0 | 2014 |
| US - Accelerator technology | 144 000 | 3 000 | 48.0 | 2014 |
| India | - | - | - | 2015 |
| OPAL | - | - | - | 2015 |
| INR, Pitesti** | 120 000 | 3 000 | 40.0 | 2015 |
| Jules Horowitz*** | 108 000 | 3 000 | 36.0 | 2016 |
| South Korea (KAERI) | - | - | - | 2017 |
| PALLAS | 266 390 | 6 215 | 42.9 | 2020 |
| MYRRHA | 178 290 | 5 200 | 34.3 | 2022 |

** Project includes three reactors, two of which would be used to produce Mo-99 in a continuous fashion, with the third being a back up.*
*** Research reactor already exists, but is not yet irradiating targets for Mo-99 production.*
**** Under active construction.*
***** Projects in Europe would face a processing capacity limitation.*
Source: OECD Nuclear Energy Agency, "Supply of Medical Radioisotopes," p.18; Ira Goldman, "Toward a More Secure Future? Mo-99 Supply," September 2011.

These changes come at an economic cost—the South African process is said to cost at least 30-40 percent more than the previous HEU process—although the cost increase for the delivered pharmaceutical would be a fraction of that because it includes other costs that would not change, such as transport and marketing—the increased irradiation costs, for example, would represent less than one percent of the total cost.[41] NECSA is also still trying to iron out bugs in the process—particularly problems with obtaining a consistent yield of Mo-99.[42] The two major European producers Covidien and the Belgian National Institute for Radioelements (IRE) are working with NNSA towards being able to process LEU targets. In doing so, they have opted to accept a lower yield in the short term in order to meet the 2015 deadline for conversion. Over the longer term, they are working with the U.S. national laboratories to develop high yield targets intended to yield more Mo-99 and produce less waste.

Still, particularly in the short term, the combination of lower yield, waste and other costs[43] will put processors like the South Africans, Europeans, and Australians at a disadvantage compared to the Canadian giant MDS Nordion, which has shown no sign that it intends to convert from HEU to LEU targets. For now, Nordion continues to rely primarily on Mo-99 produced by the aging NRU reactor in

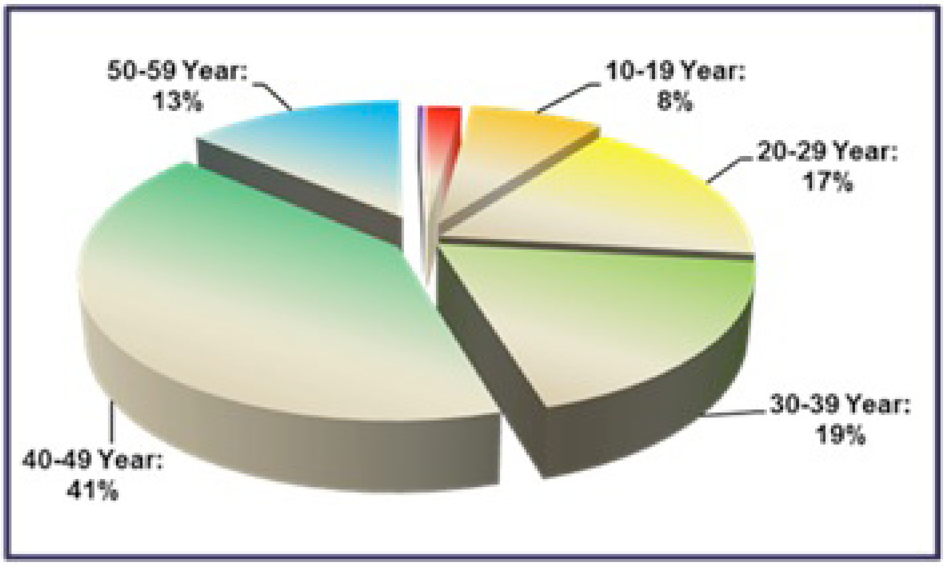
Chalk River, Canada, managed by the government-run Atomic Energy of Canada Limited (AECL). The facility, built in 1957, provides Mo-99 for about one-third of the world's medical isotopes and often more than half of those used in the world's biggest market, the United States. NRU operates on LEU fuel but uses HEU targets and Nordion does not have a processing line capable of processing LEU targets. Canada announced in 2010 that it would shut down the NRU reactor in 2016, but Nordion plans to continue processing HEU-based Mo-99 from Russia. Since Russia can provide its own HEU for the targets, it cannot be touched by the Schumer or Burr amendments.

