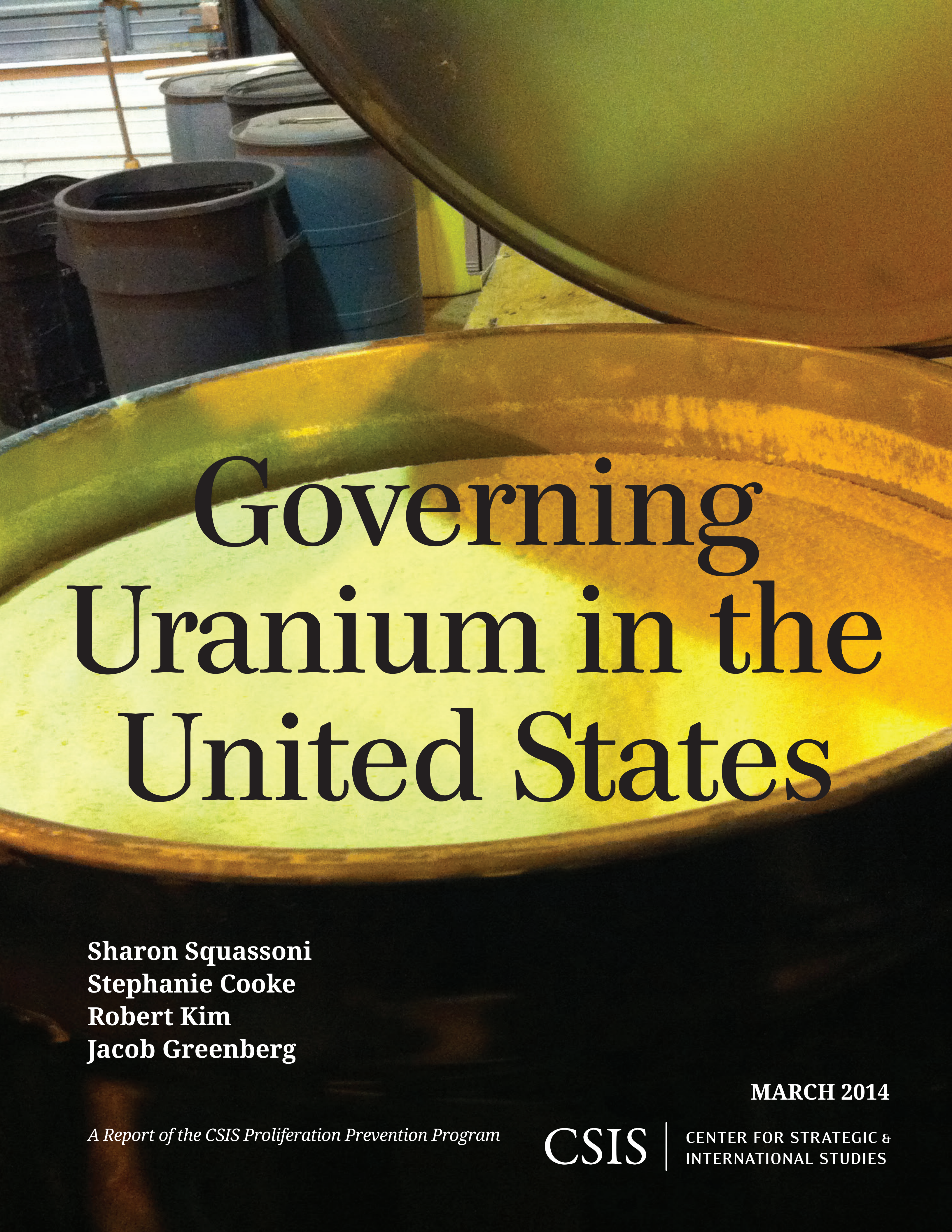

# Governing Uranium in the United States

**Sharon Squassoni**
**Stephanie Cooke**
**Robert Kim**
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**MARCH 2014**

*A Report of the CSIS Proliferation Prevention Program*

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# Acknowledgments

This report is the result of a nine-month project called “Governing Uranium.” Over the course of the project, the CSIS Proliferation Prevention Program was able to capture perspectives regarding the security of uranium mining, recovery, and conversion operations through extensive interviews, workshops, meetings, and outreach. The authors are grateful for the valuable time and insight received from a wide array of regulators, industry representatives, academics, and policy experts.

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# 1 Introduction

The Proliferation Prevention Program at the Center for Strategic and International Studies (CSIS) participated in a global project on uranium governance led by the Danish Institute for International Studies that looks at uranium accountability and control in 17 uranium-producing countries. The project seeks to identify governance gaps and provide policy recommendations for improving front-end transparency, security, and regulation. The impetus for the project is the concern that monitoring activities at the front end—uranium mining, milling, and conversion—could be strengthened.

The term "governance" is used here to include licensing and regulation by government and best practices by industry specifically to further the objectives of nuclear nonproliferation and nuclear security. Along the spectrum of activities involved in producing and processing uranium, the level of government control and regulation varies widely. Figure 1.1 shows the range of front-end processes related to extracting and processing uranium. Over time, many elements of licensing and regulation of uranium in the United States evolved to address environmental and safety concerns. While these are important, they are not the main focus of analysis. Instead, this analysis explores the degree to which uranium has been accounted for and protected from theft and/or diversion. The scope of inquiry includes uranium production, storage, and transportation, including imports and exports.

CSIS held a workshop on uranium governance practices in Washington, D.C., on June 5, 2013 (see Appendix 1 for the agenda and participants list). The conclusions from the workshop were factored into this analysis, but any errors are the sole responsibility of CSIS.

The United States has been a major producer and consumer of uranium over the years, both for nuclear weapons and for peaceful purposes, and for domestic and international consumption. As a producer, it has been eclipsed by Australia, Canada, and Kazakhstan in the past few decades. However, with roughly 100 operating nuclear power reactors, it continues to have a major appetite for enriched uranium (about 22 million kilograms of $U_3O_8$ equivalent in 2012).[1] In the past century, promotion and control of uranium production in the United States has followed roughly five phases:

- **Uranium ignorance**—years of production as a by-product of vanadium and radium (to 1939)

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[1] U.S. Energy Information Administration., "Uranium Marketing Annual Report, with data for 2012," May 16, 2013, http://www.eia.gov/uranium/marketing/.

- **Uranium positive control**—years of promotion by the Atomic Energy Commission (AEC), the “uranium rush,” and tight controls on production (to mid-1950s)
- **Uranium laissez-faire**—relaxation of strict controls; the U.S. market opens to foreign production (to 1978)
- **Uranium slump** (1982–1992)
- **Steady state uranium** (from 1992 to the present)

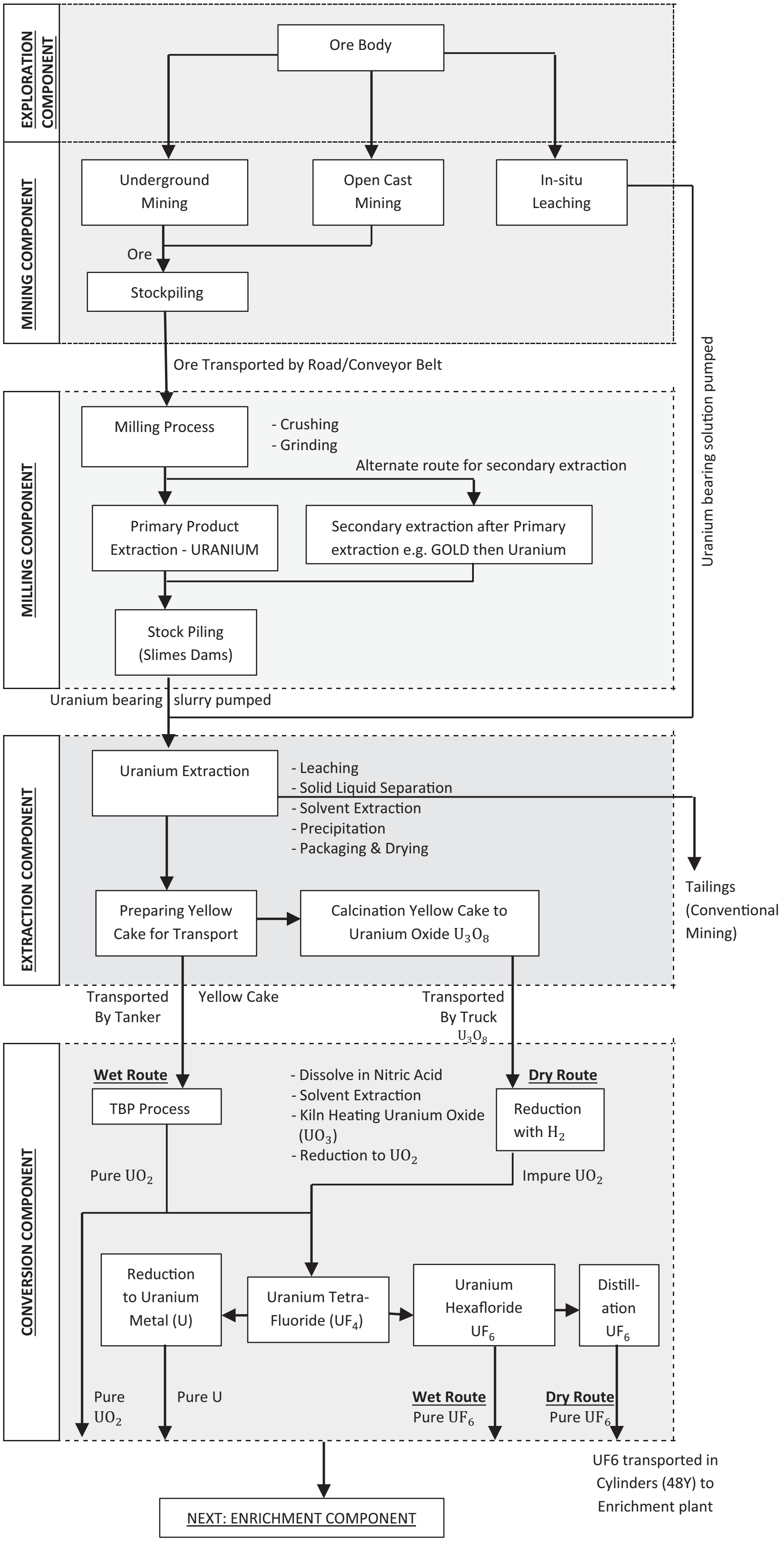
Before U.S. officials recognized uranium’s strategic importance for nuclear weapons production, its mining and handling was treated no differently from those of other ores. In fact, before nuclear weapons were invented, uranium was primarily extracted as a by-product of more economically attractive radium and vanadium. As uranium’s strategic importance became apparent, the U.S. government sought to control not only uranium supplies within the United States, but elsewhere (particularly in Canada and Africa). From their wartime vantage point, members of the 1946 Acheson-Lilienthal committee, guided by Robert Oppenheimer, included uranium among “dangerous” nuclear activities that they proposed should come under international control in the postwar period. At their most restrictive, however, U.S. uranium controls never extended into mining, but were limited to milling and enrichment ownership by the U.S. government.

A decade of simultaneous promotion and strict government control (“uranium positive control”) lasted until the mid-1950s, after which military demand for uranium declined, prompting a gradual easing of controls over both domestic production and foreign imports. Few domestic controls were in place; instead, accounting was left in private hands, which had some negative effects in terms of safety and security. The system of material accounting and control that is in use today in the United States developed slowly over time.

The uranium market fell into decline in the 1960s, but with the growth of commercial nuclear power over the next decade, demand for uranium in the United States once again grew. By the 1970s, impetus for control came from two separate though related directions: (1) public and worker safety and (2) the environment. It was accompanied by the establishment of the Department of Energy (DOE; initially the Energy Research and Development Agency), the Nuclear Regulatory Commission (NRC), and the signing of the Nuclear Nonproliferation Treaty (NPT). The greatest impact on the front end of the fuel cycle came arguably from the 1978 Uranium Mill Tailings Radiation Control Act (UMTRCA), which enacted stricter controls over uranium to improve environmental and safety performance at uranium mines and mills. Safety and environmental concerns have dominated improvements in governance since then. Although they played a key role in the mid-1940s, security concerns have not been a motivating force for change in uranium governance in the United States since about the mid-1950s, even after September 11, 2001.

That said, the United States has led international efforts to strengthen the nuclear nonproliferation regime, some of which have addressed uranium governance concerns. For example, efforts over the past 20 years have focused increasingly on closing gaps in the

## Figure 1.1. Diagram of Uranium Production Process



Source: International Atomic Energy Agency, "Nuclear Security in the Uranium Industry," Draft IAEA Nuclear Security Series, November 2012.

system of declarations and inspections. States party to the NPT were required to report exports of uranium to non-nuclear-weapon state parties and imports of uranium for nuclear end uses under comprehensive safeguards agreements; they are now required to provide more information about their uranium imports and exports under the Additional Protocol (INFCIRC/540), as well as information specifying the location, operational status, and estimated annual production capacity of uranium mines and concentration plants (the same is true of thorium). Information about individual mines may also be requested by the International Atomic Energy Agency (IAEA). The Additional Protocol does not require detailed material accountancy in these cases, but just general information. There are still no requirements for inspections or material accounting at mines, mills, or conversion plants, because the starting point of IAEA safeguards is the point at which uranium is ready for enrichment or fuel fabrication. However, the Additional Protocol also provides for access by inspectors to sites identified, including uranium mines. Many of the provisions do not apply to uranium ore and ore residues, which are not considered to be source material, but would apply to concentrates.[2] For source material that has not reached the stage of suitability for fuel fabrication, states adopting the Additional Protocol must report details about the uranium where it exists in quantities over 10 metric tons,[3] as well as details about imports and exports, regardless of the end use.[4]

The United States has had a Safeguards Agreement in force with the IAEA since 1980 and an Additional Protocol Agreement put in place in 2009. The Safeguards Agreement states that IAEA safeguards do not apply to material in mining or ore processing activities. With respect to complementary access, the U.S. agreement specifies that access will be on a selective basis (Article 4.a.i), among other restrictions. With respect to reporting exports and imports, the United States, the Union of Soviet Socialist Republics (USSR), and the United Kingdom informed the IAEA in 1974 (INFCIRC/207) that they would report exports to non-nuclear-weapon states of nuclear material exceeding one effective kilogram (including source material, which is not ore or ore residue and excluding material for nonnuclear uses) and imports of such material from states where it was subject to IAEA safeguards right before its export. The information provided prior to export would include the exporter, importer, and a description of the material (including quantities and composition) and shipments would be confirmed afterwards. In 1995 the U.S. government agreed to voluntarily report imports and exports of one kilogram or more of source material (natural uranium, depleted uranium, and thorium) to the IAEA on a monthly basis.

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[2] For reference, "uranium ore concentrate," "yellowcake," and "$U_3O_8$" are defined in the Appendix 4 Glossary of Terms. "Natural uranium" is defined as uranium that has not yet been enriched; natural uranium includes ore, yellowcake, and unenriched uranium hexafluoride ($UF_6$).

[3] "Protocol Additional to the Agreement between the United States of America and the International Atomic Energy Agency for the Application of Safeguards in the United States of America," International Atomic Energy Association, INFCIRC/288/Add.1, March 9, 2009.

[4] 10 Code of Federal Regulations (CFR), §40.31. Uranium processing plant owners and any other applicant for a license to possess and use source material are required to submit information referred in the particular Department of Commerce/Nuclear Regulatory Commission (DOC/NRC) AP form. The AP-6 form for uranium mines and the AP-7 form for concentration plant operations can be found at http://www.bis.doc.gov/index.php/forms-documents/doc_view/458-report-handbook-for-locations.

Underground uranium mining in Nucla, Montrose County, Colorado.
Source: U.S. National Archives and Records Administration, ARC #543775. 1972. Environmental Protection Agency.

The United States has extensive international reporting commitments because of its treaty and other voluntary obligations. Other nuclear weapon states could be encouraged to adopt such international reporting commitments for source material, including uranium ore concentrates. However, U.S. practices for uranium governance are likely to be less useful as a model for emulation by non-nuclear-weapon states. The evolution of control nonetheless may indicate some useful leverage points for other countries that may become active in uranium mining and transport.

# 2 The History of Uranium in the United States

## Uranium Ignorance

For 150 years after its discovery in 1789, uranium was used primarily as a coloring agent for ceramic glazes. The 1898 discovery of radium by Marie and Pierre Curie heightened interest in uranium-bearing ores, since trace amounts of radium are typically found alongside much larger quantities of uranium. In the United States, the first important radium sources were from sandstone deposits in western Colorado and eastern Utah. Between 1898 and 1923, that area produced some 275,000 tons (250,000 metric tons) of ore, yielding about 200 grams of radium, 2,000 tons (1,814 metric tons) of vanadium, and a small but indeterminate amount of uranium, most of which ended up in the tailings piles.[1] The 1872 Mining Act made it relatively easy to stake claims for ore, including uranium ore. Under the Act, prospectors could stake out areas and file claims for resources, despite (or because of) the fact that the federal government owned almost 90 percent of the western land where uranium was sought. Mining on private lands required negotiations, although surface owners could not deny mining access.

In 1923 U.S. production was supplanted by output from the large, rich Shinkolobwe vein in the southern part of the Belgian Congo (currently the Democratic Republic of the Congo), mined by Union Miniere du Haut Katanga, a subsidiary of the Belgian mining giant Union Miniere. A decade later, in 1933, production began at Eldorado's Port Radium deposit in Canada's Northwest Territories on the shore of the Great Bear Lake. Between 1924 and 1935 the Congolese and Canadian mines produced the bulk of global radium output, with only minor amounts of U.S. production from the uranium-vanadium deposits. The price of radium, which stood at $6 million an ounce ($211,630 per gram) in 1912, when the Joachimsthal mines on the Czech-German border were the only major source of output, fell some 90 percent over the next two decades to $600,000 per ounce ($21,162 per gram).[2] However, radium's popularity—the highly radioactive element was claimed to

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[1] Warren I. Finch et al., "Nuclear Fuels," in *United States Mineral Resources*, ed. Donald Albert Brobst and Walden P. Pratt (Washington, D.C.: GPO, 1973), http://pubs.er.usgs.gov/publication/pp820.

[2] Earle Gray, *The Great Uranium Cartel* (Toronto: McClelland and Stewart Limited, 1982), 18–20. Eldorado Gold Mines Ltd. (established in 1925) landed on the frozen ice of Great Bear Lake in March 1930; along with copper and cobalt, they found pitchblende, and the richest radium and uranium-bearing ore ever discovered: one gram of radium per 6.5 tons (5.9 metric tons) of ore, five times as rich as the concentrates in the Congo and 20 times those in the United States. By mid-1934, the mine had shipped 65 tons (59 metric tons) of uranium

A miner hauling a car of silver and radium ore, 340 feet below the surface, at the Eldorado mine, located at Port Radium, Northwest Territories, Canada. circa 1930.
Source: Eldorado Mining & Refining Ltd. Library and Archives Canada, C-023983. http://en.wikipedia.org/wiki/File:A_miner_hauling_a_car_of_silver_radium_ore,_340_feet_below_the_surface,_Eldorado_Mine_of_Great_Bear_Lake.jpg.

cure everything from hair loss to cancer, and was used in luminous paint for clocks and watches—began to wane amidst lawsuits and public concern over its connection to numerous cancer deaths.[3] Mining in Colorado and Utah ramped up again in the mid-1930s, as producers raced to capitalize on the steel industry's growing demand for vanadium, which was found in the same uranium-bearing ores from which radium had been extracted.

The global market for uranium in the early years was small, and U.S. production was less than 100 tons (91 metric tons) a year. In 1939 non-U.S. uranium could be imported for

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concentrate, and the refinery processed 58 tons (53 metric tons), recovering 5.5 grams of radium, 30,000 ounces (850,500 grams) of silver, and nearly 18 tons (16 metric tons) of uranium. With the uranium price at $1.50 per pound ($3.30 per kilogram), the mine was shut down and allowed to fill with water; it re-opened two years later in 1942 to produce uranium for nuclear weapons.

[3] Susan Quinn, *Marie Curie—A Life* (New York: Simon & Schuster, 1995), 409–410. Quinn writes: "A 1929 pharmacopoeia listed 80 patent medicines whose ingredients were radioactive; they came in the form of bath salts, liniment, suppositories, toothpaste, and chocolate candies."

1.83 cents a kilogram.[4] Prior to 1940 total global production of $U_3O_8$ has been estimated at 7,500 tons (6,800 metric tons).[5]

This changed significantly during World War II; by 1939, when the United Kingdom and France declared war on Germany, top government officials in Europe and the United States were beginning to recognize uranium's strategic importance as a result of meetings with scientists. From the Manhattan Project's creation in 1942, after the United States entered the war, through the immediate postwar period, key U.S. officials familiar with the project saw uranium as critical to controlling both the development of nuclear weapons and of nuclear energy. Uranium purchasing was carried out by a special unit of the Manhattan Project known as the Murray Hill Area, which began a clandestine program to identify and purchase uranium from other countries.

About half of the uranium used in the U.S. nuclear weapons complex was initially imported from Canada, the former Belgian Congo, and other areas.[6] The first U.S. wartime order to Eldorado was in the spring of 1941, when Dr. Lyman J. Briggs, chairman of Roosevelt's Advisory Committee on Uranium, ordered eight tons of refined uranium oxide for preliminary experiments with an atomic pile.[7] In 1942 the United States purchased another 60 tons of uranium oxide from Eldorado's stockpile at Port Hope, Ontario, which was used by Dr. Enrico Fermi to create the world's first self-sustaining nuclear chain reaction at the University of Chicago. While quantities of supply during the war from the Eldorado mine is unclear, estimates place the total amount at 1,000 tons of uranium.[8] An additional 2,500 tons were imported from the Belgian Congo, and small quantities were recovered from vanadium mining on the Colorado Plateau.[9]

In 1943 the Manhattan Project contracted with the Union Carbide and Carbon Corporation to assist in the purchasing effort (the company was already involved in other aspects of the bomb project, including enrichment). Union Carbide set up a task force of geologists and other experts, which led to several breakthroughs, including the discovery of significant quantities of uranium in South African gold deposits. In a September 1944 report to Secretary of War Henry L. Stimson, the Manhattan Project leader Lt. Gen. Leslie R. Groves predicted the United States would directly and indirectly control some 90 percent of the global uranium supply by the end of the war.