In addition, NECSA and some officials in the countries also cite the difficulties in winning licensing approval from European and other governmental authorities to use the new materials in medical treatments, pointing to "complex and cumbersome" regulations as deterring potential customers. NECSA officials point out that technetium-99m manufacturers in Europe have to gain regulatory approval for new LEU-based isotopes from each country in the union. Even though the new LEU-based Mo-99 conforms to current standards for the isotope and should not affect the resulting technetium-99m, these regulatory approvals are expensive and time-consuming as they involve several sets of validation tests with many samples.[44] The licensing holdup has slowed NECSA' s conversion to full LEU-based production by an estimated two years—to the end of 2013.[45]

By contrast, the U.S. government took great pains to ensure that licensing did not pose a significant obstacle to the development of LEU-based Mo-99, closely coordinating efforts between NNSA, the Food and Drug Administration and other agencies.[46]

In addition to political obstacles, politicians have had to confront periodic shortages in the Mo-99 market, the result of deep structural problems. Market demand for Mo-99 has soared over recent decades amid rising demand for diagnostic scans; however, there has been little incentive for new irradiation facilities to be constructed as current producers built their facilities decades ago with government funding. They continue to benefit from operating subsidies and pass these on to processors in the form of below-market Mo-99 prices. The result has been an aging of the research reactor fleet, particularly those involved in isotope production. [47]

**Figure 8: Aging Reactors**




*Jong Kyung, "Current Status of the Construction of New Reactor in Korea," conference presentation 15 November 2010.

Likewise, the growth of processing facilities has been limited by a lack of market incentives including government reimbursement rates for isotopes that do not reflect the full costs of processing. The lack of adequate geographic distribution of these facilities also hampers the final supply of isotopes.[48]

These problems were made evident between May 2009 and August 2010 by the shut down of the NRU reactor. A survey of 1217 respondents conducted by the Society of Nuclear Medicine shortly after the Chalk River shut down found 90.71 percent of their facilities were affected by the Mo-99 shortage, with 64.17 percent having no access to an alternate technetium generator source. Many of the scheduled treatments had to be postponed, cancelled, or changed.[49] Further exacerbating the shortage, the HFR in the Netherlands was shut down for scheduled maintenance for a month in July 2009. Together, the reactors normally supply two-thirds of the world's Mo-99.[50]

*Consequences of the 2009-2010 NRU Shutdown*

The extended shut down affected the Mo-99 market in three different ways, all of which have an effect on efforts to convert to LEU fuel and targets, both in the short and long term:

1) Governments sought ways to ensure a sufficient supply of isotopes given long-term projections of supply shortages.[51] Methods included better sharing of information about proposed reactor shutdowns for maintenance reasons and efforts to coordinate such shutdowns and conversions to LEU fuel or targets so as not to interfere with sufficient supply. Longer-term measures included increasing production and asking the OECD Nuclear Energy Agency and the International Atomic Energy Agency to hold meetings and conduct fundamental studies to make recommendations for altering the market structure to prevent such supply shocks. The NEA concluded that governments should terminate their effective subsidies for irradiation facilities and allow both

these facilities and processors to recover full market prices. It also concluded that this change would not have a significant effect on the price charged to patients or their availability.