Without a clue about the ubiquity of uranium resources across the globe, the June 1945 Franck Report proposed controlling nuclear development by rationing uranium to prevent

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[4] June Taylor and Michael Yokell, Footnote: Robert Golarski, "The Uranium Pricing Puzzle," *The Orange Disc* 23, no. 1 (September–October 1977).

[5] Finch et al., "U.S. Mineral Resources," in *United States Mineral Resources*, 457.

[6] National Nuclear Security Administration, *Highly Enriched Uranium: Striking a Balance* (Washington, DC: Department of Energy, January 2001), 28, http://www.fas.org/sgp/othergov/doe/heu/striking.pdf. Some other areas include uranium recovered as a by-product of gold mining in South Africa and early uranium recover in Australia.

[7] Wilfrid Eggleston, *Canada's Nuclear Story* (London: Clarke, Irwin & Company, 1965), 44.

[8] Gray, *Uranium Cartel*, 33.

[9] Ibid., 34.

any country from getting enough of it to build a bomb. The plan, which also argued against dropping an atomic bomb on Japan, was rejected. In 1946 U.S. plans for controlling the postwar international development of nuclear energy also included control of uranium as a key element. The plan that eventually went to the United Nations—authored by Bernard Baruch—differed significantly from the Acheson-Lilienthal plan from which it derived. Baruch's plan called for private ownership of uranium. However, it proposed the establishment of a United Nations Atomic Development Authority to control all atomic activities deemed "dangerous"; it listed uranium mining and milling in that category, along with other nuclear fuel cycle activities such as conversion and enrichment.

## Uranium Post–World War II: From Positive Control to Laissez-Faire

In the United States, the 1946 Atomic Energy Act authorized the transfer of all of the Manhattan Engineer District's (aka Manhattan Project) activities and assets to a new Atomic Energy Commission (AEC). The AEC was responsible for fissile material production for the U.S. nuclear weapons program. However, the AEC eventually had responsibility for both military and civilian uses of uranium. In the early years, there was little overlap because civilian nuclear power was just in development. In 1957, the year in which the first U.S. civilian nuclear power plant began operating, the AEC declared it had enough fissile material for its weapons requirements. Although the AEC continued to import foreign uranium until 1966, presumably some of this uranium fueled the growing U.S. nuclear power program. There are no publicly available documents on the separation of military and civilian uranium under the AEC.

The 1946 Atomic Energy Act established a "program for Government control of the production, ownership and use of fissionable material to assure the common defense and security and to insure the broadest possible exploitation of the fields."[10] Uranium ore was regarded as source material (and therefore not strictly subject to government control, except once it was mined from public lands), but could be controlled by the Atomic Energy Commission through regulations if deemed necessary.

The AEC encouraged domestic uranium production with guaranteed prices and other incentives. It supported its ore-buying program with a government-run domestic exploration program that included the use of low-flying aircraft with specially equipped radiation monitoring equipment to identify potential deposits. By watching the "rim fliers," prospectors could sometimes identify potentially lucrative deposits, stake their claims, and profit from mining particular areas. The AEC program set off a uranium "rush" in the western United States, particularly in Colorado, New Mexico, Utah, and Wyoming. The AEC accepted truckloads of ore from individual prospectors, only to have to transport it to the only existing milling facility in Utah.

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[10] Atomic Energy Act of 1946, Public Law 585, 79th Congress, Section 1(b)(4), 1, http://science.energy.gov/~/media/bes/pdf/atomic_energy_act_of_1946.pdf.

President Harry S Truman signs the Atomic Energy Act of 1946 establishing the U.S. Atomic Energy Commission. Source: Department of Energy Office of History and Heritage. 1946. http://en.wikipedia.org/wiki/File:Atomic_Energy_Act_of_1946_signing.jpg.

But domestic production did not take off until significant discoveries of uranium in Colorado in 1952. In the seven years following the war, more than 85 percent of all U.S. uranium came from the Congolese Shinkolobwe mine.[11] During that time, the Atomic Energy Act required vanadium producers to sell uranium (otherwise disposed of in mill tailings) to the government, which meant establishing special uranium production lines in their mills. The Atomic Energy Act prohibited private ownership of milled uranium without special licenses—it had to be sold to the government. The AEC prohibited private uranium mills for at least a decade. This changed in the late 1950s; by 1962 there were 27 private mills owned by 25 companies.

During the early years, uranium was crucial for the U.S. nuclear weapons program as fuel for the early plutonium production reactors at Hanford Site, Washington (and later, at Savannah River Site, South Carolina) and as feedstock for uranium enrichment at Oak

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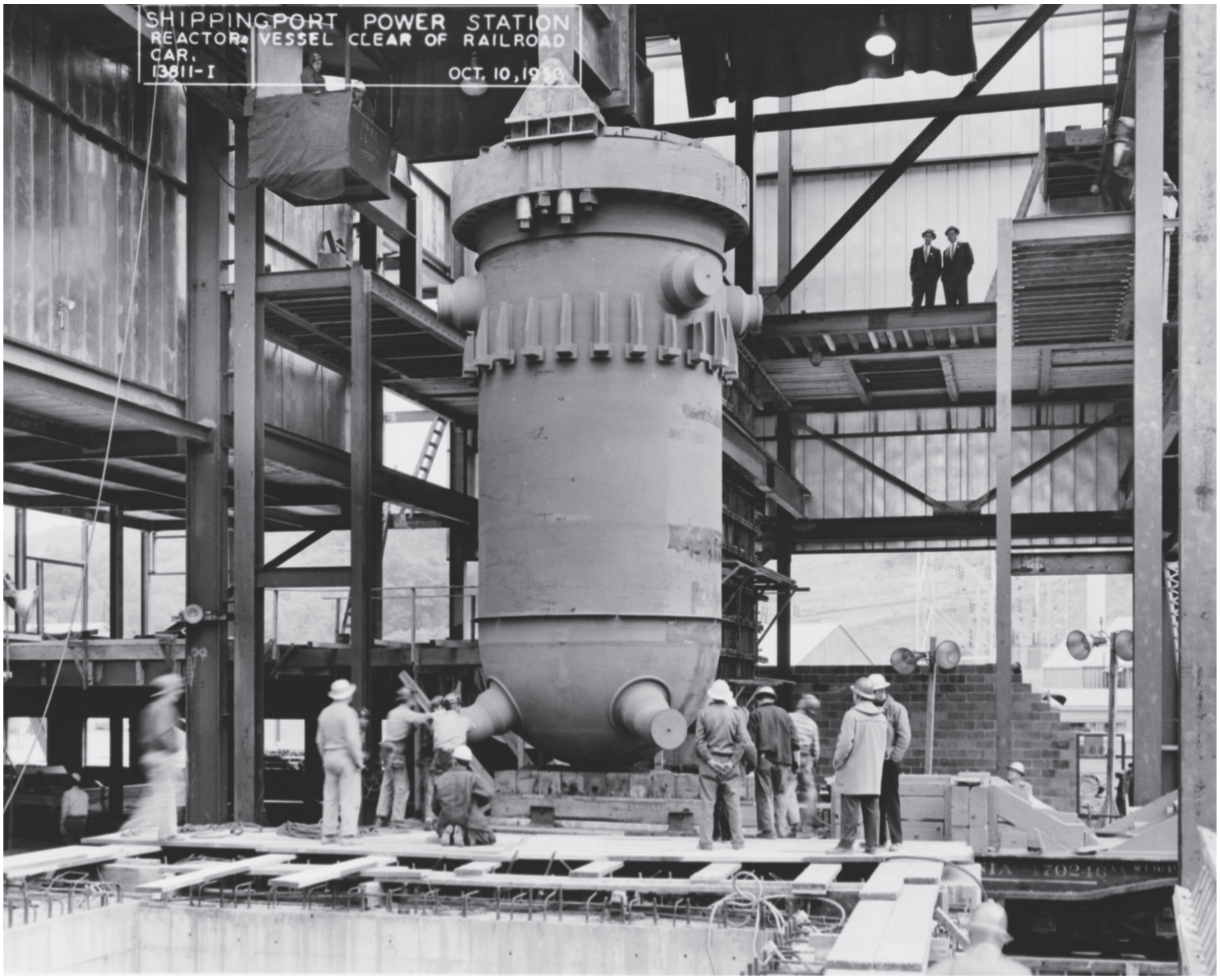
[11] Ibid., 37.



Shippingport reactor pressure vessel during construction.
Source: U.S. Department of Energy, Naval Reactors Program. 10 October 1956. United States Library of Congress's Prints and Photographs, ID hhh.pa1658. http://en.wikipedia.org/wiki/File:Shippingport_LOC_135430pu.jpg.

Ridge, Tennessee. The nine reactors at Hanford initially ran on natural uranium metal fuel, but were eventually configured to slightly enriched uranium fuel. Of the five production reactors at Savannah River, several were converted to use high enriched uranium (HEU) fuel in 1968 and also to produce tritium for nuclear weapons. Approximately 67.4 metric tons of plutonium was produced at the Hanford site, and 36.1 metric tons were produced at the Savannah River site.

In addition to plutonium production, natural uranium was enriched to HEU at the K-25 gaseous diffusion plant at Oak Ridge, which began operating in 1945, and was later supplemented by three more process facilities in the 1950s. In addition to Oak Ridge, gaseous diffusion plants were built in the mid-1950s in Paducah, Kentucky, and Portsmouth, Ohio.[12] Paducah never produced HEU, but provided low enriched uranium (LEU) that would later

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[12] Kent Williams, "A History of U.S. Uranium Enrichment in the 1950s," Oak Ridge National Laboratory, http://web.ornl.gov/~webworks/cpr/pres/104042.pdf.

be processed into HEU at Portsmouth and Oak Ridge. A total of 491.8 metric tons of uranium containing 348.9 metric tons of uranium-235 (U-235) was produced at Oak Ridge between 1945 and 1964. A total of 552.2 metric tons of uranium containing 509.2 metric tons of U-235 was produced at Portsmouth between 1956 and 1992.[13]

One notable early exception to uranium's weapons program use was research on experimental production of electricity from a nuclear reactor, which was achieved in 1951. Although the Atomic Energy Act of 1946 had provisions for the development of a civilian nuclear power industry, the first commercial U.S. reactor did not achieve criticality until December 1957 in Shippingport, Pennsylvania.[14]

In the mid-1950s, the AEC no longer purchased ore, but rather yellowcake. In 1954 Congress amended the Atomic Energy Act (AEA), opening doors to private industry for expansion in nuclear power by sharing previously restricted information on nuclear energy and allowing patent processes, while maintaining control over sensitive nuclear-related defense and security information. The AEA defined forms of nuclear material (source, by-product, special nuclear material) and kinds of facilities. At the same time, the AEC was buying foreign uranium, sending geologists around the world to encourage further uranium exploitation in Australia, Argentina, Brazil, Chile, Colombia, Peru, Portugal, Spain, and South Africa.

On October 28, 1957, the AEC declared that existing supplies and increased domestic production were enough to cover military requirements. In 1959 the AEC began phasing out its foreign uranium purchases, eventually halting them altogether in 1966. AEC purchases of domestic uranium also slowed considerably, leaving producers with no other outlets for their uranium since the civilian reactor industry was still in its infancy. By 1971, when the purchasing program ended, the AEC had bought 172,000 metric tons of uranium, of which 45,000 metric tons ended up in the government's surplus stockpile.[15]

Meanwhile, Congress further loosened federal controls over uranium mining in the 1959 revision of the Atomic Energy Act by creating the Agreement State program, allowing states to effectively assume responsibility for uranium regulation from the AEC as long as their programs complied with federal regulations. In 1962 Kentucky became the first agreement state. By 1964 Congress passed the Private Ownership of Special Nuclear Materials Act, which allowed the nuclear power industry to own its own fuel.

The AEC also sought to tightly control the influx of material into the United States. It embargoed enrichment of foreign uranium for use in U.S. reactors from the early 1960s to the mid-1970s, which effectively prohibited U.S. utilities from using foreign-origin uranium. An unintended consequence of this policy was the rise of a clandestine international

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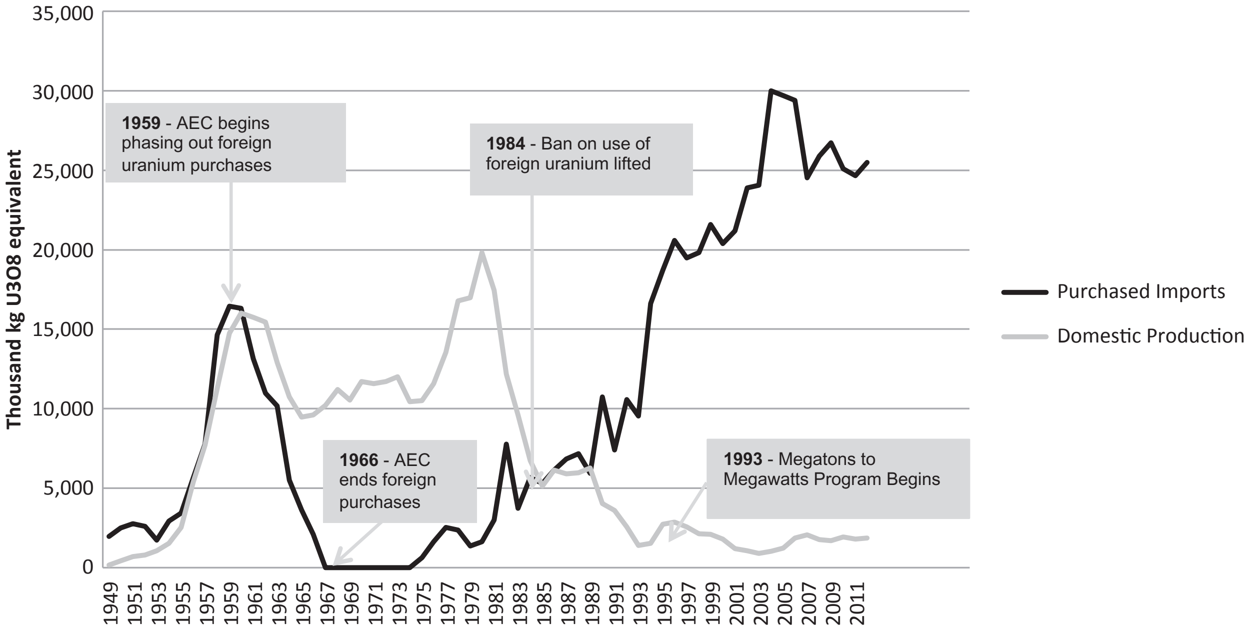
13. National Nuclear Security Administration, *Highly Enriched Uranium*, 62.
14. Gray, *Uranium Cartel*, 41.
15. Ibid., 41.

**Figure 2.1. U.S. Domestic Production and Imports of Uranium Concentrate, 1949–2012**



See Appendix 2 for more data on the U.S. uranium industry.

Note: Includes all forms of uranium concentrate in $U_3O_8$ equivalent. AEC, Atomic Energy Commission.

Sources: "Annual Energy Overview," U.S. Energy Information Administration, September 2012, http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0903; "Uranium Industry Annual 1992," U.S. Energy Information Administration, October 1993, http://www.eia.gov/uranium/marketing/archive/047892.pdf.

uranium cartel to buoy uranium prices in the mid-1970s. However, in recognition that domestic mines and mills would be unable to fulfill U.S. demand, the AEC's embargo began to be phased out in 1977, with foreign-origin uranium allowed to make up 10 percent of U.S. utilities' stock. This amount was increased to 20 percent in 1978, with additional annual 10 percent allowances until 1984. After reaching a peak in 1979, when the United States was the largest producer of uranium concentrate, with an estimated 45 percent of global production, domestic production started to decline significantly, as shown in Figure 2.1. Today, the United States ranks eighth in global uranium concentrate production.

In the mid-1990s, uranium concentrate imports reached levels last seen during the peak of the AEC's purchasing program in the 1950s. The Megatons to Megawatts Program, which blended down HEU from Soviet weapons to LEU fuel for U.S. nuclear power plants, played a significant role in the rise of imports in the mid-1990s. When foreign uranium was phased back in, it was primarily at the expense of the domestic industry, which in 1985, one year after all restrictions were lifted, saw its concentrate production fall to almost a quarter of what it was just five years earlier. Employment at operating mills fell 90 percent, from a peak of about 22,000 in the early 1960s to 2,200 by 1985. Uranium prices plunged to below $22 per kilogram and there were only five active uranium recovery facilities operating, though usually at less than peak capacity.[16] U.S. mills that once accounted for half of global uranium supply, were now meeting less than 25 percent of U.S. domestic requirements.[17] Today, there is only one conventional operating mill in the United States (White Mesa Mill in Blanding, Utah) and it has been processing only alternate feeds.[18] However, there are also five operating in-situ leach (ISL) facilities that both mine and produce concentrate and another two conventional mills on standby.

## Uranium from 1978 to the Present: From Slump to Steady-State

With the boom over in the early 1960s, operators from mill sites in 11 states and 4 Indian reservations in the West walked away from their plants, leaving tailing ponds filled with radioactive effluent from the ore-processing operations. The sludgy effluent dried over time into a fine, white, sand-like material, which was blown about by wind or used by contractors for building roads and foundations of houses, schools, offices, and hotels. The resulting widespread radiation contamination became a cause of great concern among the public and their elected local and state officials. However, states failed in large part to provide adequate protection for the public, and the AEC did little to help in that regard.

This began to change after Congress passed the 1974 Energy Reorganization Act, abolishing the Joint Atomic Energy Commission and the AEC, and creating the Nuclear Regulatory Commission (NRC) as an independent body with a mandate to regulate civilian nuclear power, associated safety and security, licensing, and waste management. The AEC's responsibility for development and production of nuclear weapons was assigned to a new organization, the Energy Research and Development Agency, later the Department of Energy (DOE), which was also tasked with promoting nuclear power and other energy-related work. In 1978 Congress passed the Uranium Mill Tailings Radiation Control Act (UMTRCA) as an amendment to the Atomic Energy Act. In that year Congress mandated the NRC to review state programs for compliance in uranium recovery. In 1980 Congress granted the NRC power to suspend state programs for failing to meet minimum standards.

The UMTRCA established two individual programs designed to protect against the detrimental effects of uranium mill tailings. The primary intent was to diminish the negative health and environmental effects of the spread of radon, either at the mines or from mill tailings. The legislation required the government to establish new environmental standards for both radiological and nonradiological hazards, and methods for controlling these hazards. The Title I program established federal control over abandoned mill tailings sites, where tailings were chiefly by-products of uranium produced for the

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[16] Eric W. Mogren, *Warm Sands: Uranium Mill Tailings Policy in the Atomic West* (Albuquerque: University of New Mexico Press, 2002), 169.

[17] Ibid., 169.

[18] Stephanie Cooke, "Uranium: Energy Fuels—Treading Water With Alternate Feed," *Nuclear Intelligence Weekly*, October 11, 2013, http://www.energyintel.com/pages/Eig_Article.aspx?DocId=824600&IsSearchResult=true.

The Umetco Minerals Corporation mill in Gas Hills, Wyoming, ceased operation in 1984 and was decommissioned in 1990. This picture depicts the site before its reclamation under the Uranium Mill Tailings Radiation Control Act (UMTRCA).

Source: NRC Presentation. "Uranium Recovery Sites." Workshop on Regulatory Framework and Oversight for Uranium Recovery Operations. January 2013. Copenhagen, Denmark.

This picture depicts the UMETCO site in reclamation before finishing in 2006.

Source: NRC Presentation. "Uranium Recovery Sites." Workshop on Regulatory Framework and Oversight for Uranium Recovery Operations. January 2013. Copenhagen, Denmark.

weapons program. The DOE is responsible for remediation and clean-up, while the NRC ensures that its effort meets Environmental Protection Agency (EPA) standards. The cleanup project, which has still not completely ended, costs taxpayers millions of dollars, while producers who did not qualify under the amendment spent millions more in an attempt to stabilize tailings piles. The UMTRCA Title II program oversees all uranium mill sites licensed by the NRC or Agreement States in or since 1978. Under Title II the NRC has responsibility for controlling radiological and nonradiological hazards and the EPA must set general standards for these types of hazards. Title II also eventually brings disposal sites under state or federal jurisdiction and NRC license.

## Unconventional Uranium Resources

Historically, the United States has also explored unconventional uranium resources, or by-product uranium. In the United States, Blockson Chemical Co. first attempted uranium extraction from phosphoric acid in 1952, at a facility in Joliet, Illinois. Two other plants in Florida began operating in 1955 and 1957. These facilities, which extracted uranium mostly for military purposes, had short lives, closing in response to the drop in uranium prices in the early 1960s.[19] By the 1970s uranium prices had risen substantially, and uranium extraction from phosphoric acid once again became economically viable. A total of eight facilities were brought online during this period. Six of these facilities were located in Florida and two in Louisiana. Several of these plants operated on long-term contracts, explaining why operation continued despite sustained decreases in the price of uranium.

Table 2.1 shows production capacities for uranium recovery from phosphoric acid. Determining the historical uranium production totals by type of unconventional resource is unfortunately not possible due to uneven production reporting over the years. Particularly when production began to decline in the late 1980s, a few agencies, including the DOE, stopped reporting uranium from phosphate production individually, lumping production totals in with other unconventional forms of uranium production.

Interest in extracting uranium from phosphoric acid has fluctuated greatly over time and estimates vary regarding how much uranium could be recovered via this method in the United States. The 2011 edition of the Organization for Economic Cooperation and Development's *Red Book* on uranium resources, production, and demand reports that anywhere from 14,000–33,000 metric tons of uranium exist within reported U.S. phosphate deposits.[20] The World Information Service on Energy (WISE) Uranium Project assesses that uranium inventories in phosphate deposits in the United States could total up to 1.2 million

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[19] Vaughn Astely and Regis Stana, "Recovery of Uranium from Phosphoric Acid: History and Present Status," in *Beneficiation of Phosphates: New Thought, New Technology, New Development*, ed. Patrick Zhang, J. D. Miller, and Hassan E. El-Shall (Englewood, CO: Society for Mining, Metallurgy, and Exploration, 2012), 133–140.

[20] Marten Walters, Thomas Baroody, and Wes Berry, "Technologies for Uranium Recovery from Phosphoric Acid," June 7, 2008, http://www.aiche-cf.org/Clearwater/2008/Paper1/8.1.4.pdf.

**Table 2.1. Uranium from Phosphoric Acid Recovery Facilities in the United States**

| *Owner* | *Location* | *Full Production Capacity $P_2O_5$ short-tons/year (metric tons/year)* | *Full Production Capacity $U_3O_8$ pound/year (metric tons/year)* | *Years Operational* |
|---|---|---|---|---|
| Blockson Chemical Co. | Joliet, IL | 100,000 (91,000) | 80,000 (36) | 1952–1961 |
| Gardinier Inc. | Tampa, FL | 200,000 (181,000) | 160,000 (73) | 1957–1961 |
| | | 450,000 (408,000) | 360,000 (163) | 1979–1982 |
| International Minerals and Chemicals Corp. | Bartow, FL | 100,000 (91,000) | 80,000 (36) | 1955–1961 |
| | | 1,700,000 (1,542,000) | 1,360,000 (617) | 1980–1992 |
| W.R. Grace | Bartow, FL | 330,000 (299,000) | 264,000 (120) | 1976–1980 |
| Wyoming Minerals Corp. | Pierce, FL | 450,000 (408,000) | 360,000 (163) | 1978–1981 |
| CF Industries | Plant City, FL | 950,000 (862,000) | 760,000 (345) | 1980–1992 |
| Freeport Uranium Recovery Co. | Convent, LA (Uncle Sam facility) | 950,000 (862,000) | 760,000 (345) | 1978–1998 |
| | Donaldsonville, LA (Faustina facility) | 540,000 (490,000) | 432,000 (196) | 1980–1998 |

Note: $P_2O_5$, diphosphorous pentoxide.

Source: Marten Walters, Thomas Baroody, and Wes Berry, “Technologies for Uranium Recovery from Phosphoric Acid,” June 7, 2008, http://www.aiche-cf.org/Clearwater/2008/Paper1/8.1.4.pdf.

**Table 2.2. Uranium Concentration Ranges in Various U.S. Phosphate Deposits**

| *Deposit Location* | *Concentration Range (U ppm)* | *Average Concentration (U ppm)** |
|---|---|---|
| Central Florida | 59–200 | 150 |
| North Florida | 59–143 | 60 |
| Idaho | 60–141 | 60 |
| North Carolina | 41–93 | 90 |

Note: ppm, parts per million, U, uranium.

*Inconsistency between concentration range figures and average concentration figures are likely due to the fact that concentration range numbers are from a much more recent report; average concentration numbers have not been updated/reported for many years.

Source: Marten Walters, Thomas Baroody, and Wes Berry, "Technologies for Uranium Recovery from Phosphoric Acid," June 7, 2008, http://www.aiche-cf.org/Clearwater/2008/Paper1/8.1.4.pdf.

metric tons.[21] (Both sources acknowledge the imprecise nature of their projections.) Table 2.2 shows the uranium concentration ranges in various U.S. phosphate deposits.

With regard to other by-product uranium operations, only one facility has operated in any sizeable capacity in the United States. Kennecott Copper Corp. operated a plant from 1978–1989 that was capable of recovering roughly 65 metric tons of $U_3O_8$ per year from copper mining operations in Bingham Canyon, Utah.[22] Plans for additional operations were discussed, with some projections estimating that up to 1,050 metric tons of $U_3O_8$ could be recovered per year from U.S. copper operations by the mid-1980s.[23] Bingham Canyon uranium production peaked at roughly 200,000 pounds (90.71 metric tons) per year of $U_3O_8$. By the time uranium prices fell again in the late 1980s, plans for additional by-product plants had been scrapped and the Kennecott facility was put on standby.

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[21] WISE Uranium Project, "Uranium Resources in Phosphate Rocks," April 5, 2012, http://www.wise-uranium.org/purec.html.

[22] Walters et al., "Technologies," 293.

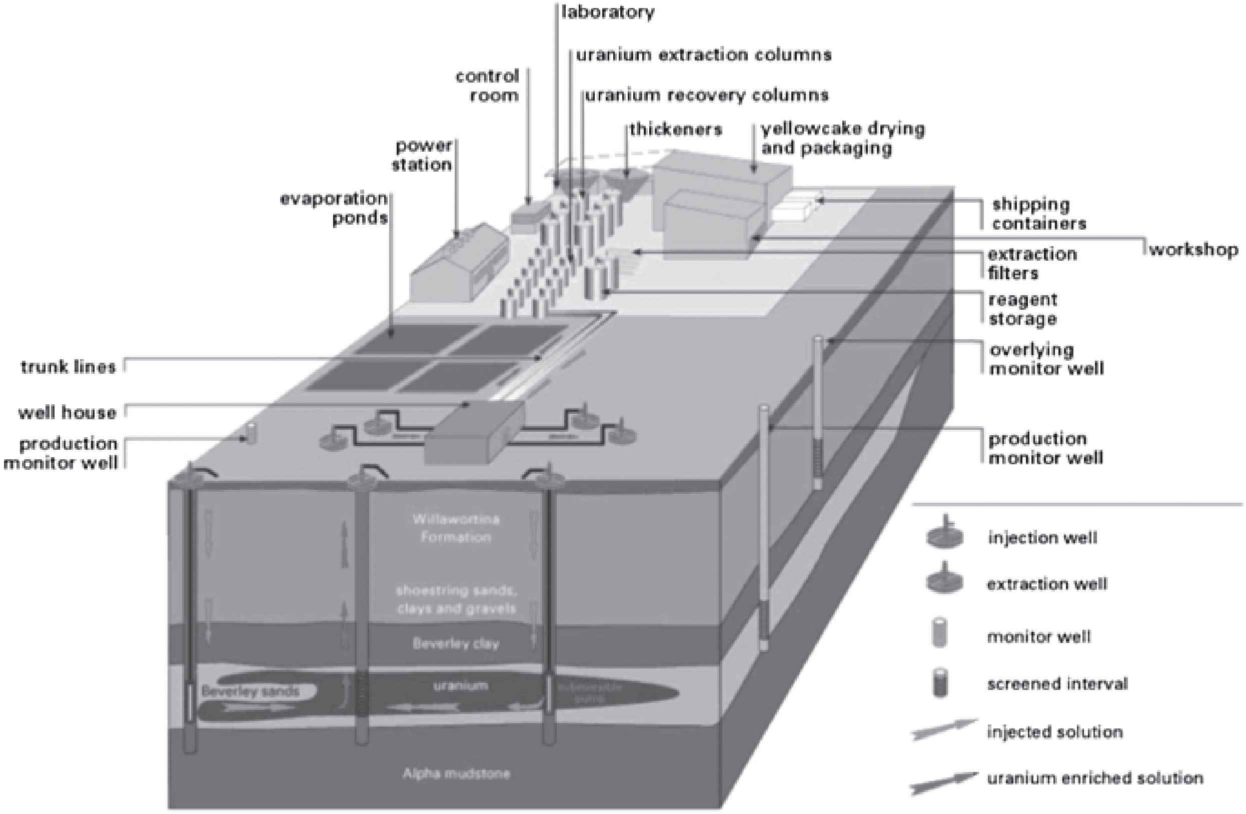
[23] Ibid., 304.

# 3 U.S. Uranium Industry Today

In 2011, 1.9 million kilograms of $U_3O_8$ was produced by five in-situ leaching (ISL) plants and the White Mesa Mill in Blanding, Utah, with ore supplied by five conventional underground mines. This concentrate was sold at a weighted-average price of $115.43 per kilogram $U_3O_8$.

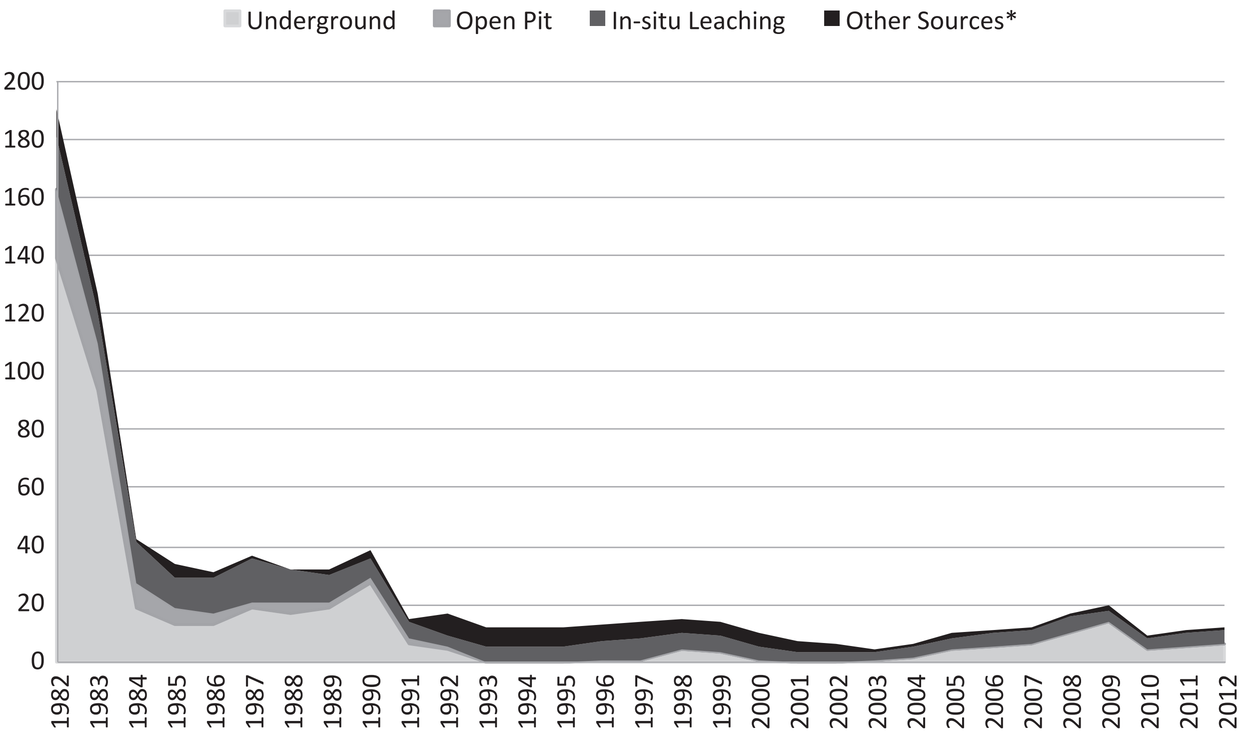
Commercial ISL mining was first employed in the United States in 1964 at the Shirley Basin mine in Mills, Wyoming. The practice involves pumping a leaching solution through the ore body so that it dissolves the uranium ore. The resulting solution is then pumped to

**Figure 3.1. The In-situ Leaching (ISL) Process**



Source: Peter Woods, "Figure 2. Schematic of mining at Beverley," *Bulletin: Sustainability Aspects of the Beverley Uranium Mines*, http://www.heathgate.com.au/userfiles/docs/news/Beverley%20Uranium%20Mines_The%20Bulletin_June%202011.pdf.

**Figure 3.2. Operating Mines, 1982–2012**



See Appendix 2 for a complete list of U.S. mills, In-situ Leach facilities, and industry data.
*Other sources include mine water, mill site cleanup and mill tailings, and well field restoration.
Sources: "Domestic Uranium Production Report—Annual," U.S. Energy Information Administration, June 6, 2013, http://www.eia.gov/uranium/production/annual/; "Uranium Industry Annual 1992," U.S. Energy Information Administration, October 1993, http://www.eia.gov/uranium/marketing/archive/047892.pdf.

the surface to be processed in a similar fashion to conventional mills, the key distinction being that the whole process, from mining to concentrate, takes place on-site (see Figure 3.1). The five operating ISL plants have a combined capacity of 4.9 million kilograms $U_3O_8$ per year. Additionally, there are two other ISL operations on standby with a potential to produce 0.9 million kilograms $U_3O_8$ per year, and nine more ISL plants in various stages of planning and construction.[1]

In addition to the White Mesa Mill, with an input capacity of 1,814 tons of ore per day and output of 3,629 metric tons of natural uranium annually, two more conventional mills are on standby (Shootaring Canyon Uranium Mill in Garfield, Utah and Sweetwater Uranium Project in Sweetwater, Wyoming) with a total capacity of 3,400 metric tons of ore per day. The Piñon Ridge Mill is partially permitted and licensed in Montrose, Colorado.[2]

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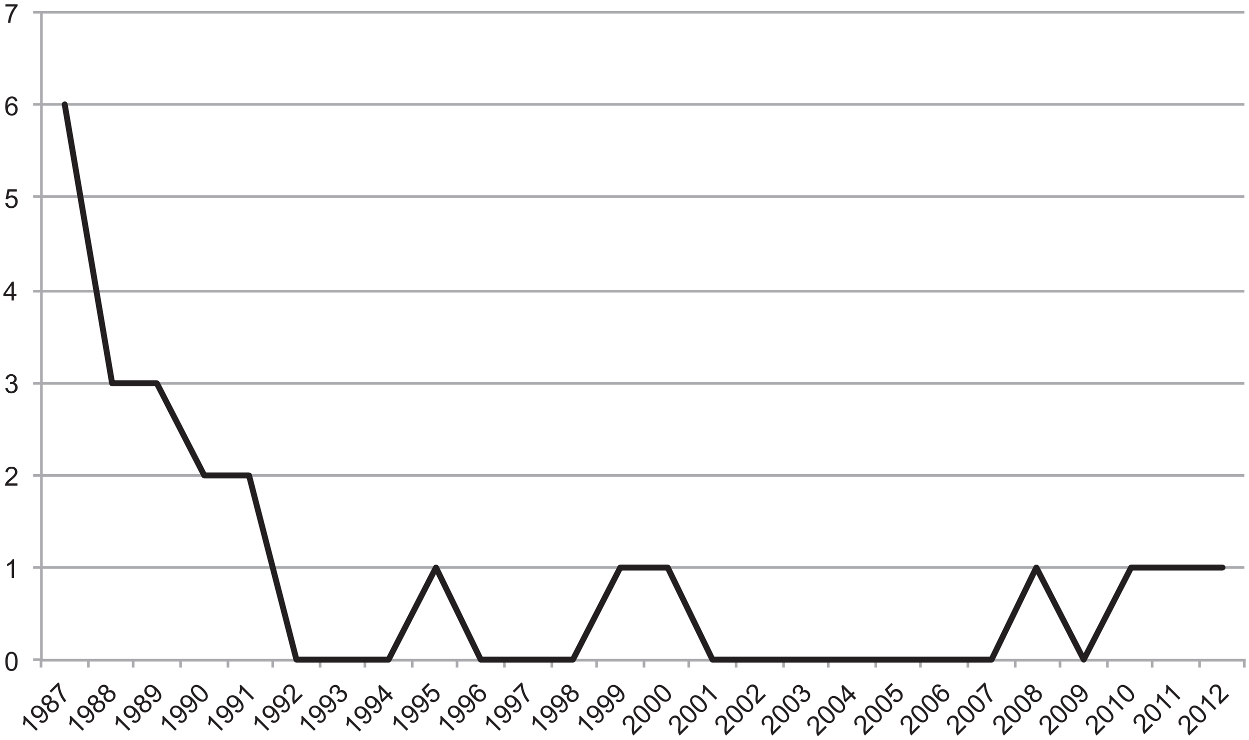
1. U.S. Energy Information Administration, "U.S. uranium in-situ-leach plants by owner, location, capacity, and operating status, data for 2nd quarter 2013," http://www.eia.gov/uranium/production/quarterly/qupdtable4.cfm.

2. U.S. Energy Information Administration, "U.S. uranium mills and heap leach facilities by owner,

**Figure 3.3. Operating Conventional Mines, 1987–2012**



Sources: "Domestic Uranium Production Report—Annual," U.S. Energy Information Administration, June 6, 2013, http://www.eia.gov/uranium/production/annual/; "Uranium Industry Annual 1992," U.S. Energy Information Administration, October 1993, http://www.eia.gov/uranium/marketing/archive/047892.pdf.

The number of mines and mills in operation decreased drastically from the 1980s to the early 1990s (see Figures 3.2 and 3.3), before somewhat recovering as the price of uranium rose in the mid- to late 2000s. During the years with no operating conventional mills, all uranium concentrate came from ISL plants, by-product recovery plants (which produce concentrate as a by-product of phosphate production, though none have operated since 1999), and conventional mills processing alternate feeds instead of ore. The only operating conventional mill since 2005 has been the White Mesa Mill, purchased by Energy Fuels from Denison in 2012; it can produce up to 3.6 million kilograms of uranium per year, although since June 2013 it has only been processing alternate feeds.

U.S. uranium mining remained robust through the ban on the use of foreign uranium, hit its peak in late 1970s and early 1980s, then declined sharply and never recovered once imports were phased back in (see Figure 3.4). Production levels have remained relatively steady since 1990. The number of operating mines fell from 191 to 39 in the eight years from 1982 to 1990, with a proportional drop in production (from 20.1 million kilograms in 1980 to 2.6 million kilograms in 1990). Since 1993, 10 to 12 mines have remained in operation, with several others on standby.

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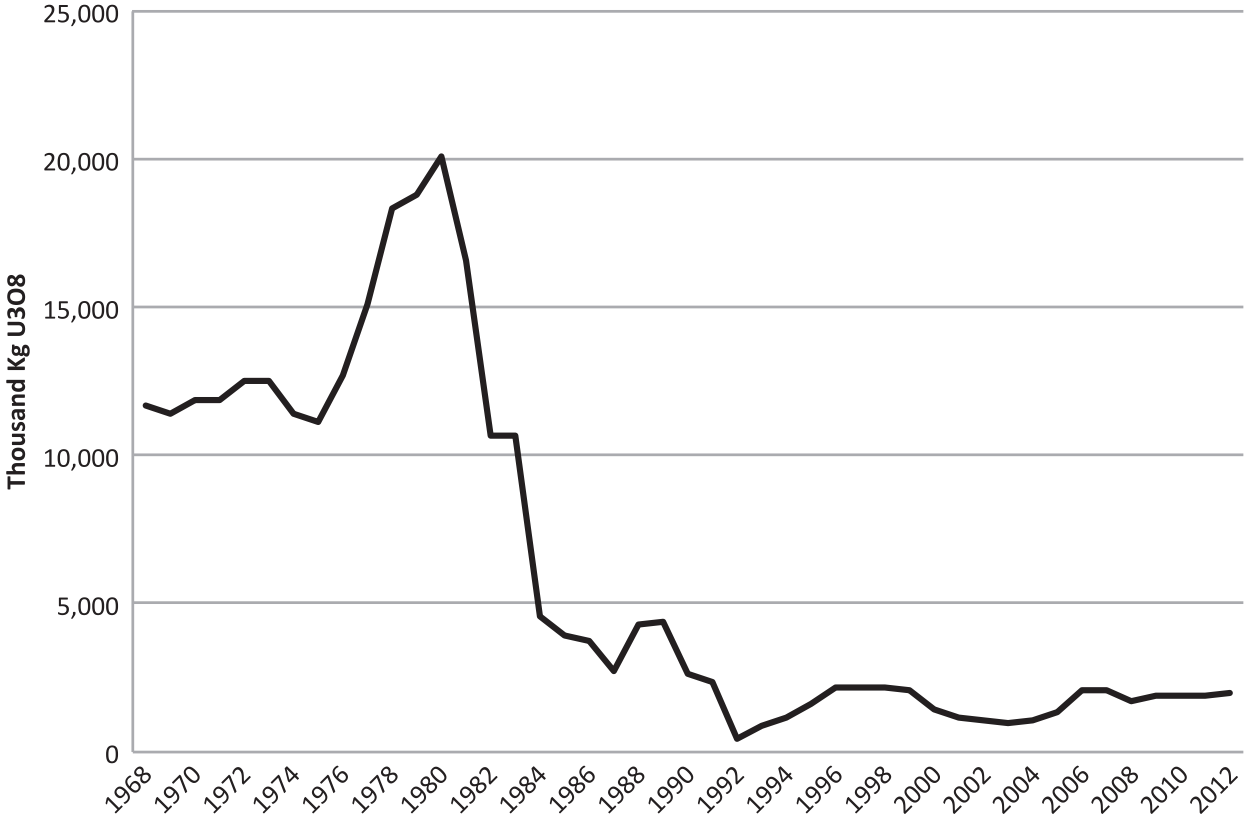
location, capacity, and operating status, data for 2nd quarter 2013," http://www.eia.gov/uranium/production/quarterly/qupdtable3.cfm.

Aerial view of the White Mesa Mill in Blanding, Utah. The White Mesa Mill is the only fully licensed and operating conventional uranium mill in the United States.

Source: NRC Presentation. "Uranium Recovery Sites." Workshop on Regulatory Framework and Oversight for Uranium Recovery Operations. January 2013. Copenhagen, Denmark.