2) One way of increasing production was for new entrants to join the field or for reactors that only supplied local markets to seek more of a global reach. Some of these included countries such as Poland and the Czech Republic that initially used HEU but are now moving to convert. Other countries such as South Korea have decided to move forward with their own LEU-based (see Table 3).[52] A worrying case, however, has been that of Russia. As noted before, the Russian Mo-99 processor ISOTOPE concluded an agreement with MDS Nordion in September 2010 to supply the Canadian processor with Mo-99 and hopes to provide around one-fifth of the world market for Mo-99 (see Table 3).[53] The Mo-99 will be produced by Russia's Rosatom, which employs both HEU fuel and targets in its reactors at Dmitrovgrad. Russian officials have indicated that they will only begin to consider conversion after they capture this market share and they are confident there is sufficient supply of medical isotopes in the global market.[54]

3) The 2009-10 supply crisis prompted physicians and other participants in the supply chain to try to eke out greater efficiencies in the use of Mo-99 and technetium 99-m and for doctors to restrain the use of the technology. Demand dropped during the supply crisis for medical imaging services using Mo-99 and has continued for at least some time afterwards. That led to an effective oversupply as the NRU facility was restarted and new entrants joined the field.[55] Companies like NECSA whose bottom lines were already squeezed by having to pay a premium for using fully LEU-based Mo-99 felt a particular pinch. The changes also indicated that there was more flexibility in demand than may believed previously and that better models for forecasting demand and how it and public health might be affected under various scenarios were needed.

*U.S. Legislation*

Meanwhile, some in Congress have attempted to reinvigorate U.S. leadership by effectively repealing the Burr Amendment and supporting domestic production of fully LEU-based isotopes. In 2009, the House of Representatives passed "The American Medical Isotopes Act" on a 400-17 vote. Similar legislation passed the Senate in November 2011. The Senate legislation provides three key incentives for LEU-based production. First, the act would once again ban U.S. exports of HEU for targets to Western Europe and Canada, although the legislation provided for such exports to be phased out over 7 to 13 years, a time when many of the current reactors using HEU targets will have ceased operating. It also authorizes cost-sharing arrangements to generate domestic isotope production (as noted above, four projects in the United States have already received some seed funding and are highlighted in Table 3). Finally, it established government responsibility for waste disposition, providing a means to relieve operators of the financial, practical and legal burdens of waste disposal.[56] To become law, the House must pass the Senate bill or compromise legislation must be approved by both Houses.

Obama administration officials, while welcoming the legislation, have also told House lawmakers recently that they would like to develop incentives to encourage purchases of LEU based isotopes, in particular to deal with the potential HEU-based imports from Russia. Such "preferential procurement" they said could include special labels for LEU-based isotopes, additional export constraints on HEU as LEU-based isotopes become available, examining whether to change the costs, fees, and other reimbursement processes to favor LEU-based isotopes.

## THE 2012 SUMMIT: AMBITIOUS HOPES, BUT MINIMAL OUTCOME?

Some ambitious ideas have been put forward as the sherpas and sous-sherpas have engaged in the process of drafting a communiqué for the 2012 Seoul Summit.

France, for example, has circulated a non-paper calling for the creation of HEU management guidelines (modeled on existing plutonium guidelines) to provide greater transparency on states' HEU holdings and tougher standards for security, transportation and international transfers. The guidelines would aim in part at raising the cost of storing the material, encouraging states that are making little use of stocks to eliminate or consolidate them.[57]

The United States has sought to convince summit participants to endorse a 2015 deadline for eliminating the use of HEU in the production of medical isotopes, partly in a bid to convince Russia to embark on course of LEU-based production rather than HEU-based production.

Those negotiating the summit communiqué continue to discuss the HEU guidelines and isotopes initiatives, but have met substantial resistance. Some developing countries have resisted drafting HEU guidelines as part of the summit process, saying such issues were best addressed within the IAEA. They and Russia have also resisted a U.S.-led effort to set a date certain for phasing out the use of HEU in research reactors that produce medical isotopes. However, U.S. officials have indicated that European officials may be willing to commit bilaterally to a 2015 deadline for conversion and to unveil that commitment at the summit.