In addition to domestic production, the United States imports approximately 25 million kilograms of uranium in various forms annually (see Figure 3.5). In 2012 U.S. reactor operators purchased predominantly foreign-origin uranium (83 percent of 26 million kilograms of $U_3O_8$-equivalent) deliveries. The 17 percent of domestic uranium supply was slightly more expensive than the foreign-origin (weighted average price of $131.04 per kilogram versus $119.20). Of the foreign suppliers, Australia and Canada accounted for 35 percent; Kazakhstan, Russia, and Uzbekistan provided 29 percent; and the remaining 19 percent came from Brazil, China, Malawi, Namibia, Niger, South Africa, and Ukraine. In all, U.S. civilian nuclear power reactors purchased uranium for 2012 deliveries from 32 sellers.

**Figure 3.4. U.S. Uranium Mine Production, 1968–2012**



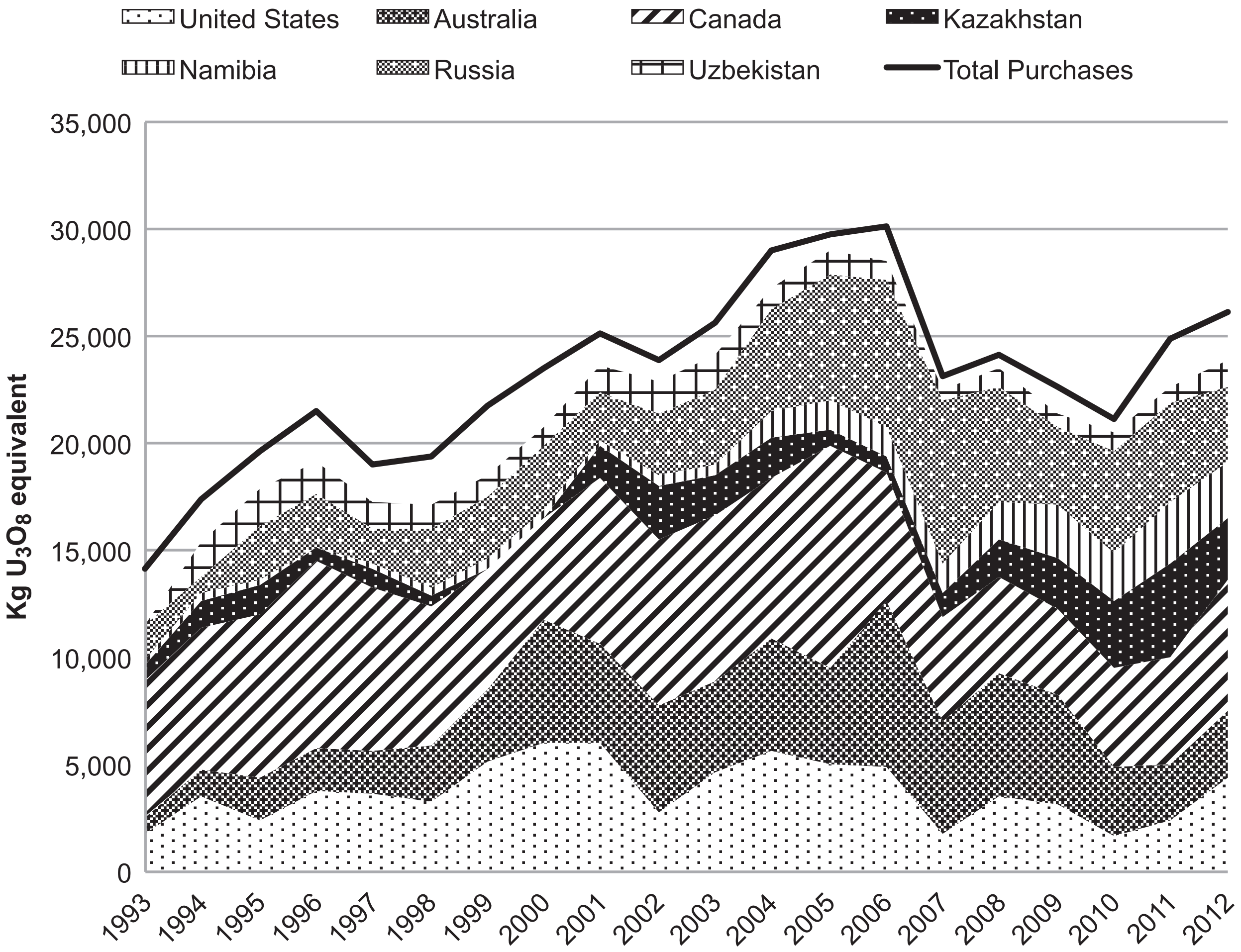
Note: Represents actual $U_3O_8$ from in-situ leach and by-product recovery plants and estimated contained $U_3O_8$ from underground and open pit mines.

Sources: "Domestic Uranium Production Report—Annual," U.S. Energy Information Administration, June 6, 2013, http://www.eia.gov/uranium/production/annual/; "Uranium Industry Annual 1992," U.S. Energy Information Administration, October 1993, http://www.eia.gov/uranium/marketing/archive/047892.pdf.

U.S. purchases of non-U.S. uranium rose significantly after the end of the Cold War, from 13.9 million kilograms in 1993 to 21.6 million kilograms in 2012. While the U.S.-Russian high enriched uranium (HEU) downblending agreement played a large role in this, new entrants on the supply side in countries such as Namibia, Niger, and Malawi, and in the former Soviet Union (e.g., Kazakhstan and Uzbekistan) were also a factor.

In 2012 U.S. utilities purchased 26.1 million kilograms of uranium, half in concentrate form and the other half in uranium hexafluoride ($UF_6$). Civilian owner/operators (COOs) delivered 23.6 million kilograms $U_3O_8$ of natural uranium feed to enrichers, 62 percent of which went to U.S.-based enrichment suppliers, with the remaining 38 percent delivered to non-U.S. enrichers. The average price paid by the COOs for the 16 million separative work units (SWUs) purchased was $141.36 per SWU. Uranium in fuel assemblies loaded into U.S. civilian nuclear power reactors during 2012 contained 22 million kilograms of $U_3O_8$ equivalent, of which 10 percent was U.S.-origin uranium and 90 percent was foreign-origin.

**Figure 3.5. Uranium Purchases by U.S. Civilian Nuclear Power Operators, 1993–2012**



Sources: "Domestic Uranium Production Report—Annual," U.S. Energy Information Administration, June 6, 2013, http://www.eia.gov/uranium/production/annual/; "Domestic Uranium Production Report: 2004 Summary," U.S. Energy Information Administration, March 29, 2005, http://www.eia.gov/uranium/production/annual/archive/dupr2004.pdf; "Uranium Industry Annual 1992," U.S. Energy Information Administration, October 1993, http://www.eia.gov/uranium/marketing/archive/047892.pdf.

Total U.S. commercial inventories (including inventories owned by COOs, U.S. brokers, converter, enrichers, fabricators, producers, and traders) were 55 million kilograms $U_3O_8$ as of the end of 2012. Of that, converters, enrichers, fabricators, and producers owned 8 million kilograms, while U.S. brokers and traders owned 3 million kilograms.[3]

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[3] U.S. Energy Information Administration, "Uranium Marketing Annual Report, with data from 2012," May 16, 2013, http://www.eia.gov/uranium/marketing/.

# 4 Risk Assessment

In any nuclear weapons program, production of fissile material is the most significant hurdle in terms of time, effort, and money. The key technologies are uranium enrichment and spent fuel reprocessing, yielding high enriched uranium (HEU) or separated plutonium, respectively. The further down the production chain that material can be diverted or stolen, the less additional work that must be performed by the proliferator. For a clandestine HEU bomb, ore would be less preferable to yellowcake, converted uranium ($UF_6$), or enriched material (low enriched uranium [LEU] or HEU), in that order. For a clandestine plutonium (Pu) bomb, ore would be less preferable to yellowcake, converted uranium ($UF_6$), irradiated natural uranium fuel, or separated plutonium, in that order.

The desire for processed material is counterbalanced by the greater risk of detection of diversion or theft that comes with attempting to circumvent the stricter regulations associated with material of higher attractiveness. National and international regulations pertaining to production, export, and use—whether state systems of accounting and control, international safeguards, or export limits or reporting—are calibrated accordingly.

On the other hand, those seeking to acquire capabilities clandestinely are often known to seek the path of least resistance—that is, they seek capabilities or materials precisely because they are not the most attractive or closely watched. Examples include using outdated modes of production (e.g., electromagnetic isotope separation in the case of Iraq in the 1990s), or equipment that falls just under control thresholds. Natural uranium could therefore be attractive to a country or nonstate actor determined to build a nuclear weapon. There have been reports of clandestine acquisition of natural uranium in the past, whether through illegitimate deals, theft, or diversion.[1]

The discussion below outlines how much material would be required at the very front end of the fuel cycle for a rudimentary (one to two weapons) nuclear weapons capability, assuming little material loss in subsequent processes. It then explores potential pathways

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[1] For a description of natural uranium theft by Israel from the European Atomic Energy Community (EURATOM), see Elaine Davenport, Paul Eddy, and Peter Gillman, *The Plumbat Affair* (Philadelphia: Lippincott, 1978). For a description of uranium smuggling incidents in the Congo, see the UN Security Council Report, “Letter dated 18 July 2006 from the Chairman of the Security Council Committee established pursuant to resolution 1533 (2004) concerning the Democratic Republic of the Congo addressed to the President of the Security Council,” July 18, 2006, 31–33. For a description of an incident involving natural uranium theft in the United States, see 635 F.2d 814, 7 Fed. R. Evid. Serv. 994. United States of America, Plaintiff-Appellee, v. John P. O’Connor, Defendant-Appellant. No. 79-1496. U.S. Court of Appeals, Tenth Circuit.

for diversion. The discussion is not meant to provide a threat assessment of the risk of such diversions or theft in the United States, but rather to illustrate the nature of risks. As a nuclear weapon state with significant amounts of weapons-usable material in active weapons, in weapons awaiting dismantling, in fissile material stockpiles, and with active and mothballed production facilities, there are clearly more significant targets for material theft or diversion in the United States than are presented by uranium mining and milling facilities alone. This will be quite different for most other countries, with the possible exception of Russia.

## Significant Quantities

The International Atomic Energy Agency (IAEA) has established threshold quantities for timely detection of diversion of nuclear material, both direct-use and indirect-use called "significant quantities" (SQs). These quantities are approximate amounts of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. Direct-use material is defined as nuclear material that can be used for manufacture of nuclear explosive devices without transmutation or further enrichment,[2] and indirect-use material must undergo further processes before it could be used in a nuclear explosive.

The SQs for direct-use material are fairly small: (1) 8 kilograms of plutonium (for Pu containing less than 80 percent Pu-238); (2) 25 kilograms of the isotope U-235 in uranium enriched to greater than or equal to 20 percent U-235; or (3) 8 kilograms of U-233.[3] For indirect-use material, an SQ is larger: (1) 75 kilograms of U-235 in uranium enriched to less than 20 percent U-235 (or 10 tons of natural uranium or 20 tons of depleted uranium); or (2) 20 tons of thorium.

Calculating an equivalent SQ for source material requires several assumptions about process losses in mining, milling, and refining. At the front end of the fuel cycle, the grade of the ore significantly affects the equivalent SQ for ore. For the purposes of this report, mill extraction losses and conversion process losses are assumed to be negligible.[4]

In ore form, the amount of uranium required as input for a "significant quantity" of material is highly dependent on the quality of the uranium ore. Prior studies on the feasibility of safeguarding uranium mines have assumed an amount of 250 tons of unprocessed high-grade ore as input for a significant quantity of HEU.[5] In the United States, the highest grade deposits of ore, located in the breccia pipe environment of northwestern Arizona,

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[2] Definition 4.25, IAEA Safeguards Glossary, 2001 edition, International Nuclear Verification Series No. 3, 33. http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf.

[3] Ibid., Definition 3.14. 23.

[4] For reference, conventional mills typically aim for a 95 percent extraction rate. In-situ leach (ISL) sites typically have a range of 60 to 80 percent recovery from the ore body.

[5] R. Scott Kemp, "On the Feasibility of Safeguarding Uranium Mines," *Nonproliferation Review* 13, no. 2 (2006): 421. This amount assumes 28 to 42 percent losses corresponding to a 0.2 to 0.3 percent tails-assay enrichment cascade, and assumes a fairly high grade of ore, roughly around 2 percent. This also does not refer to the IAEA's significant quantity definition for indirect-use material.

**Table 4.1. Equivalent Significant Quantities of Source Material (per 10 tons of natural uranium)**

| | *2 Percent Grade Unprocessed Uranium Ore (tons)* | *0.086 Percent Grade Unprocessed Uranium Ore (tons)* | $U_3O_8$ *(tons)* | *Natural* $UF_6$ *(tons)* |
|---|---|---|---|---|
| Equivalent significant quantity per 10 tons of natural uranium (pure U content) | 500 | 11,628 | 11.8 | 14.8 |

Note: U, uranium; $UF_6$, uranium hexafluoride.

averaged about 0.65 percent grade from 1980–1988.[6] By the end of the period, Energy Fuels Nuclear had increased the grade to 1 percent.[7] At 1 percent grade, one SQ of ore would be 1,000 tons of ore.[8] On the other hand, assuming uranium is trading at $50 per pound ($110 per kilogram), the lowest grade of economically feasible uranium from open pit mines[9] in the United States is 0.086 percent grade.[10] At 0.086 percent grade, one SQ for ore would be 11,628 tons (see Table 4.1). This is more than 10 times the above-mentioned estimate of 1,000 tons. In short, the lower the quality of ore, the more that is needed for an SQ of indirect-use material.

Ten tons of natural uranium can be used to produce a range of direct-use material, depending on processing capabilities and inefficiencies. Enriching 10 tons of natural uranium can produce roughly 45 kilograms of HEU.[11] However, this can vary significantly according to the tails assay. Using 10 tons of natural uranium to fuel a production reactor would yield a little more than 1 SQ of separated Pu, if one assumes it takes 1 metric ton of natural uranium to produce 1 kilogram of Pu.[12]

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[6] Karen J. Wenrich and Spencer R. Titley, “Uranium exploration for northern Arizona (USA) breccia pipes in the 21st century and consideration of genetic models,” *Arizona Geological Society Digest* 22 (2008): 296, http://www.acertgroup.com/23AGS22WenrichandTitley(final-Protect).pdf.

[7] Karen J. Wenrich, “Uranium Mining in Arizona Breccia Pipes—Environmental, Economic, and Human Impact,” Legislative Hearing on H.R. 644, July 21, 2009, http://www.acertgroup.com/WeinrichUraniumMiningi nArizonaTestimony21Jul09.pdf.

[8] Estimates of ore quantities range corresponding to a 0.2–0.4% tails assay. 0.2% tails assay requires 500 tons, and 0.4 percent tails assay requires 800 tons.

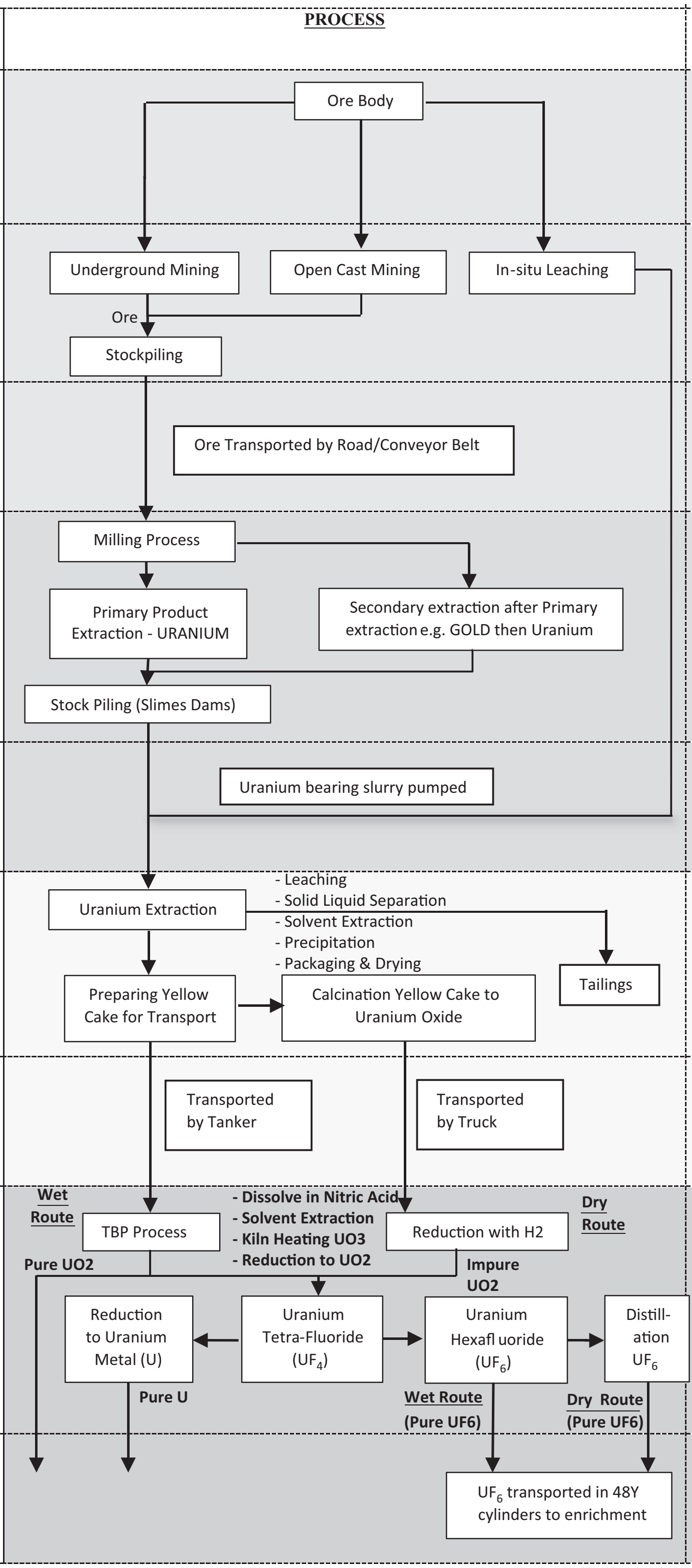
[9] As the price of $U_3O_8$ increases, more mines become economically feasible. Underground mines are typically used to mine higher grade ore than open pit mines. ISL sites can mine lower quality ore than open pit mines, but this ore does not go through the same conventional mill processing as underground and open pit mining sites, and is therefore not subject to the same security risks.

[10] U.S. Energy Information Administration, “U.S. Uranium Reserves Estimates, with data from 2008,” July 2010, http://www.eia.gov/cneaf/nuclear/page/reserves/ures.pdf.

[11] International Panel on Fissile Materials, “Figure 4.7, Global Fissile Material Report 2009,” 60, http://fissilematerials.org/library/gfmr09.pdf.

[12] National Research Council, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities* (Washington, DC: National Academies Press, 2005), 200, http://www.nap.edu/openbook.php?record_id=11265&page=200.

**Figure 4.1. Uranium Processing Risk Assessment**



| | THEFT | DIVERSION | EXPORT CONTROL FALSIFICATION |
|---|---|---|---|
| EXPLORATION | N/A | N/A | N/A |
| MINING | LOWEST/LOW | LOWEST/LOW | LOWEST/LOW |
| TRANSPORT | LOWEST/HIGH | LOWEST/HIGH | LOWEST/LOW |
| MILLING | LOWER/HIGH<br>ISL N/A | LOWER/MEDIUM | N/A |
| TRANSPORT | N/A | N/A | N/A |
| EXTRACTION | LOWER/HIGH (ISL = LOWER/MEDIUM) | LOWER/MEDIUM | LOWER/MEDIUM |
| TRANSPORT | LOWER/HIGH | LOWER/MEDIUM | LOWER/LOW |
| COINVERSION | LOW/HIGH | LOW/LOW | LOW/MEDIUM |
| TRANSPORT | LOW/HIGH | LOW/MEDIUM | LOW/LOW |

*This gives a rough sense of material attractiveness weighed against the risk of detection of theft. Levels of material attractiveness include lowest, lower, and low (assuming HEU has a high level of material attractiveness). Risk of detection by the operator can be low, medium, or high. $H_2$, hydrogen; HEU, high enriched uranium; ISL, in-situ leaching; N/A, not applicable; TBP, tributyl phosphate; U, uranium; $UF_4$, uranium tetrafluoride; $UF_6$, uranium hexafluoride; $UO_2$, uranium dioxide; $UO_3$, uranium trioxide

Source: International Atomic Energy Agency, "Nuclear Security in the Uranium Industry," Draft IAEA Nuclear Security Series, November 2012.

Uranium hexafluoride ($UF_6$) Type 48Y cylinder being moved at Honeywell Metropolis Works, Metropolis, Illinois. Source: Wikipedia. http://en.wikipedia.org/wiki/File:Cylinder_Load.jpg.

## Potential Scenarios

The two basic pathways for obtaining uranium illegally are through outright theft or illicit diversion. Either way, insider involvement would considerably boost the chances of success. Moving material to illicit overseas destinations would almost certainly involve falsifying export control documents, such as material declarations, end uses, and end users. First- and second-stage barriers to such activities are on-site security and transport monitoring. Vigilance by export control agencies is a third barrier, particularly when it comes to spotting falsified documents or other evidence suggesting illegal trafficking.

Theft scenarios could include (also see Figure 4.1):[13]

- ore stockpiles at the mining site
- ore in transit to milling

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[13] Please note that this discussion does not consider scenarios beyond the starting point of IAEA safeguards (which is the point at which nuclear material of a composition and purity suitable for fuel fabrication or for being isotopically enriched leaves the plant or process stage in which it has been produced or when such material is imported into a state).