The difficulties in winning support for these efforts reflects in part the problems often seen in large multilateral engagement: difficulty focusing the participants towards problem-solving and away from established positions, a tendency to settle at the lowest common denominator and challenges in making sure all the participants are still engaged and on board with discussions. The organizers have also faced a more basic problem of questions about the legitimacy and lifespan of the nuclear security summit process vis-à-vis other more established multinational institutions such as the Nuclear Nonproliferation Treaty review process or the IAEA. Although these bodies tend to give short shrift to nuclear security, they are the strongholds of developing countries, which generally view nuclear security as a lower priority than other nuclear policy goals. Some countries have also questioned the legitimacy of any global attempt to address the issue of nuclear security, seeing it a potential violation of their national sovereignty and something that would allow other countries to discover their security vulnerabilities.

Meanwhile, South Korea and the United States continue to encourage countries to make "house gifts" related to HEU minimization. One particularly telltale sign will be how forthcoming Russia is with its pledges in this field. Two important gifts in this regard are expected to be the conversion of Poland's MARIA reactor and the Czech LVR-15 reactor.[58]

However, one gift that the organizers had hoped to receive is now not expected to materialize. Belarus, which was excluded from the first summit for its failure to make a similar commitment on HEU, subsequently made a similarly important commitment. In December 2010, U.S. Secretary of State Hilary Clinton and Sergei Martynov, the foreign minister of Belarus, signed a joint statement in which Minsk said, it "has decided to eliminate all of its stocks" of HEU by the time of the Seoul Summit. NNSA officials said shortly thereafter that it was anticipated that the shipments of the most dangerous fuel, including 40 kg (88 pounds) of weapon-grade HEU would take place in early 2012, shortly before the summit. In August 2011, however, Minsk said it would suspend the shipments until the United States lifted sanctions it had recently imposed on Minsk in response to a crackdown by President Alexander

Lukashenko on his political opponents and the regime's ties with Iran.[59]

One contribution to HEU minimization may come from an unexpected source. South Korea is looking to build a parallel meeting for industry leaders slated to occur around the Nuclear Security Summit into something more substantial than the similar event that took place in Washington in 2010. The organizers of the Korean industry meeting are planning to put together three working groups—on HEU minimization, the intersection of safety and security and information security—that will draft recommendations related to industry for political leaders at the summit. One idea that might be considered by the HEU group is support for a voluntary code of conduct on HEU minimization in which various stakeholders—operators, customers, governments—can pledge to take steps to minimize and ultimately eliminate HEU.[60]

## NEW STRATEGIES

Whatever the eventual outcome of the communiqué, it is important to note that the summit is just one milestone in a long-term and already decades-long effort to minimize HEU. In order to achieve success in the future, this effort should include the following goals:

1. *Promote HEU Guidelines.* These do not necessarily need to be enacted by the summit. After all, they do not require the support of a large number of countries, just those countries with civil stocks of HEU. It may be easier to win support for these efforts one-by-one rather than in an extended multilateral negotiation.

2. *Set a Global Deadline for Phasing Out HEU-Based Medical Isotopes.* Ideally, given the European commitment to a 2015 deadline this deadline should be set at 2015. But if a slightly later deadline is needed to win Russian acquiescence, this might be worth the delay. Government licensing authorities and industry could also commit to having appropriate licensing rules in place by the time countries are able to produce isotopes from LEU fuel and targets so this does not become an obstacle to conversion.

3. *End Subsidies for Irradiated Mo-99 from Research Reactors.* In the near future, governments should raise prices of irradiated Mo-99 produced using HEU fuel or targets to market levels as suggested by the HLG-MR. LEU-based producers should be able to receive effective subsidies until HEU use is phased out as well as subsidies for conversion. Host governments or particularly in the case of Russia, international donors such as the United States or Canada could provide subsidies.

4. *Engage in Preferential Procurement.* In addition to the United States, national governments and the World Health Organization should consider supporting or requiring government purchases of LEU-based isotopes. This could be on the agenda for the 2014 summit in addition to a deadline for phase-out.

5. *Wield U.S. Leverage on Medical Isotopes.* Should these efforts fail or as a possible supplement, the United States could take advantage of its leverage as the world's largest importer of Mo-99 in one of several ways. One option, given that domestic producers will avoid HEU, would be to legislate that the United States must halt the import of HEU-based versions of these isotopes when a sufficient supply of the alternatives is available. Another option would be to require U.S.

health authorities to terminate authorization for use of HEU-based versions when a sufficient supply of the alternatives is available. A third option would be to impose a tax on HEU-based versions of these isotopes, channeling any resulting revenue to support domestic production without HEU.

6. *Cultivate New Leaders.* For decades, the United States has borne the lion's share of the HEU minimization effort. Particularly given U.S. budget difficulties, other countries, particularly fast-growing Asian countries such as South Korea and China, need to do more in this regard and fortunately, both are already beginning to do so. South Korea's efforts are detailed in the sidebar while China has begun to convert the HEU-based Miniature Neutron Source Reactors that it supplied to other countries and pledged to take back their fuel. An instrument that might be used to solicit further contributions in this regard, particularly for converting Russian reactors is the G-8 Partnership against Weapons of Mass Destruction, which seems to be casting about for a new mission.

7. *Ban Other HEU Uses.* Track 1.5 discussions should be initiated to see if progress can be made forward in banning other uses of civil HEU such as fast reactor core and space reactors. HEU-based space reactors, for example, have been used in the past for propulsion and to power satellites, but none are currently in operation.[61] This presents an opportunity for Russia and the United States in particular, that could prevent other countries (such as Iran) from citing such reactors as a reason to move to weapon-grade HEU.

8. *Initiate a Discussion on the Conversion of Naval Reactors.* France and others in the now regularized P-5 discussions on disarmament and nonproliferation should seek to use that forum to initiate a discussion on the use of LEU in naval and propulsion fuel. If this is not possible, this should be the subject of a dialogue between the United States and Russia, perhaps led by their academies of science. As long as fabrication or fuel facilities are still handling HEU, the possibility of terrorist acquisition of this material remains high.

9. *Link Efforts to Minimize Civil HEU to Efforts to Curtail Weapons HEU.* In the long term, the efforts to ban HEU in civil purposes and naval fuel will need to be linked with discussions on a Fissile Material Control Treaty, which would ban the production of fissile materials for nuclear weapons. The initial goal should be to ban all production of HEU for any purpose, civil or military. In the short term, the United States and Russia could bolster other countries' support for efforts to minimize civil HEU by taking further steps to reduce their holdings of weapons HEU. By the time it ends in 2013, the "Megatons to Megawatts" program will have downblended 500 tons of Russian weapons HEU for use in U.S. power reactors. In particular, the two countries should seek to continue this effort, making sufficient adjustments to make it more palatable to Russia.

## SIDEBAR

***Korea's Contribution to HEU Minimization Efforts—By Ferenc Dalnoki Veress***

In the 1970s, the United States exported more than 28 kg of HEU to the Republic of Korea that was used to fuel two TRIGA reactors for isotope production and research. Both reactors are now decommissioned, and all of the U.S.-origin HEU in the form of fresh and spent fuel bundles has been shipped back to the

United States. In addition, to the repatriation of U.S.-origin HEU, the Republic of Korea has also become an important technical contributor to the global effort to convert research reactors from utilizing HEU fuel to LEU. It has developed a novel technique known as Centrifugal Atomization to create an LEU fuel with a greater uranium density. This technique produces small uranium-molybdenum (U-Mo) spheres that can be easily incorporated into a fuel element matrix made of another metal (for example aluminum). Using this technique, the U-Mo metal is heated to a temperature greatly exceeding its melting point causing the bulk metal to change state from a solid into a liquid. The U-Mo metal liquid is then deposited onto a rapidly rotating disk which forces the liquid to quickly become droplets a fraction the size of a human hair. The droplets cool immediately and are collected in the solid state at the periphery of the disk where they can be incorporated into research reactor fuels.