- yellowcake at milling
- yellowcake en route to conversion
- yellowcake and/or $UF_6$ in storage at conversion sites.
- $UF_6$ en route to enrichment

Outright theft of ore is an unattractive proposition; large amounts would be required and detection would be fairly easy. Given that dump trucks used to transport ore typically have 20- to 30-ton capacity (dependent upon the addition of a trailer), it could require anywhere from 17 to 390 trucks' worth of material to acquire one SQ, depending on the ore grade.[14] Even assuming a high-grade uranium site, it is unlikely that there would be enough trucks available to steal. It is extremely unlikely that such an operation could happen without notice. Of course, this scenario is virtually impossible at in-situ leach (ISL) sites, given that the "ore" slurry is typically piped directly to the main plant to be turned into yellowcake, unless the uranium-bearing resins are transported via tanker from a satellite facility to the main plant.[15] Even then, multiple tanker shipments would need to be stolen (about nine tanker shipments for one SQ), and the uranium would need to be extracted from the resins, which would involve a process of stripping the uranium, precipitation of the uranium into slurry, and filtering and drying the uranium.[16]

Theft at a conventional mill or ISL plant is more attractive than theft of ore, given that much less yellowcake is needed to produce a significant quantity of fissile material. However, conventional mill sites tend to be much more secure than mines, given their continuous hours of operation and relatively increased level of physical protection and security measures. Still, these measures are not uniform to all uranium recovery facilities. Several ISL sites in the United States do not have the same level of security measures as conventional mills, such as armed guards on the premises. On the other hand, ISL sites usually do not produce as much material as conventional mills.[17] There is also currently one operating conventional mill facility in the U.S., the White Mesa Mill in San Juan County, Utah. This limits the number of theft scenarios at conventional mill sites, although there are two

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[14] This estimate assumes that the trucks are 30-ton capacity. The range is based on 2 percent to 0.086 percent ore grade.

[15] In the cases of smaller ore bodies that are distant from the central process plant, a satellite plant is set up that will typically use a resin/polymer remote ion exchange (RIX) system for uranium extraction. The resins will then be loaded onto a tanker so that the uranium can be stripped from the resins and dried at the central processing plant.

[16] Capacity depends on various factors including the size and the design of the tanker and resin qualities. Tankers are Department of Transportation (DOT) approved, specially designed "sole-use" for yellowcake slurry, with separate compartments for uranium loaded resin, unloaded resin, and an empty compartment. Each run between the well field and the plant can bring between 900 to 1,360 kilograms of $U_3O_8$, with 2.7 to 3.6 kilograms of $U_3O_8$ per cubic foot of resin. The tanker estimate assumes 1,360 kilograms of $U_3O_8$ per shipment. Also see James Finch, "New Technique to Boost US Uranium Mining Production," *Seeking Alpha*, March 20, 2007, http://seekingalpha.com/article/30045-new-technique-to-boost-us-uranium-mining-production.

[17] The White Mesa Mill, the only fully licensed and operating conventional mill in the United States, can produce up to 8 million pounds, or 3,629 metric tons of uranium per year, which is up to three to four times the peak amount of uranium expected to be produced annually by most of the other ISL mining sites in the United States.

other conventional mills on standby and one in development. It is also general practice to stockpile ore at a mill site in order to run the mill for a continuous period, which does not occur at ISL sites.

Only one truck would need to be stolen en route to the conversion plant in order to acquire uranium sufficient for a rudimentary capability, assuming a 40-foot truck trailer that can hold up to 60 drums.[18] Yellowcake is typically transported in 200-liter drums. Depending on how thoroughly the yellowcake is dried and the degree of impurities in the material, the amount of $U_3O_8$ in each drum can range from 300 to 400 kilograms. Assuming that there are 400 kilograms of $U_3O_8$ per drum, someone seeking to divert one SQ of $U_3O_8$ would need to steal 30 drums. A trailer containing 60 drums is equivalent to roughly two SQs.

It is more likely that such material would be stolen during transport, rather than at the mill site. This is because the material has already been packaged and prepared for transport, and is outside the confines of the milling facility. Ore shipments are obviously far more frequent than yellowcake shipments because of the need to continually feed an operating mill. However, yellowcake shipments travel much further, thus providing more opportunities for theft or diversion. Yellowcake is also valuable; a truckload of 60 drums would be worth $2.1 million at a price of $35 per pound ($77 per kilogram).[19] This gives mill operators and transporters a reason to be concerned with the physical security of their material, and therefore more vigilant than they might be with ore.

The Honeywell/Converdyn conversion facility in Metropolis, Illinois, the only $UF_6$ production plant in the United States, with no others planned, might be viewed as a tempting target for theft because of the enormous numbers of drums of yellowcake in storage there. However, the Honeywell facility has significant security measures in place, such as armed guards and restricted areas.

Theft during transportation of unenriched $UF_6$ might also be viewed as attractive, given that one Type 48Y canister holds nearly enough uranium for one SQ. The Type 48Y cylinder model, which holds 12.5 metric tons of $UF_6$ (equivalent to about 8.45 metric tons of natural uranium), is the most commonly used cylinder for transporting natural $UF_6$. Each cylinder of natural uranium $UF_6$ contains about 60.1 kilograms of uranium-235 (U-235).[20] A single 48Y cylinder would contain a little less than one SQ of $UF_6$. However, theft of such a truck would be arguably more conspicuous than theft of a truck containing yellowcake, assuming that the canisters are being transported via open back trailer, which is often the case. Furthermore, 48Ycanisters are extremely large, making them difficult to handle.[21]

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[18] Senes Consultants Limited, “Risk Assessment for Proposed Uranium and Vanadium Mill at the Piñon Ridge Property,” November 2009, 69, https://www.colorado.gov/cdphedir/hm/Radiation/licenseapplication/rpt%281%29riskassessment.pdf.

[19] Prior to the Fukushima accident in 2011, uranium was trading at roughly $68 per pound ($150 per kilogram).

[20] Natural uranium is 0.711 percent U-235, thus 8,450 kilograms of natural uranium contains 61 kilograms of U-235.

[21] 48Y cylinders are about 12 feet long, and 4 feet in diameter. For a more detailed model of a 48Y $UF_6$ cylinder, please see http://www.oro.doe.gov/duf6disposition/cylinder_TYPE_48Y.pdf.

Honeywell Metropolis Works, Metropolis, Illinois.
Source: Wikipedia. http://en.wikipedia.org/wiki/File:MTW_Picture.jpg.

Diversion scenarios assume there are one or more insiders in a facility who can evade detection and/or security measures. One possibility is to manipulate material accounting in order to disguise an illicit diversion (in effect, "undeclared" production) to allow for clandestine shipments later. In fact, state employees in Kazakhstan allegedly made a clandestine deal, without approval of the Kazakh government, to sell 1,350 tons of yellowcake to Iran, taking advantage of overproduction and poor accounting of uranium output.[22] In U.S. uranium recovery operations, where the qualities and quantities of inputs and outputs are central to profitability, such allegations would imply either corruption at the highest level of the company or a failure in material accounting.

One example of insider diversion in the United States occurred in 1978, when five barrels of yellowcake were stolen from the Standard Oil of Ohio (Sohio) uranium mill in New Mexico by lower level employees who took advantage of gaps in material accounting.[23] The mill ran a batch operation, and only completely filled barrels were accounted for; excess was diverted by the employees. As one of the thieves stated, "The easiest part of everything was to get it out of the plant. . . . The way they take inventory down there, it would never be missed."[24] The thieves then contacted a broker, who attempted to find a buyer for the yellowcake through intermediaries. The yellowcake was eventually recovered by the Federal Bureau of Investigation (FBI), which had been notified by the potential buyer. However, had the potential buyer not been suspicious of the terms of the deal and

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[22] George Jahn, "Iran Seeking to Smuggle Raw Uranium From Kazakhstan: Report," *Huffington Post*, December 29, 2009, http://www.huffingtonpost.com/2009/12/29/iran-seeking-to-smuggle-r_n_406258.html.

[23] P.A. Budinger, T.L. Drenski, A.W. Varnes, J.R. Mooney, "The Case of the Great Yellow Cake Caper," *Analytical Chemistry* 52, no. 8 (1980): 942A–948A, http://pubs.acs.org/doi/abs/10.1021/ac50058a777?journalCode=ancham.

[24] UPI, "Uranium theft brings review of security," *Roswell Daily Record*, April 10, 1979, http://www.newspapers.com/newspage/14944500/.

notified the authorities, it is likely that the transaction and theft would have gone completely unnoticed. Even more unsettling, the broker had expressed a willingness to sell the stolen yellowcake abroad. The two thieves received misdemeanor charges in exchange for testifying against the broker, who eventually received harsher felony charges.[25] The security of the five then-operating mills in New Mexico was reviewed after the incident, although it is unclear whether any regulatory improvements were implemented. Eventually, for reasons related to Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 implementation,[26] New Mexico would cede authority of regulation over uranium recovery facilities to the Nuclear Regulatory Commission (NRC) in 1986.

Falsifying export control documents, such as material declarations, end-use, or end-user certificates, constitutes another pathway for illicit shipments. In August 2006 a Tanzanian customs officer discovered Congolese uranium hidden within a cargo container disguised as a shipment of coltan, a mineral used to make chips in cellular phones.[27] The uranium was hidden under a layer of coltan. The customs officer detected the radioactivity with a Geiger counter, which was provided by U.S. port security. Without inside information, it is debatable how thoroughly a ship containing hundreds of cargo containers stacked on one another could be searched for radioactive materials.

Ore could also be shipped abroad under the guise of nonnuclear end use, but the enormous amounts required and the marginal quantities of uranium that would be recovered make this extremely uneconomical and unlikely. It is far more likely that a state would seek yellowcake or $UF_6$ should it choose to pursue a nuclear weapon.

Finally, another route could involve deception regarding the ultimate end user, possibly involving unwitting suppliers and middlemen. These kinds of techniques reportedly were used in the Plumbat operation in the early 1960s to divert yellowcake within Europe to Israel.[28] Techniques included shell companies, falsified end-use documents, and poorly enforced European Atomic Energy Community (EURATOM) safeguards. A modern-day Plumbat-style operation would take advantage of lax transit matching between shipper and receiver, inadequate export licensing procedures to spot suspicious behavior, and failure to verify receipt and ultimate end use. Undoubtedly some of these gaps in export controls exist today.

In the United States, the most controversial incident related to nuclear material losses involved HEU at the Nuclear Materials and Equipment Corporation (NUMEC) Corporation in Apollo, Pennsylvania, in 1965. NUMEC did not produce material, but primarily fabricated fuel using HEU and plutonium. Poor accounting practices, lack of process controls,

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[25] United States of America, Plaintiff-Appellee v. John P. O'Connor, Defendant-Appellant, Decided December 19, 1980, 635 F.2d 814, https://law.resource.org/pub/us/case/reporter/F2/635/635.F2d.814.79-1496.html.

[26] Organization of Agreement States, "Topical Discussion of the NRC/Agreement State Program," Illinois Department of Nuclear Safety, October 1994, 11, http://nrc-stp.ornl.gov/special/topical.pdf.

[27] Jack Edlow, "Can We Track Source Materials Better: Do We Need To?," in *Falling Behind: International Scrutiny of the Peaceful Atom*, ed. Henry D. Sokolski (Carlisle, PA: Strategic Studies Institute, February 2008), 66, http://www.strategicstudiesinstitute.army.mil/pdffiles/pub841.pdf.

[28] Davenport et al., *The Plumbat Affair*.

facility accidents, and persistent security vulnerabilities contributed to significant losses of HEU, first estimated at 100 kilograms and then at 269 kilograms.[29] Some analysts suspect the material was diverted to Israel for use in its early nuclear weapons program.[30]

The NUMEC incident occurred before the implementation of domestic safeguards in the United States and before the Department of Energy (DOE) and the NRC were created. Nonetheless, the case may hold some salience for other countries. First, it proved the inadequacy of delegating accounting to private companies based on the assumption that the high market value of the material will encourage material protection. In this case, there were no stand-ins for ensuring material accountancy, such as health or safety regulations. Second, the unwillingness of the Atomic Energy Commission (AEC) to exercise its regulatory authority by demanding material accountancy from contractors, canceling of security clearances, or tracking nuclear materials in transit presumably contributed to a culture of unaccountability.[31]

The 1946 Atomic Energy Act included provisions for FBI investigations of criminal violations.[32] However, regulations state that these investigations must center on potential breaches of access to "Restricted Data," which is closely tied to special nuclear material and the production of weapons, not source material. The regulation itself addresses security concerns during the earlier years of uranium governance, and remains relevant. The FBI investigated Zalman Shapiro, the president of NUMEC, in connection with possible espionage, not the loss of HEU; charges were never filed against him. The AEC determined that it had no evidence to prove that diversion had occurred. The AEC talked the FBI out of investigating the loss.[33]

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[29] Victor Gilinsky and Roger Mattson, "Revisiting the Numec Affair," *Bulletin of the Atomic Scientists*, no. 2 (March/April 2010): 66, http://thebulletin.org/2010/march/revisiting-numec-affair.

[30] Grant F. Smith, *Divert! Numec, Zalman Shapiro and the Diversion of the US Weapons Grade Uranium into the Israeli Nuclear Weapons Program* (Washington, DC: Institute for Research, 2012), 53–60.

[31] Ibid., 35.

[32] "Atomic Energy Act of 1946," Section 10, *Control of Information*, http://science.energy.gov/~/media/bes/pdf/atomic_energy_act_of_1946.pdf.

[33] Gilinsky and Mattson, "Revisiting the Numec Affair," 64. Also see R. W. Borchart, "NRC Letter to Senator Arlen Specter," November 2, 2009, http://pbadupws.nrc.gov/docs/ML0927/ML092720878.pdf.

# 5 U.S. Uranium Regulation Today

The bulk of source material regulation falls primarily under the authority of the Nuclear Regulatory Commission (NRC). The NRC, however, does not regulate conventional mining, which is subject to the 1872 Mining Act. Regulation is further complicated by the federalist nature of the Agreement State system, which allows some states to perform regulatory functions that the NRC otherwise would. Applicants for a license for handling the designated nuclear materials under the Agreement State program must file those applications with the Agreement State government, not with the NRC. However, even if a state makes an "agreement" with the NRC, the NRC still provides substantial input into

**Nuclear Regulatory Commission**

- Fiscal year (FY) 2012 budget is $1,038.1 million, with 3,862 full-time equivalents (FTEs); proposed FY 2014 budget is $1,055.0 million, with 3,919 FTE.
- Employs approximately 4,000 people.
- Headquartered in Rockville, Maryland, with regional offices in King of Prussia, Pennsylvania; Atlanta, Georgia; Lisle, Illinois; and Arlington, Texas.
- More than 20,000 active source, by-product, and special nuclear material licenses are in place nationwide. Around one-quarter of these are administered by the NRC, with the rest administered by states participating in the Agreement State program.
- Spent $227.1 million in FY 2012 on regulatory activities related to the safety and security of nuclear materials and waste, including $56.1 million to regulate fuel facilities spanning the whole fuel cycle and $93.1 million to regulate nuclear materials users (most of the remaining amount is spent on waste).
- Proposed budget for FY 2014 allots $231.5 million on nuclear materials and waste safety, with $60.2 million on fuel facilities and $86.9 on materials users.

Source: Nuclear Regulatory Commission, *2014 Congressional Budget Justification*, http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1100/v29/fy2014-cbj.pdf.

decisionmaking, and state regulations must conform to NRC regulations. State regulations should not be less stringent than those of the NRC, and sometimes state regulations may be more stringent than NRC rules. Penalties for violations of regulations can include revoking of licenses, injunctions or court orders, and criminal sanctions.

## The Agreement State Program

The Agreement State program (section 274 of the Atomic Energy Act of 1954) grants licensing and inspection authority to states for by-product, source, or certain quantities of special nuclear materials used or possessed within Agreement State borders. Those wishing to handle the aforementioned materials in an Agreement State must file an application with the state, not with the NRC. The majority of the 50 states are Agreement States; the non-Agreement States are Idaho, Montana, Wyoming, South Dakota, Michigan, Indiana, Missouri, West Virginia, Vermont, Connecticut, Delaware, and the District of Columbia.

**Colorado: An Agreement State**

Colorado became an Agreement State on February 1, 1968. Its uranium mill amendment was instituted on April 29, 1982. It has assumed authority over Byproduct materials (11e1), Mill Tailings (11e2), naturally occurring and/or Accelerator-produced Radioactive Material (NARM) (11e3), discrete sources (11e4), source materials, special nuclear materials in quantities not sufficient to form a critical mass, and sealed source and device evaluation.

Uranium recovery regulation is split primarily between two main authorities. The first is the Department of Natural Resources Mined Land Reclamation Board (MLRB), which works with the Division of Reclamation, Mining, and Safety (DRMS), and the second is the Radiation Program of the Hazardous Materials and Waste Management Division of the Colorado Department of Public Health and Environment (CDPHE). There are three permits from the CDPHE in order to license an ISL facility: an Air Quality Permit, a Groundwater Discharge Permit, and a Radioactive Materials License. For the Radioactive Materials license, the main concerns primarily center on safety issues such as a description of the radioactive materials, how the materials will be used, safety procedures, documentation of workers training and experience, facility diagrams, calculations to demonstrate compliance with public radiation dose limits, etc. The licensing process also includes substantial public involvement, especially for uranium mills. Furthermore, a reclamation permit must be filed with the MLRB, similar to all mining operations in the state. There are also local permits that need to be filed as well.

The process of becoming an Agreement State typically takes from four to five years. The NRC Management Review Board biannually reviews each state's performance to ensure that the state's program is adequately enforcing its regulations and obligations, and maintains reassertion authority in the case of accidents or emergencies, though there is a probationary period before an Agreement State can lose its authority. While it is generally understood that state regulations must, at a minimum, be as stringent as NRC regulations, this has sometimes led to conflict between states and the NRC, as state regulators can sometimes loosely interpret "compliance." In order to be compatible with NRC regulations, state definitions and regulations need to be identical or more stringent than those of the NRC. Agreement states are not able to craft their own guidelines on the import and export of source material and do not have the authority to grant import and export licenses. This also applies to the disposal of source material. NRC authority supersedes that of the states in these areas.

This framework, combined with the numerous issues regarding public land ownership, tribal authorities, and environmental concerns, leads to a complex regulatory framework for uranium recovery operations.

**Wyoming: Regulated by the NRC**

Wyoming is currently not an Agreement State. However, it has recently been considering applying for Agreement State status and has commissioned a study to explore the option. Given that it is not an Agreement State, regulatory authority falls primarily under the jurisdiction of the NRC. There are a number of inactive mine sites in the state that are being reclaimed under Title I and Title II of the UMTRCA laws. Sites established prior to 1978 tend to fall under Title I, and there are two of these sites in Wyoming. There are nine Title II sites in Wyoming (post 1978). In addition to NRC regulation on ISL activities, the Land Quality Division of the Wyoming Department of Environmental Quality regulates these operations through its Underground Injection Control (UIC) program. As noted, most of this regulation tends to be driven by environmental concerns, especially with regards to underground water quality.

The currently active uranium recovery projects in Wyoming are ISL operations, including Cameco's Smith Ranch-Highland ISL operation, which produced 500 metric tons of $U_3O_8$ in 2012. The most recent addition in May 2012 was Uranium One's Willow Creek mine, which includes the Irigaray ISL central processing plant and the Christensen Ranch satellite ISL facility. Ur-Energy also has an NRC-licensed facility at the Lost Creek deposit, which is scheduled to begin production in mid-2013. There are numerous additional facilities in Wyoming that are in the licensing or exploration phases.

# Physical Protection Requirements

Since natural uranium is not "special nuclear material," as defined in 10 Code of Federal Regulations (CFR) Part 73,[1] and since milling and mining facilities are not considered either "production" or "utilization" facilities, there are no physical protection requirements of the NRC specifically targeted toward uranium recovery facilities for source material, although there are some physical protection requirements during transit.

After September 11, 2001, the NRC conducted a risk-based, comprehensive review of the entire regulatory system. Because the NRC does not regulate conventional mines, these were not included in the review. The NRC did not recommend improvements for the security of uranium recovery facilities. Post-9/11 changes included certain inventory requirements for facilities that handled nuclear materials, but they did not apply to mines, mills, or conversion plants. There were also orders for increased site security at conversion plants; however, the new regulations are still being finalized, as the priority of improvements fell mostly on power reactors.

Most of the physical protection measures are self-imposed by industry out of economic interest: each drum of yellowcake holds roughly 400 kilograms of $U_3O_8$, which translates into $30,000 to $50,000 based on current uranium prices. Given that trucks can transport up to 60 barrels at a time, each truck is potentially holding roughly $2 to $3 million worth of material.

Despite a lack of requirements for physical protection, there are several barriers to potential theft at mill sites. Uranium recovery operations take place in fairly remote locations, which forms an inherent barrier to theft. Uranium producers tend to use armed guards at their mills, including 24-hour surveillance and barbed wire fences, although this is not universal, especially at in-situ leach (ISL) facilities. Drums are typically assigned numbers and placed in their appropriate lots. As explained later, some environmental and safety regulations have spillover effects in terms of physical protection.

Physical protection practices during transportation tend to be more rigorous than those at mill sites. Transporters take precautions to ensure timely delivery of uranium, which can include designated routes with designated rest stops, additional drivers, and global positioning system (GPS) tracking on trucks to monitor engine conditions and speeds. There are also seals on the trailer to detect tampering, with verification of container numbers when the transport reaches its destination. However, tracking is not necessarily attached to the trailer, leaving open the possibility of switching trailers from cabs. While the risk of diversion could begin at a mine, it would necessarily involve transport—either with the theft of ore and subsequent shipment to an operating mill, where little certification for milling is necessary, or the diversion of uranium concentrates after leaving the mill.

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1. 10 CFR Part 73.2, "Definitions," Special Nuclear Material, http://www.nrc.gov/reading-rm/doc-collections/cfr/part073/part073-0002.html.

This level of physical protection does not extend to uranium ore at the mine. In the case of conventional mines, anecdotal evidence has pointed to the ease of break-ins and stealing of ore, which is later resold at a mill.[2] Since little certification (typically only proof of property ownership) is needed in order to sell the ore at the mill, stealing ore at unguarded mines can provide lucrative profit when the prices of uranium are high.