This Centrifugal Atomization technique outperforms the standard technique, which is to grind solid U-Mo metal into small spheres. The fuel was originally developed for Korea's HANARO research reactor (at KAERI's headquarters in Daejeon); however the Korean program has been so successful that various versions of the fuel have been exported to labs in the United States, France and Argentina since 1997. In fact, this year KAERI signed a memorandum of understanding with the United States to help develop fuels for the BR-2 high performance reactor in Belgium, which still uses tens of kilograms of HEU annually to produce medical isotopes. As part of the agreement, KAERI will supply as much as 100 kg of fuel at no cost. Korea remains an important partner in the global effort to reduce the enrichment of research reactors. The KAERI-Belgium agreement will be announced in March at the Seoul Nuclear Security Summit as one of Korea's "House gifts."

In another contribution to HEU minimization efforts, Korea is in the process of constructing a new reactor near Pusan specifically dedicated to the indigenous production of medical isotopes. The targets used will utilize a thin LEU uranium foil that has been developed as part of a Coordinated Research Project (CRP) collaboration with many other nations under the leadership of the IAEA. This novel target is expected to be used in many indigenous research reactors around the world. Korea's contribution has been very significant in delivering test foils to many of the participants of the CRP to use and test new Mo-99 production techniques.

## (Endnotes)

1 Pablo Adelfang, "Non-proliferation and the Reduction of Commercial Traffic in HEU," Symposium on Progress, Challenges, and Opportunities for Converting U.S. and Russian Research Reactors from Highly Enriched to Low Enriched Uranium Fuel, Moscow, June 8-10, 2011.

2 The International Atomic Energy Agency says that 25 kg of U-235 in HEU is sufficient for one nuclear weapon, although experts say that states could construct one with less material. The IAEA, on the other hand, estimates that terrorists would probably need about 50 kg of HEU to build a simple nuclear device, allowing for some experimentation, material loss, and other.

3 See Alan J. Kuperman, "Can RERTR Be Expanded to a Global HEU Phase-Out?" delivered at the 33rd International Meeting on Research and Test Reactors (RERTR), October 25, 2011, Santiago, Chile. The nine reactors are the U.S. ATR, HFIR, MURR, NBSR, and MIT reactors, as well as the HFR, FRM-2, BR-2, and Orphee reactors in Western Europe.

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13 UN Security Council Resolution 1887, September 24, 2009. Paragraph 25, http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N09 /523/74/PDF/N0952374.pdf?OpenElement.

14 Communiqué of the Washington Nuclear Security Summit, April 13, 2010, http://www.america.gov/st/texttrans-english/2010/April/ 20100413171855eaifas0.6155773.html.

15 Washington Nuclear Security Summit Workplan, April 13, 2010, http://www.america.gov/st/texttrans-english/2010/April/20100413182810ihecuor0.8188702.html.

16 "Highlights of the National Commitments Made at the Nuclear Security Summit," White House press release, April 13, 2010, http://www.whitehouse.gov/the-press-office/highlights-national-commitments-made-nss; "NNSA Achieves Milestone in Removal of HEU from Ukraine," National Nuclear Security Administration Press Release, December 31, 2010, http://nnsa.energy.gov/mediaroom/pressreleases/ukraineheuremoval.

17 It actually is not likely that the 400 kg would suffice for 16 bombs as this amount, per endnote 1, would require 100 percent U-235, which is not only unlikely technically but probably not characteristic of some of the ship material which had significantly lower enrichment levels.

18 Thomas Young, Cole Harvey, and Ferenc Dalnoki-Veress, "It's not just New START: Two other U.S.-Russian Nuclear Agreements Boost U.S.-Russian Reset," James Martin Center for Nonproliferation Studies, December 21, 2010, http://cns.miis.edu/stories/101221_nuclear_agreements.htm.

19 Braden Civins, "Conversion Aversion: The Sources of Russian Reluctance to Conversion of HEU-Fueled Research Reactors," University of Texas at Austin, 2011, http://www.heuphaseout.org/wp-content/uploads /2011/04/Civins2.pdf; Elena Sokova, "Phasing out Civilian HEU in Russia: Opportunities and Challenges," *The Nonproliferation Review*, Vol. 15, No. 2, July 2008, p. 209-236.

20 An estimated 10 tons of HEU are tied up with critical and subcritical assemblies. See Kuperman, "Can RERTR Be Expanded to a Global Phase Out," and Pablo Adelfang, "Non-proliferation and the Reduction of Commercial Traffic in HEU."

21 Adelfang, "Nonproliferation and the Reduction of Commercial Traffic in HEU"; Kuperman, "Can RERTR

Be Expanded to a Global HEU Phaseout?"
22 F. Arinkin, et al., "Program of Critical Assembly Conversion to Low-Enriched Uranium Fuel at the Institute of Nuclear Physics in Kazakhstan," delivered at the 33rd International Meeting on Research and Test Reactors (RERTR), October 24, 2011, Santiago, Chile. Japan is the other pioneer in this regard and has been conducting a feasibility study on the conversion of the Kyoto University Critical Assembly. See H. Unesaki, et al, "On the Feasibility Study for Utilization of Low Enriched Uranium Fuel at Kyoto University Critical Assembly (KUCA)," 33rd annual meeting of RERTR.
23 "Medical Isotope Production Without Highly Enriched Uranium," National Academy of Sciences, 2009, p. 2, 18, http://www.nap.edu/catalog.php?record_id=12569.
24 Extracted from the Food and Drug Administration approved pharmaceutical list, 2008; National Academy of Sciences, "Medical Isotope Production Without Highly Enriched Uranium," p. 2, 20.
25 Miles A. Pomper and William C. Potter, "Medical isotope production: The U.S. must follow South Africa's Lead," *Bulletin of the Atomic Scientists*, December 17, 2010, p. 2, www.thebulletin.com; Nuclear Energy Agency, "The Supply of Medical Radioisotopes: Interim Report of the OECD/NEA High-level Group on Security of Supply of Medical Isotopes," Organization for Economic Co-operation and Development, 2010, p. 7.
26 "Weapon-grade Uranium and Radiopharmaceutical Production," International Physicians for the Prevention of Nuclear War, http://www.ippnw.org/PDF%20files/HEUMedicalFactSheet.pdf.
27 "Medical Isotope Production Without Highly Enriched Uranium," National Academy of Sciences, 2009, p. 25, http://www.nap.edu/catalog.php?record_id=12569.
28 Ibid., p. 29.
29 Ibid., p. 11.
30 Nuclear Energy Agency, "The Supply of Medical Radioisotopes," Organization for Economic Co-operation and Development, 2010, p. 23.
31 For More details, see G.F. Vandergrift et al, "GTRI Progress in Technology Development for Conversion of Mo-99 Production to Low Enriched Uranium," delivered at the 33rd International Meeting on Research and Test Reactors (RERTR), October 24, 2011, Santiago, Chile.
32 F/ Charrolais et al, "Leonidas U(Mo) Dispersion Fuel Qualification Program: Progress and Perspectives," delivered at the 33rd International Meeting on Research and Test Reactors (RERTR), October 24, 2011, Santiago, Chile.
33 Nuclear Energy Agency, "The Supply of Medical Radioisotopes," p. 2.
34 National Academy of Sciences, "Medical Isotope Production Without Highly Enriched Uranium," p. 2.
35 Ibid., p. 91-92.
36 Ibid., p. 140.
37 Previously, the reactor had been fueled with HEU from the former South African nuclear weapons program. See the company's press release at http://www.necsa.co.za/Press-Room/Press-Releases-427.aspx. Chloe Colby, "The Conversion of South Africa's Medical Isotope Production from HEU to LEU: Policy Implications for Global Conversion," University of Texas at Austin, p. 9, http://www.heuphaseout.org/wp-content/uploads/2011/04/Colby.pdf.
38 NECSA was already using two to three times the number of targets because its enrichment was at the 45 percent level rather than the typical 90 percent. This eased the conversion process—and the resultant costs considerably from what might face other producers. (Colby, p. 5) The uranium density in its new LEU fuel is 2.75g/ $cm^3$ compared to 1.42 $g/cm^3$ in the previous HEU fuel. New varieties would require changes to processing effort but would seek to attain higher densities to get a greater Mo-99 yield and reduce waste. In particular, current dispersion LEU targets have more impurities than with HEU targets.
39 See Roy Brown, "Covidien's Experience with the Conversion from HEU to LEU;" Jean-Michal Veanderhofstadt, "Conversion of Belgium's IRE Mo-99 Production Process," remarks delivered at National Nuclear Security Administration Topical Meeting on Mo-99, December 4-7, 2011, Santa Fe, New Mexico.
40 ANSTO has won agreement in principle to build a larger processing plant that can handle up to 3000 six-day curies per week—around 15-25 percent of current global market—as well as a waste treatment facility. But ANSTO officials have said that they can only go forward with this investment estimated at around $250 million if other producers are paying full costs of irradiation and processing. See Adi Paterson, "An International Perspective on Practical and Economc LEU Based Production of Mo-99 incorporating the Full Materials Cycle," remarks at NNSA Mo-99 Topical Meeting.
41 Interview with Gavin Ball, NECSA and Ron Cameron, "OECD-Nuclear Energy Agency's Policy Approach