## Transportation Requirements

Most transportation requirements for source material arise from safety considerations. Materials are packaged and transported in such a way as to avoid contamination that may result from accidents, leaks, or spills. The Department of Transportation (DOT) harmonizes with International Atomic Energy Agency (IAEA) guidelines for transportation of uranium in its different forms. Natural uranium is exempt from NRC Part 71 on Packaging and Transportation of Radioactive Material, since natural uranium is classified as a Low Specific Activity-1 (LSA-1) material.[3] Agreement states may have their own regulations under which they issue general licenses to carriers in reference to DOT regulations, NRC approval (Certification of Compliance), and quality assurance requirements for domestic transport of radioactive materials.

The DOT plays a role in regulating the transport of source materials, although primarily for the purpose of avoiding spills. In focusing on packaging, labeling, and truck conditions, the DOT does not typically include security as a guidance metric. Additionally, the training of DOT employees tends to be more oriented for the case of a spill rather than for theft or diversion. In terms of personnel, there are roughly 60 total field investigators working for the DOT's Office of Hazardous Materials. Of these investigators, there is one radioactive material specialist in each of the five designated regions of the United States.

As stated above, natural uranium (ore, uranium concentrates, and unenriched uranium hexafluoride) is classified as a LSA-1 material under federal regulations.[4] These classifications are primarily for safety and radiation purposes, particularly in the case of a spill. Accordingly, these classifications prescribe certain packaging requirements to reduce the risk of unintentional radioactive release. LSA-1 materials at a minimum require an Industrial Packaging-1 (IP-1) standard quality container, which is the least rigorous of the industrial packaging classifications. This is because even in the case of a spill, the amount of natural uranium that must be ingested to produce a significant radiation dose is significantly greater than uranium in other forms. This is consistent with IAEA industrial package requirements for LSA material.[5] Generally, the DOT tries to

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[2] Personal interview, industry representative, April 5, 2013.

[3] Code of Federal Regulations, NRC Regulations, 10, sec. 71.14, http://www.nrc.gov/reading-rm/doc-collections/cfr/part071/full-text.html.

[4] Ibid., 10, sec. 71.4.

[5] "Regulations for the Safe Transport of Radioactive Material, 2005 Edition, Requirements and Controls for Transport, Table 4, Industrial Package Requirements for LSA Material and SCO," International Atomic Energy Agency, 55, http://www-pub.iaea.org/mtcd/publications/pdf/pub1225_web.pdf.

**Department of Transportation**

- Fiscal Year (FY) 2012 budget is $77 billion in total.
- Employs approximately 60,000 people.
- 190 Full Time Equivalent employees and approximately 60 field investigators work in the Office of Hazardous Materials Safety.
- One radioactive specialist resides in each region, headquartered in:
    - Atlanta, GA
    - Des Plaines, IL
    - Houston, TX
    - Ontario, CA
    - West Trenton, NJ
- The Office of Hazardous Materials Safety operated on a $42,338,000 budget for FY 2012. It is requesting $51,801,000 for FY 2014.

Source: U.S. Department of Transportation, *Budget Estimate: Fiscal Year 2014, Pipeline and Hazardous Materials Safety Administration*, http://www.dot.gov/sites/dot.dev/files/docs/PHMSA_FY2014_Budget_Estimates.pdf.

not unduly hamper commerce through regulation, and yellowcake is treated as very low risk.

The DOT licenses Type A package transportation (which includes 200-liter steel drums, the most common transportation for yellowcake, and the standard Type 48Y steel cylinders typically used for unenriched $UF_6$),[6] while the NRC certifies Type B package transport, typically reserved for highly radioactive materials. Type A packages are designed to withstand normal handling and smaller accidents. Licensing for Type A material is a certificate of approval that the packaging meets the requirements.

Shippers are required to have a security plan, but the plan does not need DOT approval. This security plan only applies to quantities of uranium hexafluoride that require placarding, and does not apply to yellowcake or ore.[7] Each transport vehicle, portable tank, or freight container that contains 454 kilograms or more gross weight of fissile or LSA ura-

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[6] For a list of approximately 300 different types of packaging that have been determined to meet DOT Specification 7A Type A, please see “Test and Evaluation Document for the U.S. Department of Transportation Specification 7A Type A Packaging,” DOE/RL-96-57, Rev. 0-F, Vol. 1, http://rampac.energy.gov/certinfo/special/noncertified/dot7a/rl96-57/ptoc.htm.

[7] Code of Federal Regulations, Transportation, 49, sec. 172.800(b)(14), http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&sid=da1ee7320994aedb01c2312902db2229&rgn=div6&view=text&node=49:2.1.1.3.8.9&idno=49.

nium hexafluoride must meet this requirement.[8] During the process of evaluating shipments of source material, however, the DOT does not review the security plan.

There are several components to the security plan.[9] At minimum, such security plans must cover three areas: personnel security, unauthorized access, and en route security.

- Personnel security involves confirming employment information regarding employees involved in handling of the material, and that such information is consistent with state and federal regulations regarding employment practices and individual privacy.
- Unauthorized access regulations state that the security plan must have measures to prevent unauthorized access to either the materials transported or the vehicle of transport.
- En route security involves protection during transport from origin to destination.

Security plans must also identify the senior management official responsible for development and implementation of the security plan, the duties of employees or departments during the execution of the security plan, and a plan for training hazardous materials (hazmat) employees for security situations.

Persons who transport a placarded shipment of uranium hexafluoride are required to take security awareness training courses on a recurrent basis according to DOT regulations.[10] Employers are required to keep records on their employees and their fulfilled training requirements. These records are not regularly checked by the DOT, although they must be available upon request. Such requirements include “security awareness” training and an additional “in-depth security” training component, if a security plan is required.[11] Security awareness training covers studying methods for enhancing transportation safety, as well recognizing and responding to security threats. In-depth security training is centered on the security plan, involving details such as organizational security hierarchy and objectives, specific security actions and procedures, and employee-specific responsibilities and actions in the case of a security breach.

There are also distinct DOT regulations for different types of transportation—rail, ship, air, or highway—of Class 7 radioactive materials, which covers a broad range of materials that emit radiation (including LSA materials, Surface Contaminated Objects, and fissile material). While intended for safety and environmental purposes, these transportation regulations can have implications for security. For example, most shipments of natural uranium tend to take place as exclusive-use shipments (also referred to as sole use by the IAEA), which means that the consignor has exclusive use over a conveyance, and that all loading is done under the direction of consignor or consignee by personnel with

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[8] Ibid., 49, sec. 172.505(b).
[9] Ibid., 49, sec. 172.802.
[10] Ibid., 49, sec. 172.704.
[11] Ibid.

**Table 5.1. U.S. Department of Transportation (DOT) Inspection Requirements by Mode of Transport**

| *Mode of Transport* | *Inspection Required?* | *Security-Relevant Inspection Notes* | *Party Responsible for Inspection* |
|---|---|---|---|
| Rail | Yes | Must occur at every location where radioactive materials are loaded. | Carrier |
| | | Includes searching for suspicious items and explosive devices. | Carrier |
| Air | Yes | Ensures that packaging and sealing is not broken. | Aircraft Operator |
| | | Includes “discrepancy” clause in event that materials are mislabeled or packaged suspiciously. | Aircraft Operator |
| Ship | Yes | Conducted every 24 hours after stowage. | Carrier |
| | | Primary purpose is to ensure that packages have not tipped. | Carrier |
| | | Freight containers or individual barges do not have to be opened. | Carrier |
| | | Holds with smoke or fire detectors do not have to be inspected except after stowage is completed and heavy weather conditions. | Carrier |
| Highway | No | Inspections must be made available to the DOT if it chooses to inspect. | DOT |

Source: Code of Federal Regulations, Transportation, 49 Subtitle B, Chapter I, Subchapter C, Parts 174–177. http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title49/49cfrv2_02.tpl.

appropriate radiological training and resources.[12] There are also inspection requirements for each mode of transport, some of which are intended for security purposes (see Table 5.1).

For transportation by rail, there are safety-based requirements for packaging drums, cylinders, or other types of containers to avoid spillage and loose material. Carriers are responsible for inspections at each location where hazardous materials are accepted.[13] This includes searching for tampering, suspicious items, and, particularly, improvised explosive devices. There is also a requirement that a person shall not unnecessarily remain in or near a transport vehicle containing Class 7 radioactive materials.[14] Exclusive use transport vehicles must be washed after use and surveyed for radiation afterward; the vehicle cannot be used again until the radiation dose rate at any accessible surface is 0.005 mSv (millisievert) per hour or less.[15]

For transportation by air, aircraft operators must inspect the shipments to confirm they are authorized, marked, labeled, and packaged according to all relevant requirements,

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[12] Code of Federal Regulations, NRC Regulations, 10, sec. 71.4.

[13] Code of Federal Regulations, Transportation, 49, sec. 174.9.

[14] Ibid., 49, sec. 174.700(f).

[15] Ibid., 49, sec. 174.715.

including seals integrity.[16] There are also reporting requirements in the case of spills. In the event of a "discrepancy," for example, faulty or nonexistent labeling, procedures require contacting the nearest Federal Aviation Authority regional or field security office.[17] Aircraft used routinely for transporting Class 7 materials are periodically checked for radioactive contamination, with the frequency of checks related to the likelihood of contamination and extent of Class 7 transportation.[18]

For sea transport, there are not many security-specific regulations. A ship's captain, in "emergency situations" that threaten the safety of the crew or vessel, may adopt whatever procedures he or she deems necessary for protection, and notify the U.S. Coast Guard if the packages in question have been damaged.[19] However, some of the safety-related requirements may have security benefits. For example, individuals should not stay unnecessarily near packages that contain radioactive materials.[20] Radioactive shipments are required to be accounted for in the dangerous cargo manifest and data in the manifest must match the data on the shipping papers. Such manifests are confirmed through signature of the individual preparing the manifest and the master of the vessel.[21] Measures to control contamination as a result of a spill or leak, and to ensure that stowage has taken place in a safe manner can also have security benefits. For example, daily inspections after stowage in order to ensure that the containers with hazardous material have not tipped or spilled can help with accounting, even though freight containers and individual barges do not have to be opened for the inspection. Holds with smoke or fire detectors are exempt from these inspections except after stowage is completed and during periods of heavy weather.[22]

On roadways, regulations are similarly focused on safety rather than security, but there may be synergies. For example, contamination control measures provide basic security assurances on whether material has moved from one location to the next by requiring transporters to survey the interior surface of the conveyance for radiation. Labeling and segregation of nuclear materials, and the use of exclusive-use shipments, also help to isolate the material in question and arguably make it easier to track. Carrier inspections of packages to confirm no broken seals, leaks, or tampering also can help provide basic security assurances.

On the whole, however, it is unclear how often these regulations are enforced. For example, while there are requirements for inspections and a general framework of objectives for such inspections, the inspections aim to establish whether material has been correctly packaged and labeled, rather than to verify the material itself. Noncompliance with DOT regulations can result in a fine and possible jail time.

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16. Ibid., 49, sec. 175.30(b).
17. Ibid., 49, sec. 175.31.
18. Ibid., 49, sec. 175.705.
19. Ibid., 49, sec. 176.45.
20. Ibid., 49, sec. 176.700(d).
21. Ibid., 49, sec. 176.30(b).
22. Ibid., 49, sec. 176.39.

Yellowcake canisters.
Source: NRC. http://www.flickr.com/photos/nrcgov/6946374501/in/photostream/.

Security plans are necessary and useful, but without evaluation or approval, it is unclear how effective they might be in the case of a real security threat. Shipments of yellowcake and ore also do not require security plans. Security regulations on transportation via rail tends to be the most detailed out of the modes of transportation covered. Finally, these security plans are mostly addressed toward the scenario of theft of hazardous materials, and, in some cases, outright theft by force (as in the case of sea transport). However, such security plans would not detect a clandestine diversion of nuclear material.

## Material Accounting

All NRC and Agreement State program licensees that possess more than one kilogram of foreign obligated source material must report their holdings to the Department of Energy's Nuclear Materials Management & Safeguards System (NMMSS) each year. NMMSS is the federal government's database for shipment, receipt, and inventory of nuclear materials, including source materials. Uranium at mines, uranium recovery facilities, or conversion plants that is imported or exported must be reported to NMMSS.[23] In 2001 the DOE Office of the Inspector General expressed concerns regarding the accuracy of the data held in NMMSS and whether licensees were upholding their commitments to reporting foreign-obligated source material. This led to subsequent amendments to reporting requirements, but there is no information on how rigorously inspectors investigate potential discrepancies of source material data in NMMSS. Inspections at uranium recovery facilities in Agreement States are conducted by the state regulatory bodies. For uranium recovery facilities that are in non-Agreement States, the inspections are handled by NRC regional inspectors. The core NRC Fuel Cycle Facility Operational Safety and Safeguards Inspection Program covers conversion but not uranium recovery. If the licensee has source material with the pursuant purpose of enrichment, downblending of enriched uranium above 10 percent uranium-235 (U-235), or for the fabrication of mixed oxide (MOX) fuel, the licensee must report its entire inventory of source material.

Public data on actual source material export amounts by licensee is protected for business confidentiality and security reasons, although the Energy Information Administration (EIA) provides general data on U.S. purchases and sales of $U_3O_8$ equivalent in its marketing reports.[24] Export licenses only authorize exports up to a stated quantity. The export license holder is not required to export the permitted quantity, thus the actual quantity of export should not be assumed to be the licensed quantity. Figures 5.1 and 5.2 respectively show the natural uranium exports and imports to the United States. However, one should note that this also includes extremely small quantities. Some are small enough that they may not even require a specific license, and many of those are not for a strict nuclear end use. Appendix 3 lists specific licenses and provides more detailed information on end uses as well as country destinations for source material exports.

NMMSS was originally created to capture data on fissile material during the Manhattan Project. In the early days NMMSS mostly tracked movements of high enriched uranium (HEU) and plutonium between plants in the nuclear weapons complex. It functioned as an accounting tool, allowing the Atomic Energy Commission to gauge whether penalties to contracts had been triggered. In the 1960s NMMSS was automated, and in the 1970s information on nuclear exports was added to the database.

NRC regulations reveal the extent to which the theft or diversion of source material is considered a risk: the NRC requires a report from specific license holders when an attempt of theft or unlawful diversion is made of source material above 15 pounds within four hours of knowledge of the incident.[25] These reporting requirements do not apply to uranium ore from hard rock mines because the NRC has no jurisdiction over this ore until it arrives at the mill.

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[23] 10 CFR 40, 72, 74, and 150 require licensees to report their inventory to NMMSS, which was previously done through 741 forms but is now submitted electronically.

[24] "Uranium Marketing Annual Report, with data from 2012," Table S3a, U.S. Energy Information Administration, May 16, 2013, http://www.eia.gov/uranium/marketing/.

[25] Code of Federal Regulations, NRC Regulations, 10, Sec. 40.64(c).

**Figure 5.1. NMMSS Map of U.S. Exports of Natural Uranium**

NMMSS, Nuclear Materials Management & Safety System.
Source: U.S. Department of Energy, National Nuclear Security Administration.

This system does not allow for reports to be made public, and there is no available information about whether thefts have been reported under it. Government officials have stated that they were unaware of any thefts or diversions. It is also true that this requirement is largely one of self-reporting; there do not appear to be repercussions for the industry if it does not report thefts. It is also questionable whether the amount—15 pounds—of material is a realistic amount to track, given that process losses are likely greater than this.

At conversion plants, reporting such losses could potentially be problematic, because drums of yellowcake are stacked and stored in facilities for years without being measured. While the gross weight of the drum is taken into account, it is generally accepted that there could be a possible 1 percent gain or loss in weight. This. in and of itself, would seem to trigger the above-mentioned 15-pound loss. However, the fact that drums are not opened and the inner contents are not weighed for some time is a potential area of concern.

There is no system in the United States for determining the amount of unaccounted for source material. Thus it is impossible to know for certain how much uranium has gone missing, if any. Mills keep records on material they have produced and the ore that they have received, primarily for commercial reasons. Conventional mills take ore from a variety of separate mine sites, and need to measure the grade by first probing the ore, and then ensuring that they are maintaining, ideally, a 95 percent recovery rate. The loss, or the tailings, depends on the quality of the ore. Mills typically aim to be as precise as

**Figure 5.2. NMMSS Map of U.S. Imports of Natural Uranium**

NMMSS, Nuclear Materials Management & Safety System.
Source: U.S. Department of Energy, National Nuclear Security Administration.

possible in order to properly account for these losses and recovery rates, generally attempting to extract every bit of yellowcake possible to maximize operational economics.

## Book Transfers

A complicating factor for uranium governance is how transfers of uranium are tracked, particularly at conversion facilities. The types of practices that converters engage in may hinder closer tracking of uranium at conversion sites. For example, the flexibility inherent in book transfers at converters could possibly facilitate taking advantage of differences in export control requirements between countries. Title shifts to a utility or other buyer takes place through a simple book transfer at the converter to accommodate delivery schedules and contract terms, with converters effectively acting as a storage "bank" for yellowcake and $UF_6$. At the converter sites, there are some innate hurdles to setting up a trading account, such as negotiation of the various contracts and fees for trade and familiarity with the applicant (e.g., long-established industry relationships help). Beyond that, all that is required of a company wishing to set up an account is that it be deemed creditable by the converter.

Uranium can change hands any number of ways, with few restrictions. For example, producers can sell to traders, who can sell to other utilities, or other producers. Knowledge of associated restrictions on end use can be muddled as uranium changes hands, although trading in the United States is obviously not done with countries on the Treasury Department's blacklist, such as Iran and North Korea. Unlike Australia and Canada, the United

States does not require end-use information for uranium trades, although it does for enriched uranium. Information regarding the country of origin is retained and taken into account, for example, when considering Russian Suspension Agreement quotas.

Ownership of, or title to uranium, is not the same as possession. Title over uranium requires a general license from the NRC. To physically possess source material, owners must file for a separate license with the NRC. However, this distinction between title and actual possession is not universal. It is possible that uranium could be traded to countries with less stringent regulations on possession.

## Export and Import Regulations

For major nuclear exports, the Atomic Energy Act (AEA) requires U.S. government officials to negotiate a peaceful nuclear cooperation agreement (known colloquially as a "123" agreement after Section 123 of the AEA). Exports of uranium for nuclear end use require a 123 agreement to be in place between the United States and the importing country. The United States has more than two dozen such agreements in force. Such framework agreements do not guarantee trade, but set out the terms under which licenses can be approved, including nonproliferation and nuclear security requirements.[26]

The United States exports uranium ore abroad, but only rarely (once or twice annually) and then, the export is usually for nonnuclear end uses. A 123 agreement is not required for exports of source material for nonnuclear end uses; export is allowed so long as it is deemed not inimical to the common defense and security of the United States. U.S. law defines ore as having 0.05 percent uranium content.

Trade in uranium is generally prohibited with "embargoed countries" (Iran, Iraq, Syria, Cuba, Sudan, and North Korea) and is restricted with "restricted countries" (Afghanistan, India, Andorra, Israel, Angola, Libya, Burma [Myanmar], Pakistan, Djibouti, and South Sudan). Exports to countries on the embargo list are not entirely prohibited, although exporters have to apply to the NRC for a specific, as opposed to a general, license in order to make the shipment. Specific licenses must be submitted for review by the Executive Branch of the U.S. government. Middlemen destinations must specified, among other obligations. An initial export of 250 kilograms of source material to an embargoed or restricted country must be reviewed by the NRC's five-member commission.[27]

Under general licenses, only small amounts of source material can be exported: 10 kilograms or less per shipment, not to exceed 1,000 kilograms per year. However, this applies only to countries not on the embargoed or restricted destinations list. The annual

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[26] The U.S. regulations for the export and import of nuclear material and equipment for peaceful purposes can be found in 10 Code of Federal Regulations (CFR) Part 110.

[27] The NRC Commission consists of five commissioners appointed by the president and confirmed by the Senate for five-year terms. Currently, they are Chairman Allison M. Macfarlane, Kristine L. Svinicki, George Apostolakis, William D. Magwood IV, and William C. Ostendorff.

limit is 500 kilograms if the uranium is Canadian-obligated.[28] Exports to restricted countries have a lower threshold (1 kilogram per shipment, and not more than 100 kilograms per year).[29] Proposed exports that do not qualify for an NRC general license must apply for an NRC specific license by submitting an NRC Form 7 and an appropriate fee. Some of these are reviewed by an interagency process. Those specific licenses requiring Executive Branch review (see 10 CFR 110.41) are reviewed by the Department of State, DOE/National Nuclear Security Administration (NNSA), the Department of Defense, the NRC, and the Department of Commerce.

When exporting quantities above 500 kilograms, an advance notification of export must be sent to the NRC. This notification includes contact information of the shipper, receiver, and carriers; a physical description of the shipment; a list of the modes of shipment as well as a description of the routes taken; the estimated time and date of arrival; and a certification of an arrangement that the Division of Security Policy, Office of Nuclear Security and Incident Response will be notified once the shipment has arrived.[30]

Exports of source material for nuclear end use require an agreement for peaceful nuclear cooperation (otherwise known as a “123” agreement) between the United States and the importing country. Specific export licenses must be filed with the NRC (see 10 CFR 110.32).[31] These licenses must meet the export requirements listed in 10 CFR 110.42(a), including:

- IAEA safeguards as required under Article III(2) of the Nuclear Non-Proliferation Treaty will be applied to any material exported;
- No material or special nuclear material produced from use of such material will be used for a nuclear explosive device or for its research and development;
- Adequate physical security measures will be maintained, with adequacy determined by reference to INFIRC/225/Rev.4, “The Physical Protection of Nuclear Material and Nuclear Facilities” and information obtained in some cases through country visits, information exchanges, or other sources;
- No retransfer of such material without prior approval of the United States;
- No reprocessing of material exported or of special nuclear material produced through use of such material, or alteration in form or content of irradiated fuel elements without prior approval of the United States;
- For nonnuclear weapon states, IAEA safeguards will be maintained with respect to all peaceful activities in under the jurisdiction of such state at the time of export. This criterion can be waived by the president on a nonproliferation or common

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[28] Code of Federal Regulations, NRC Regulations, 10, sec. 110.22(b).