for a Reliable Supply of Mo-99," remarks at NNSA Mo-99 Topical Meeting.

42 Colby, "The Conversion of South Africa's Medical Isotope Production," p. 6-8.

43 Roy Brown from Covidien points to one-time conversion costs, development costs, facility modification costs, and regulatory costs in addition to the additional operational costs of using LEU (waste and lower yield). Brown, "Covidien's Experience with the Conversion from HEU to LEU."

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49 The Society of Nuclear Medicine, "Isotope Shortage Survey Final Results," The Society of Nuclear Medicine, 2009, http://www.snm.org/docs/Isotope%20Shortage%20Survey%20Results%208-6-09.pdf.

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51 Nuclear Energy Agency, "The Path to A Reliable Supply of Medical Radioisotopes," *Nuclear Energy in Perspective*, June 2011.

52 Nuclear Energy Agency," The Supply of Medical Radiosotopes," p. 11, 18.

53 Kendra Vessels, "HEU Isotope Production in Canada and Russia," p. 7-10.

54 Ibid, P 11-12, The official cited in the Vessels paper is NIIAR Deputy Director Rostislav Kuznetsov. Rosatom Director General Sergei Kiriyenko offered similar remarks at a March 2011 event in the Russian Embassy in Washington. Kiriyenko said Russia supported the idea of moving to LEU production but that Moscow's first priority was ensuring sufficient supply of isotopes to patients.

55 Chloe Colby, "The Conversion of South Africa's Medical Isotope Production", p. 12.

56 Miles A. Pomper and William C. Potter, "Medical isotope production," p. 4.

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58 The Czech reactor was fully converted, ahead of schedule, in 2011and the Maria reactor is expected to be converted by June 2012. See V. Broz et al, "Completed Conversion of the LVR-15 Research Reactor," and G. Krzysztoszek, "Qualification Process of LEU Fuel—CERCA type and Conversion Planning for MARIA Research Reactor," both at the 33rd Annual Meeting on Reduced Enrichment for Research and Test Reactors.

59 For more information, See Miles A. Pomper, "Bringing Belarus Back to the Table," WMD Junction, September 20, 2011, http://cns.miis.edu/wmdjunction/110920_belarus.htm.

60 For information about a proposed code see Christina Hansell et al, "Building Momentum to Minimize HEU Use, Improve Nuclear Security and Combat Nuclear Terrorism," presentation at the International Symposium on Nuclear Security, Vienna, April 2, 2009, http://wwwpub.iaea.org/mtcd/meetings/PDFplus/2009/cn166/CN166_Presentations/Session%208/074%20hansell_et_al27mar09.pdf.

61 Adelfang, "Nonproliferation and the Reduction of Commercial Traffic in HEU."

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