[29] Ibid., 10, sec. 110.22(c).

[30] Ibid., 10, Sec. 40.66(a), 40.66(b).

[31] These export licenses are all publicly viewable on the NRC website at their online ADAMS database. A compilation of source material licenses is given in Appendix 3.

defense and security basis, but section 128 of the Atomic Energy Act regarding congressional review will apply;

- Such export is not inimical to U.S. common defense and security.

The amount of time that an NRC export license is valid can vary significantly. Sometimes it is a license granted for the duration of a one-time transaction. Or, it can span the entirety of a contract length that a company may have for export, delivery, or services. Licenses, however, cannot exceed the duration of the 123 agreement between the nations in question. Transshipments through the United States do not require an NRC import and export license, but they do have to comply with the DOT/IAEA packaging, and state transportation requirements.[32] Transient shipments of natural uranium other than the form of ore or ore residue that have scheduled stops at a U.S. port require notification to the NRC's director, Division of Security Policy, Office of Nuclear Security and Incident Response.[33]

A glance at the licenses for source material exports from the United States reveals the network of established players in U.S. uranium production. According to industry experts, close relationships tend to form a barrier to theft or diversion from the mine to conversion facilities. With only five conventional mines, five ISL facilities, one mill, and one conversion facility operating in the United States, the industry is fairly small and the players are well known.

Licenses for the export of source material are listed on the NRC website on its public Agencywide Documents Access and Management System (ADAMS) database.[34] A comprehensive collection of licenses, beginning with 2000, appears in Appendix 3. These licenses are classified as "XSOU," which stands for the export of source material, followed by a license number identification. The quantities listed on the export licenses, however, are not the actual amount of material exported, but the maximum quantity allowed for export under the license. Actual export quantities are business confidential, and therefore not publicly accessible.

Since 2000, the quantities licensed for export have broken down as follows:

- 112,409,582 kilograms $UF_6$ or $U_3O_8$ for enrichment
- 18,085,476 kilograms $UF_6$, $U_3O_8$, or $UO_2$ for conversion
- 63,965 kilograms $U_3O_8$ or ore for nonnuclear end uses
- 1,780 kilograms $UO_2$ or natural UNH (Uranium Nitrate Hexahydrate) for testing

As shown, virtually all U.S. exports of uranium are sent abroad for enrichment or conversion. Of the small amount sent for nonnuclear end uses, most goes to recipients in

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[32] Code of Federal Regulations, NRC Regulations, 10, sec. 110.1(b)(5).

[33] Ibid., 10, sec. 40.23.

[34] Agencywide Documents Access and Management System (ADAMS) database, Nuclear Regulatory Commission, http://adams.nrc.gov/wba/.

China (with a few to recipients in Estonia, Brazil, Thailand, and Japan). These ultimate consignees are companies that deal with rare metals such as tantalum, niobium, and tungsten somewhere along the supply chain; because these ores are especially high in uranium content, they require a license.

Each new NRC license issued for the export of $UF_6$ for enrichment was for shipments to Urenco facilities in the United Kingdom, the Netherlands, or Germany, or the Eurodif facility in France, while all material for conversion was shipped to Cameco in Canada or the French Comurhex facility (see Appendix 3). Over the same time period, the largest export license strictly for ore, XSOU8808, authorized 2 million kilograms of tantalum containing just 12,000 kilograms of natural uranium to be distributed amongst 13 companies in Estonia, Brazil, China, Japan, and Kazakhstan for nonnuclear end uses, whereas the XSOU8787 license alone allowed 52 million kilograms of natural uranium in the form of $UF_6$ to be shipped to Urenco facilities in the United Kingdom, Germany, and the Netherlands for enrichment.

With regard to imports, the NRC issues general import licenses for recipients licensed to receive and possess source material. Possession can be licensed by the NRC or an agreement state, although the export and import license can only be granted through the NRC. There are no advance notification requirements for import of natural uranium. However, there are advanced notification requirements if the natural uranium is in amounts exceeding 500 kilograms and is coming from countries that are not party to the Convention on the Physical Protection of Nuclear Material (CPPNM).[35] As noted above, the NRC requires NMMSS reports on imports of source material.[36]

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[35] Ibid., 10, sec. 40.67.

[36] Ibid., 10, sec. 60.64.

# 6 Security Implications of Safety and Environmental Regulations

The majority of uranium regulatory requirements in the United States are associated with safety and environmental objectives, rather than with security. However, such requirements can have benefits, or "spillover effects," for uranium security.

One example of such a security spillover is radiation controls on facilities. Uranium recovery facilities, such as conventional uranium mills and in-situ leach (ISL) sites, are far below the threshold of radioactivity to mandate "Control of Access to High Radiation Areas" under 10 Code of Federal Regulations (CFR) Part 20.[1] However, the general principle of As Low As is Reasonably Achievable (ALARA) still stands. The ALARA principle encourages licensees to make "every reasonable effort to maintain exposures to radiation as far below the dose limits . . . as is practical consistent with the purpose for which the licensed activity is undertaken."[2] The Nuclear Regulatory Commission (NRC) radiation limit for nonradiation workers is 100 millirem per year, and for radiation workers it is 5,000 millirem per year. ALARA, however, is not a strict dose limit but a process of instituted radiation exposure controls.

As stipulated by the "Use of Other Controls" in 10 CFR Part 20, when it is not practical to instill process or engineering controls to limit the amount of radiation, other controls such as access controls, limitation of exposure times, and the use of respiratory equipment can help achieve the intended effect of ALARA. One example of this at the recently licensed (though not-yet operating) Piñon Ridge Mill in Montrose, Colorado gives ample evidence of radiation controls that have security benefits. At Piñon Ridge, the yellowcake packaging area has its own isolated heating, ventilating, and air conditioning (HVAC) system, two sets of doors that distinguish it from the rest of the facility, and access only by required operations personnel, who are required to wear appropriate personal protective equipment (PPE) such as respirators, gloves, and coveralls.[3] Furthermore, only necessary equipment and tools are allowed in the control area. They are not allowed to leave that area unless

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[1] 10 CFR Part 20 Subpart G 1601, http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-1601.html.

[2] 10 CFR Part 20.1003 "Definitions," ALARA, http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/full-text.html.

[3] Senes Consultants Limited, "Risk Assessment for Proposed Uranium and Vanadium Mill at the Piñon Ridge Property," November 2009, 16, https://www.colorado.gov/cdphedir/hm/Radiation/licenseapplication/rpt%281%29riskassessment.pdf.

they are scanned for any radioactive material contamination. In addition to the packaging area, the interim storage facility is also another controlled area. At Piñon Ridge Mill, entry into the controlled areas must be authorized.[4] There are also required scans for employees and vehicles entering and leaving a uranium processing facility.

Elsewhere, environmental concerns also have benefited security controls. For example, at the White Mesa Mill in Colorado, ore trucks no longer dump outside the mill site, but inside a secured area. Additionally, they are washed out to avoid spreading contaminated ore in the surrounding environment. Furthermore, the remoteness of such facilities (they are usually built isolated from densely populated areas) could affect security of the facility. Unwanted intruders could be easily detected, but assistance may not be as timely as desired.

Limiting access to the more sensitive areas of the facility, such as the packaging area and the interim storage site, can help tighten security. Fencing around facilities, with appropriate signs indicating the presence of radioactive materials, can also help deter entrance by unwanted visitors. Conventional mill sites also tend to run nonstop for weeks, so the amount of downtime exposure for would-be actors seeking outright theft of nuclear material at these sites is slim.

ISL sites provide reduced hazards for employees and the environment due to the way in which uranium-bearing slurry is transported. ISL sites typically send their uranium bearing slurry through pipes directly to the processing facility or to a satellite remote ion exchange plant, where the uranium is attached to resins and subsequently transported via tanker to the central processing facility. As such, they may not have the same sorts of safety and environmental concerns and associated security concerns as conventional mill sites. While such regulations serve as barriers to outright theft, they are less likely to counter diversion through insider involvement and poorly monitored accounting practices. Placing limits on the amount of time that employees can be around yellowcake is useful from a safety perspective, but provides limited security benefit.

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[4] "UMTRA (Uranium Mill Tailings Remedial Action) Program Issues As Low As Reasonably Achievable (ALARA)," Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division, no date cited, http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheadername1=Content-Disposition&blobheadername2=Content-Type&blobheadervalue1=inline%3B+filename%3D%22The+ALARA+Principle.pdf%22&blobheadervalue2=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251811737447&ssbinary=true.

# 7 Conclusions

As a nuclear weapon state, with significant production facilities and no international requirements for uranium accounting and control, U.S. practices in controlling uranium production, storage, transport, and use may not be the model for emulation by other states. To be fair, there are clearly more significant targets for material theft or diversion in the United States than existing mining and milling facilities, such as the nuclear weapons stockpile, material in weapons awaiting dismantlement and in fissile material stockpiles, and in active and mothballed production facilities. Although more attractive, these targets are more heavily guarded and subject to much more stringent accounting and control procedures than are commercial uranium mines and uranium recovery facilities. Nonetheless, the evolution of control in the United States may indicate some useful leverage points for other countries currently or potentially engaged in uranium mining.

Seventy years ago the U.S. government identified uranium as a critical material for the U.S. nuclear weapons program, and proceeded to take extraordinary measures to ensure supply, both from foreign and domestic sources. The 1946 Atomic Energy Act (AEA) established government control of the production, ownership, and use of fissionable material to assure the common defense and security. Although uranium ore was regarded as source material (and therefore not strictly subject to government control, except as mined from public lands), the 1946 AEA left open the possibility that it too could be controlled by the Atomic Energy Commission (AEC) through regulations if deemed necessary.

Uranium mining, which peaked in the United States more than 30 years ago, nonetheless remained largely outside the sphere of strict federal government regulation. In order to spur domestic exploration, the AEC encouraged, rather than restricted, mining on public or private lands, and even provided a guaranteed price. At their most restrictive, U.S. uranium controls never extended into mining, but were limited to milling and enrichment ownership by the U.S. government. The desire to promote civilian nuclear power in the mid-1950s, coupled with overproduction of uranium for U.S. nuclear weapons, led to the relaxation of government restrictions on domestic uranium processing and the imposition of a ban on foreign imports, which was eventually lifted. Fluctuating demand and the private nature of uranium mining left producers susceptible to boom and bust cycles. In 1979, with restrictions on foreign uranium imports still in place, the United States led the world in annual yellowcake output by a substantial margin, but it now ranks eighth. It currently has five operating conventional mines, five in-situ leach (ISL) operations, one conventional milling operation, and one conversion plant.

The impetus for tighter controls came from the 1978 Uranium Mill Tailings Radiation Control Act (UMTRCA), with its focus largely on safety and the environment. While federal and state regulations governing uranium mining and milling have spillover effects on security, the benefits are limited. Best practices at mines and mills (that is, business practices that are not mandated by government regulations) for safety and environmental reasons have some spillover security benefits. Both forms of control—government and private—can make theft more difficult and perhaps less likely. However, controls are not specifically formulated to counter diversion through insider threats, weak internal controls, and/or poor accounting practices.

All operating conventional mills and ISL facilities, including satellites, are inspected annually by either the NRC or the Agreement State (if the state is a member of the Agreement State program). If problems are detected, inspection frequency can increase. The United States, consistent with its Additional Protocol, however, provides information to the International Atomic Energy Agency (IAEA) on the location, operational status, and estimated annual production capacity of uranium mines and concentration plants.

In thinking through how uranium accounting might be improved generally, some measures might be possible in the following areas:

1. *At mines:* Given that the IAEA's Additional Protocol requires only general data on mining, transparency could be improved with more actual data about ore production (whether monthly, quarterly, or yearly reporting) rather than just estimated production capacity. Additional transparency measures might include provision of rough flowcharts for ore movement through production from mine to mill or ISL processing plant, if feasible, to converter.

2. *At uranium recovery facilities:* Similar reporting procedures at uranium recovery facilities as suggested above for mines could also improve transparency. Data could be kept on-site or submitted electronically to a federal database.

3. *Transportation:* Some of the measures put in place commercially for material that requires more security could also be applied to material prior to its conversion. For example, technologies such as "geofencing" software could provide alerts if diversions from established routes are made. New technology for tracking trailers as well as cabs could be applied. Finally, barcoding technology could be applied to drums of yellowcake or cylinders of uranium hexafluoride ($UF_6$). These make more commercial sense for material that has additional value added from processing, but the costs may not be so onerous to apply if requirements for continuous monitoring are adopted.

4. *Converter:* At conversion sites, more transparency on who has registered for accounts at the conversion plant and how uranium is trading hands could be helpful in establishing chains of custody.

5. *Federal level:* In the United States specifically, a better description and enforcement of consequences should be developed if Nuclear Materials Management & Safety

> System (NMMSS) or NRC inspections reveal discrepancies between stated amounts of material. The Department of Transportation (DOT) should have a greater role in and more resources for physical protection, particularly beyond its current limited focus on $UF_6$, to help improve implementation of accountancy and security measures.

Countries that face governance challenges in general may find it quite challenging to put in place a system of stringent controls on uranium mining, milling, and conversion where there are few international requirements for such controls. However, they may find that establishing baseline measures for safety and environmental reasons can contribute to approaches that help improve uranium governance in general.

# Appendix 1. CSIS Uranium Workshop

**Uranium Governance: Workshop on Best Practices**
June 5, 2013
Center for Strategic and International Studies (CSIS)

## Agenda

| | |
|---|---|
| 9:00–9:30 a.m. | **Introductory Remarks** |
| | Dr. Cindy Vestergaard, Visiting Fellow, Proliferation Prevention Program, CSIS |
| | Ms. Sharon Squassoni, Senior Fellow and Director, Proliferation Prevention Program, CSIS |
| 9:30–10:15 a.m. | **Historical Overview of the U.S. Front End** |
| | Ms. Sharon Squassoni, Senior Fellow and Director, Proliferation Prevention Program, CSIS |
| 10:15–10:30 a.m. | **Break** |
| 10:30–11:30 a.m. | **How the U.S. Government Tracks Uranium** |
| | Ms. Charlotte Abrams, Chief of International Cooperation and Assistance Branch, Nuclear Regulatory Commission (NRC) |
| | Mr. Chris Behan, Project Manager, National Nuclear Security Administration (NNSA)/Department of Energy (DOE) |
| 11:30–12:30 p.m. | **Industry Perspectives on Uranium Governance** |
| | Mr. Jack Edlow, President, Edlow International Company |
| | Mr. George Glasier, Consultant, Founder and former chief executive office (CEO)/president of Energy Fuels |
| 12:30–1:30 p.m. | **Lunch** |
| 1:30–2:30 p.m. | **Identification and Discussion of Issues** |
| 2:30–2:45 p.m. | **Break** |
| 2:45–3:45 p.m. | **Breakout Groups** |

| | |
|---|---|
| 3:45–5:00 p.m. | **Reports and Discussion** |
| 5:00–5:15 p.m. | **Wrap-up** |

# Participants

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**Dr. Cindy Vestergaard**, Visiting Fellow, Proliferation Prevention Program, CSIS

# Appendix 2. U.S. Uranium Industry Data

**Table A2.1. Current U.S. Uranium Recovery Facilities: Mills**

| *Owner* | *Mill and Heap Leach Facility Name* | *County, State (existing and planned locations)* | *Capacity (short tons of ore per day)* | *Operating Status* |
|---|---|---|---:|---|
| EFR White Mesa LLC | White Mesa Mill | San Juan, Utah | 2,000 | Operating |
| Energy Fuels Resources Corp | Piñon Ridge Mill | Montrose, Colorado** | 500 | Partially Permitted And Licensed |
| Energy Fuels Wyoming Inc | Sheep Mountain* | Fremont, Wyoming** | 725 | Undeveloped |
| Kennecott Uranium Company/Wyoming Coal Resource Company | Sweetwater Uranium Project | Sweetwater, Wyoming | 3,000 | Standby |
| Strathmore Resources (US) Ltd. | Gas Hills* | Fremont, Wyoming** | 2,200 | Developing |
| Strathmore Resources (US) Ltd. and Sumitomo Corp | Pena Ranch | McKinley, New Mexico** | 2,000 | Developing |
| Uranium One Americas, Inc. | Shootaring Canyon Uranium Mill | Garfield, Utah | 750 | Standby |
| **Total Capacity:** | | | **11,175** | |

*Heap leach facilities

**Planned locations

Source: U.S. Energy Information Administration, Domestic Quarterly Uranium Report, August 7, 2013, http:// www .eia .gov/uranium /production /quarterly /.

**Table A2.2. Current U.S. Uranium Recovery Facilities: In- Situ Leach**

| *In-Situ-Leach Plant Owner* | *In-Situ-Leach Plant Name* | *County, State (existing and planned locations)* | *Production Capacity (thousand kg $U_3O_8$ per year)* | *Operating Status*** |
|---|---|---|---|---|
| Cameco | Crow Butte Operation | Dawes, Nebraska | 454 | Operating |
| Hydro Resources, Inc. | Church Rock | McKinley, New Mexico* | 454 | Partially Permitted And Licensed |
| Hydro Resources, Inc. | Crownpoint | McKinley, New Mexico* | 454 | Partially Permitted And Licensed |
| Lost Creek ISR, LLC | Lost Creek Project | Sweetwater, Wyoming | 907 | Under Construction |
| Mestena Uranium LLC | Alta Mesa Project | Brooks, Texas | 680 | Producing |
| Power Resources, Inc. dba Cameco Resources | Smith Ranch-Highland Operation | Converse, Wyoming | 2,495 | Operating |
| Powertech Uranium Corp | Dewey Burdock Project | Fall River and Custer, South Dakota* | 454 | Developing |
| South Texas Mining Venture | Hobson ISR Plant | Karnes, Texas | 454 | Operating |
| South Texas Mining Venture | La Palangana | Duval, Texas | 454 | Operating |
| Strata Energy Inc | Ross | Crook, Wyoming* | 1,361 | Partially Permitted And Licensed |
| URI, Inc. | Kingsville Dome | Kleberg, Texas | 454 | Restoration |
| URI, Inc. | Rosita | Duval, Texas | 454 | Restoration |
| URI, Inc. | Vasquez | Duval, Texas | 363 | Restoration |
| Uranerz Energy Corporation | Nichols Ranch ISR Project | Johnson and Campbell, Wyoming | 907 | Under Construction |
| Uranium Energy Corp. | Goliad ISR Uranium Project | Goliad, Texas* | 454 | Permitted And Licensed |
| Uranium One Americas, Inc. | Jab and Antelope | Sweetwater, Wyoming* | 907 | Developing |
| Uranium One Americas, Inc. | Moore Ranch | Campbell, Wyoming* | 227 | Permitted And Licensed |
| Uranium One USA, Inc. | Willow Creek Project (Christensen Ranch and Irigaray) | Campbell and Johnson, Wyoming | 590 | Producing |
| **Total Production Capacity** | | | **12,519** | |

Note: ISR, in- situ recovery. Synonymous with in- situ leaching.
*Planned locations
**A status of “Operating” indicates the in- situ leach plant was producing uranium concentrate at the end of the period.
Source: U.S. Energy Information Administration, Domestic Quarterly Uranium Report, August 7, 2013, http:// www .eia .gov /uranium /production /quarterly /.

## Table A2.3. Domestic Uranium Concentrate Production, 1949–2012 (thousand kilograms $U_3O_8$)

| *Calendar Year* | *Domestic Production* | *Calendar Year* | *Domestic Production* |
|---|---|---|---|
| 1949 | 163 | 1981 | 17,452 |
| 1950 | 417 | 1982 | 12,187 |
| 1951 | 699 | 1983 | 9,597 |
| 1952 | 789 | 1984 | 6,750 |
| 1953 | 1,052 | 1985 | 5,132 |
| 1954 | 1,542 | 1986 | 6,126 |
| 1955 | 2,522 | 1987 | 5,893 |
| 1956 | 5,407 | 1988 | 5,956 |
| 1957 | 7,693 | 1989 | 6,276 |
| 1958 | 11,285 | 1990 | 4,030 |
| 1959 | 14,733 | 1991 | 3,607 |
| 1960 | 16,003 | 1992 | 2,561 |
| 1961 | 15,740 | 1993 | 1,389 |
| 1962 | 15,431 | 1994 | 1,520 |
| 1963 | 12,900 | 1995 | 2,741 |
| 1964 | 10,750 | 1996 | 2,867 |
| 1965 | 9,471 | 1997 | 2,559 |
| 1966 | 9,606 | 1998 | 2,134 |
| 1967 | 10,209 | 1999 | 2,091 |
| 1968 | 11,220 | 2000 | 1,803 |
| 1969 | 10,532 | 2001 | 1,197 |
| 1970 | 11,707 | 2002 | 1063* |
| 1971 | 11,587 | 2003 | 907* |
| 1972 | 11,703 | 2004 | 1,035 |
| 1973 | 12,007 | 2005 | 1,220 |
| 1974 | 10,458 | 2006 | 1,862 |
| 1975 | 10,523 | 2007 | 2,056 |
| 1976 | 11,564 | 2008 | 1,770 |
| 1977 | 13,552 | 2009 | 1,682 |
| 1978 | 16,770 | 2010 | 1,918 |
| 1979 | 16,997 | 2011 | 1,810 |
| 1980 | 19,824 | 2012 | 1,880 |

*Estimate.

Source: "Annual Energy Overview," U.S. Energy Information Administration, September 2012, http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0903.

## Table A2.4. Uranium Concentrate Imports/Exports, 1949–2012 (thousand kilograms $U_3O_8$)

| *Calendar Year* | *Purchased Imports* | *Export Sales* |
|---|---:|---:|
| 1949 | 1,950 | 0 |
| 1950 | 2,494 | 0 |
| 1951 | 2,766 | 0 |
| 1952 | 2,585 | 0 |
| 1953 | 1,723 | 0 |
| 1954 | 2,948 | 0 |
| 1955 | 3,447 | 0 |
| 1956 | 5,669 | 0 |
| 1957 | 7,756 | 0 |
| 1958 | 14,651 | 0 |
| 1959 | 16,465 | 0 |
| 1960 | 16,329 | 0 |
| 1961 | 13,154 | 0 |
| 1962 | 10,976 | 0 |
| 1963 | 10,160 | 0 |
| 1964 | 5,488 | 0 |
| 1965 | 3,628 | 0 |
| 1966 | 2,086 | 363 |
| 1967 | 0 | 635 |
| 1968 | 0 | 726 |
| 1969 | 0 | 454 |
| 1970 | 0 | 1,905 |
| 1971 | 0 | 181 |
| 1972 | 0 | 91 |
| 1973 | 0 | 544 |
| 1974 | 0 | 1,361 |
| 1975 | 635 | 454 |
| 1976 | 1,632 | 544 |
| 1977 | 2,540 | 1,814 |
| 1978 | 2,358 | 3,084 |
| 1979 | 1,360 | 2,812 |
| 1980 | 1,632 | 2,631 |
| 1981 | 2,993 | 1,996 |
| 1982 | 7,756 | 2,812 |
| 1983 | 3,719 | 1,497 |
| 1984 | 5,669 | 998 |
| 1985 | 5,307 | 2,404 |
| 1986 | 6,123 | 726 |
| 1987 | 6,849 | 454 |
| 1988 | 7,166 | 1,497 |
| 1989 | 5,942 | 953 |
| 1990 | 10,750 | 907 |
| 1991 | 7,393 | 1,588 |
| 1992 | 10,568 | 1,270 |
| 1993 | 9,525 | 1,361 |
| 1994 | 16,609 | 8,029 |
| 1995 | 18,733 | 4,445 |
| 1996 | 20,603 | 5,216 |
| 1997 | 19,490 | 7,711 |
| 1998 | 19,825 | 6,849 |
| 1999 | 21,579 | 3,856 |
| 2000 | 20,371 | 6,169 |
| 2001 | 21,173 | 5,307 |
| 2002 | 23,903 | 6,985 |
| 2003 | 24,060 | 5,987 |
| 2004 | 29,982 | 5,987 |
| 2005 | 29,704 | 9,299 |
| 2006 | 29,394 | 8,482 |
| 2007 | 24,534 | 6,713 |
| 2008 | 25,888 | 7,802 |
| 2009 | 26,716 | 10,659 |
| 2010 | 25,104 | 10,478 |
| 2011 | 24,669 | 7,575 |
| 2012 | 25,506 | |

Source: U.S. Energy Information Administration, *Annual Energy Review*, September 2012, http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0903.

## Table A2.5. Domestic Mine Production of Uranium, 1968–2012 (thousand kilograms $U_3O_8$)

| *Calendar Year* | *Total Production* | *Calendar Year* | *Total Production* |
|---|---:|---|---:|
| 1968 | 11,657 | 1991 | 2,351 |
| 1969 | 11,431 | 1992 | 447 |
| 1970 | 11,839 | 1993 | 930 |
| 1971 | 11,884 | 1994 | 1,146 |
| 1972 | 12,565 | 1995 | 1,600 |
| 1973 | 12,519 | 1996 | 2,134 |
| 1974 | 11,431 | 1997 | 2,136 |
| 1975 | 11,158 | 1998 | 2,169 |
| 1976 | 12,701 | 1999 | 2,063 |
| 1977 | 15,150 | 2000 | 1,417 |
| 1978 | 18,325 | 2001 | 1,201 |
| 1979 | 18,779 | 2002 | 1,091 |
| 1980 | 20,140 | 2003 | 998 |
| 1981 | 16,601 | 2004 | 1,112 |
| 1982 | 10,705 | 2005 | 1,381 |
| 1983 | 10,659 | 2006 | 2,128 |
| 1984 | 4,536 | 2007 | 2,060 |
| 1985 | 3,901 | 2008 | 1,759 |
| 1986 | 3,765 | 2009 | 1,880 |
| 1987 | 2,722 | 2010 | 1,922 |
| 1988 | 4,309 | 2011 | 1,866 |
| 1989 | 4,400 | 2012 | 1,966 |
| 1990 | 2,665 | | |

*Represents actual $U_3O_8$ from in-situ leaching and by-product recovery plants and estimated contained $U_3O_8$ from underground and open pit mines.

Sources: "Domestic Uranium Production Report—Annual," U.S. Energy Information Administration, June 6, 2013, http://www.eia.gov/uranium/production/annual/; "Uranium Industry Annual 1992," U.S. Energy Information Administration, October 1993, http://www.eia.gov/uranium/marketing/archive/047892.pdf.

**Table A2.6. Number of Operating Mines, 1982–2012**

| *Calendar Year* | *Underground* | *Open Pit* | *In-situ Leaching* | *Other Sources** | *Total Operating Mines* |
|---|---|---|---|---|---|
| 1982 | 139 | 24 | 18 | 10 | 191 |
| 1983 | 94 | 16 | 10 | 7 | 127 |
| 1984 | 19 | 8 | 14 | 1 | 42 |
| 1985 | 13 | 6 | 10 | 5 | 34 |
| 1986 | 13 | 4 | 12 | 2 | 31 |
| 1987 | 19 | 2 | 15 | 1 | 37 |
| 1988 | 17 | 4 | 11 | 0 | 32 |
| 1989 | 19 | 2 | 9 | 2 | 32 |
| 1990 | 27 | 2 | 7 | 3 | 39 |
| 1991 | 6 | 2 | 6 | 1 | 15 |
| 1992 | 4 | 1 | 4 | 8 | 17 |
| 1993 | 0 | 0 | 5 | 7 | 12 |
| 1994 | 0 | 0 | 5 | 7 | 12 |
| 1995 | 0 | 0 | 5 | 7 | 12 |
| 1996 | 1 | 0 | 6 | 6 | 13 |
| 1997 | 1 | 0 | 7 | 6 | 14 |
| 1998 | 4 | 0 | 6 | 5 | 15 |
| 1999 | 3 | 0 | 6 | 5 | 14 |
| 2000 | 1 | 0 | 4 | 5 | 10 |
| 2001 | 0 | 0 | 3 | 4 | 7 |
| 2002 | 0 | 0 | 3 | 3 | 6 |
| 2003 | 1 | 0 | 2 | 1 | 4 |
| 2004 | 2 | 0 | 3 | 1 | 6 |
| 2005 | 4 | 0 | 4 | 2 | 10 |
| 2006 | 5 | 0 | 5 | 1 | 11 |
| 2007 | 6 | 0 | 5 | 1 | 12 |
| 2008 | 10 | 0 | 6 | 1 | 17 |
| 2009 | 14 | 0 | 4 | 2 | 20 |
| 2010 | 4 | 0 | 4 | 1 | 9 |
| 2011 | 5 | 0 | 5 | 1 | 11 |
| 2012 | 6 | 0 | 5 | 1 | 12 |

*Includes mine water, mill site cleanup and mill tailings, and well field restoration.

Sources: U.S. Energy Information Administration, *Domestic Uranium Production Report* (2003-2011), Form EIA-851A; U.S. Office of Coal, Nuclear, Electric, and Alternative Fuels, *Uranium Industry Annual 2002*; U.S. Office of Coal, Nuclear, Electric, and Alternative Fuels, *Uranium Industry Annual 1992*.

## Table A2.7. Number of Operating Mills, 1987–2012

| *Calendar Year* | *Conventional Mills (milling uranium-bearing ore)* | *Other Operators (producing U concentrate from non-ore materials)* | *Total* |
|---|---|---|---|
| 1987 | 6 | 0 | 6 |
| 1988 | 3 | 0 | 3 |
| 1989 | 3 | 0 | 3 |
| 1990 | 2 | 0 | 2 |
| 1991 | 2 | 0 | 2 |
| 1992 | 0 | 0 | 0 |
| 1993 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 |
| 1995 | 1 | 0 | 1 |
| 1996 | 0 | 2 | 2 |
| 1997 | 0 | 3 | 3 |
| 1998 | 0 | 2 | 2 |
| 1999 | 1 | 2 | 3 |
| 2000 | 1 | 2 | 3 |
| 2001 | 0 | 1 | 1 |
| 2002 | 0 | 1 | 1 |
| 2003 | 0 | 0 | 0 |
| 2004 | 0 | 0 | 0 |
| 2005 | 0 | 1 | 1 |
| 2006 | 0 | 1 | 1 |
| 2007 | 0 | 1 | 1 |
| 2008 | 1 | 0 | 1 |
| 2009 | 0 | 1 | 1 |
| 2010 | 1 | 0 | 1 |
| 2011 | 1 | 0 | 1 |
| 2012 | 1 | 0 | 1 |

Note: U, uranium.

Sources: U.S. Energy Information Administration, *Domestic Uranium Production Report* (2003-2011), Form EIA-851A; U.S. Office of Coal, Nuclear, Electric, and Alternative Fuels, *Uranium Industry Annual 2002*; U.S. Office of Coal, Nuclear, Electric, and Alternative Fuels, *Uranium Industry Annual 1992*.

## Table A2.8. Uranium Purchases by U.S. Nuclear Power Operators by Country, 1993–2012 (thousand kilograms $U_3O_8$)

| *Calendar Year* | *Australia* | *Canada* | *China* | *Kazakhstan* | *Namibia* | *Niger* | *Russia* | *South Africa* | *Uzbekistan* | **Foreign Total** | *United States* | **Total Purchases** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 816 | 6,350 | 1,315 | 726 | 181 | 0 | 1,678 | W | W | - | 1,769 | **14,152** |
| 1994 | 1,276 | 6,628 | 769 | 1,260 | 361 | 0 | 807 | 502 | 1,610 | **13,863** | 3,501 | **17,364** |
| 1995 | 2,018 | 7,620 | 133 | 1,405 | 240 | W* | 2,495 | 454 | 1,767 | **17,325** | 2,380 | **19,705** |
| 1996 | 2,067 | 8,660 | 168 | 678 | W | W | 2,465 | 758 | 1,570 | **17,706** | 3,764 | **21,470** |
| 1997 | 1,974 | 7,581 | 105 | 877 | 351 | 0 | 1,630 | 1,167 | 1,250 | **15,372** | 3,661 | **19,033** |
| 1998 | 2,616 | 6,516 | W | 539 | 354 | 388 | 2,703 | 1,154 | 1,134 | **16,131** | 3,257 | **19,388** |
| 1999 | 3,320 | 5,665 | 315 | W | 481 | W | 2,864 | 1,233 | 1,031 | **16,556** | 5,211 | **21,749** |
| 2000 | 5,771 | 4,742 | 282 | W | 342 | 328 | 3,033 | 1,065 | 872 | **17,487** | 6,014 | **23,501** |
| 2001 | 4,678 | 7,766 | W | 1,428 | 258 | W | 2,287 | 917 | 1,199 | **19,159** | 5,982 | **25,141** |
| 2002 | 4,925 | 7,780 | W | 2,454 | 491 | W | 2,873 | 347 | 1,608 | **21,093** | 2,815 | **23,908** |
| 2003 | 4,230 | 7,734 | W | 1,920 | 469 | 0 | 3,488 | 652 | 1,690 | **21,025** | 4,627 | **25,652** |
| 2004 | 5,289 | 7,470 | W | 1,910 | 1,261 | W | 4,685 | 948 | 1,045 | **23,478** | 5,598 | **29,076** |
| 2005 | 4,516 | 10,379 | W | 743 | 1,344 | 0 | 5,878 | 260 | 1,136 | **24,831** | 4,993 | **29,823** |
| 2006 | 7,735 | 6,044 | W | 738 | 1,365 | W | 6,857 | 329 | 916 | **25,280** | 4,902 | **30,182** |
| 2007 | 5,219 | 4,861 | 0 | 1,092 | 1,413 | W | 7,605 | W | 573 | **21,324** | 1,802 | **23,125** |
| 2008 | 5,787 | 4,441 | 0 | 1,732 | 1,760 | W | 5,479 | 355 | 872 | **20,699** | 3,502 | **24,201** |
| 2009 | 5,064 | 4,071 | 0 | 2,261 | 2,600 | 908 | 3,601 | W | 646 | **19,403** | 3,199 | **22,603** |
| 2010 | 3,226 | 4,644 | 0 | 3,098 | 2,228 | 266 | 4,783 | W | 846 | **19,457** | 1,672 | **21,129** |
| 2011 | 2,722 | 4,913 | W | 4,413 | 2,812 | 791 | 4,626 | 691 | 820 | **22,510** | 2,361 | **24,871** |
| 2012 | 3,050 | 6,162 | W | 2,828 | 2,715 | 968 | 3,467 | 564 | 1,168 | **21,642** | 4,448 | **26,091** |

*W = Data withheld to avoid disclosure of individual company data.

Note: Data from certain countries including Brazil, Bulgaria, Czech Republic, France, Gabon, Germany, Hungary, Kyrgyzstan, Malawi, Mongolia, Netherlands, Portugal, Slovakia, Spain, Tajikistan, and the United Kingdom is incomplete, so this is not a comprehensive listing. Because of both this and withheld data, the purchases by country will not add up to the foreign totals.

Sources: U.S. Office of Coal, Nuclear, Electric, and Alternative Fuels, Uranium Industry Annuals 1992–2012; U.S. Energy Information Administration, *Domestic Uranium Production Report*, Annuals 2003–2012.

## Table A2.9. Average Price of Uranium, 1981–2012 (U.S. dollars per kilogram $U_3O_8$)

| *Calendar Year* | *Purchased Imports* | *Domestic Purchases* | *Difference (Domestic—Imports)* |
|---|---|---|---|
| 1981 | 72.53 | 76.39 | 3.86 |
| 1982 | 60.03 | 84.59 | 24.56 |
| 1983 | 57.67 | 84.24 | 26.57 |
| 1984 | 48.19 | 71.98 | 23.79 |
| 1985 | 44.27 | 69.29 | 25.02 |
| 1986 | 44.25 | 66.16 | 21.91 |
| 1987 | 42.20 | 60.34 | 18.14 |
| 1988 | 41.95 | 57.65 | 15.70 |
| 1989 | 36.93 | 43.12 | 6.19 |
| 1990 | 27.67 | 34.61 | 6.94 |
| 1991 | 34.28 | 30.11 | –4.17 |
| 1992 | 25.00 | 29.65 | 4.65 |
| 1993 | 23.21 | 28.97 | 5.75 |
| 1994 | 19.73 | 22.71 | 2.98 |
| 1995 | 22.49 | 24.49 | 2.01 |
| 1996 | 28.99 | 30.45 | 1.46 |
| 1997 | 26.04 | 28.37 | 2.34 |
| 1998 | 24.67 | 27.14 | 2.47 |
| 1999 | 23.26 | 26.19 | 2.93 |
| 2000 | 21.69 | 25.24 | 3.55 |
| 2001 | 20.97 | 23.04 | 2.07 |
| 2002 | 22.16 | 22.82 | 0.66 |
| 2003 | 23.35 | 23.90 | 0.55 |
| 2004 | 27.01 | 26.26 | –0.75 |
| 2005 | 32.69 | 30.82 | –1.87 |
| 2006 | 42.57 | 40.87 | –1.70 |
| 2007 | 75.35 | 73.04 | –2.31 |
| 2008 | 91.05 | 95.75 | 4.70 |
| 2009 | 90.90 | 98.17 | 7.28 |
| 2010 | 103.64 | 98.94 | –4.70 |
| 2011 | 119.05 | 117.75 | –1.30 |
| 2012 | 131.04 | 119.20 | –11.84 |

Source: U.S. Energy Information Administration, *Annual Energy Review*, September 2012, http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0903.

# Appendix 3. NRC Export Licenses, 2000–2012

| License Number | Date | Commodity | Country | Ultimate Consignee(s) | End Use | Quantity (kg) |
|---|---|---|---|---|---|---|
| XSOU8775 | 1/19/2000 | UF6 | UK, Germany, Netherlands | 1. Urenco (Capenhurst) Ltd. (GBR)*<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NLD) | Enrichment at Urenco and return to US | 2,000,000 |
| XSOU8776 | 1/28/2000 | UF6 | Canada | Cameco Corporation (CAN) | Conversion into UF6 | 39,926 |
| XSOU8777 | 2/8/2000 | Ore | China | 1. Zhuzhou Cemented Carbide Works Import/Export Co. (CHN)<br>2. Hengyang Kingxing-Lifeng New Materials Co., Ltd (CHN)<br>3. Conghua & Tantalum & Niobium Smelter (CHN)<br>4. Limu Nonferrous Co., Ltd. (CHN)<br>5. Douloshan Sapphire Rate Metal Co., Ltd. (CHN)<br>6. Jiujiang Nonfemet Factory (806) (CHN) | Recovery of tantalum for nonnuclear end use | 1,610 |
| XSOU8778 | 5/18/2000 | Ore | China | Ningxia Non-Ferrous Metals I/E Corp. (CHN) | Recovery of tantalum for nonnuclear end use | 310 |
| XSOU8779 | 5/22/2000 | Ore | Kazakhstan | Ulba Metallurgical Plant (KAZ) | Recovery of tantalum and columbium for nonnuclear end use | 700 |
| XSOU8780 | 8/10/2000 | UF6 | France, Germany, Netherlands, UK | 1. Eurodif, S.A. (FRA)<br>2. Urenco, Ltd. - Almelo (NLD)<br>3. Urenco, Ltd. - Gronau (DEU)<br>4. Urenco, Ltd. - Capenhurst (GBR) | Enrichment and use in EURATOM reactors or return to US | 11,000,000 |
| XSOU8781 | 9/29/2000 | Ore | China | 1. Ningxia Non-Ferrous Metals Import Export Corp (CHN)<br>2. Zhuzhou Cemented Carbide Works Import/Export Co. (CHN)<br>3. Hengyang Kingxing-Lifeng New Materials Co., Ltd (CHN) | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | 4. Conghua & Tantalum & Niobium Smelter (CHN)<br>5. Limu Nonferrous Co., Ltd. (CHN)<br>6. Douloshan Sapphire Rate Metal Co., Ltd. (CHN)<br>7. Jiujiang Nonfemet Factory (806) (CHN) | Recovery of tantalum and columbium for nonnuclear end use | 800 |
| XSOU8782 | 2/16/2001 | UF6 | UK | Companies not listed | Enrichment at Urenco and return to US | 23,100 |
| XSOU8785 | 4/17/2001 | Ore | China, Thailand | 1. Zhuzhou Cemented Carbide Import/Export Works Co. (CHN)<br>2. Hengyang Kingxing-Lifeng New Materials Co. Ltd. (CHN)<br>3. Conghua Tantalum & Niobium Smelter (CHN)<br>4. Limu Nonferrous Co. Ltd. (CHN)<br>5. Douloshan Sapphire Rare Metal Co. Ltd. (CHN)<br>6. Jiujiang Nontemet Factory (806) (CHN)<br>7. Ningxia Non-Ferrous Metals Smeltery (CHN)<br>8. H.C. Starck (Thailand) Co., Ltd. (THA) | Recovery of tantalum for nonnuclear end use | 1,610 |
| XSOU8787 | 6/18/2001 | UF6 | UK, Germany, Netherlands | 1. Urenco (Capenhurst) Ltd. (GBR)<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NLD) | Enrichment at Urenco and use in US reactors | 52,000,000<br>42,000,000 |
| XSOU8789 | 9/19/2002 | UF6 | France, Germany, Netherlands | PROPRIETARY | Enrichment and use in reactors | |
| XSOU8791 | Unable to verify | UF6 | Belgium | Companies not listed | Enrichment and fuel fabrication at Eurodif for use in Belgian reactors | 1,375,000 |
| XSOU8792 | Unable to verify | Ore | Estonia, Brazil, China, Japan, Kazakhstan | 1. AS Silmet (EST)<br>2. Companhia Industrial Fluminense (BRA)<br>3. Conghua Tantalum & Niobium Smeltery (CHN) | | |

*(continues)*

| License Number | Date | Commodity | Country | Ultimate Consignee(s) | End Use | Quantity (kg) |
|---|---|---|---|---|---|---|
| | | | | 4. Duoloshan Sapphire Rare Metal Co Ltd. of Zhaoqing (CHN)<br>5. F&X Electro-Materials Ltd. (CHN)<br>6. Fogang Jiata Metals Co., Ltd (CHN)<br>7. Gui-Family Tantal-Niobium LTD. (CHN)<br>8. Hengyang Kingxing-Lifeng New Materials Co., Ltd. (CHN)<br>9. Jiujiang Tanbre's Smeltery (CHN)<br>10. Mitsui Mining & Smelting Co., Ltd. (JPN)<br>11. Ningxia Non-Ferrous Metals Import and Export Corp. (CHN)<br>12. Ulba Metallurgical Plant (KAZ)<br>13. Zhuzhou Cemented Carbide Works (CHN) | Recovery of tantalum and niobium for nonnuclear end use | 6,000** |
| XSOU8793 | Unable to verify | Natural UNH | Canada | Companies not listed | Return for further experimental use after processing at BWXT | 600 |
| XSOU8794 | Unable to verify | UF6 | Canada | Companies not listed | Reconversion and use in Canadian nuclear power plants | 1,000,000 |
| XSOU8796 | Unable to verify | Ore | various (EURATOM) | Companies not listed | Recovery of tantalum and niobium for nonnuclear end use | 700 |
| XSOU8797 | 10/29/2003 | UF6 | UK | Companies not listed | Enrichment for use as fuel | 210,000 |
| XSOU8798 | 1/29/2004 | Yellowcake | Canada | Cameco Corporation (CAN) | Conversion to UF6, UO2, or UO3 and return to the US for further processing | 12,000,000 |
| XSOU8799 | 2/3/2004 | Yellowcake | France | Companies not listed | Enrichment for use as fuel | 123,832 |

| | | | | | | |
|---|---|---|---|---|---|---|
| XSOU8800 | Unable to verify | UF6 | EURATOM | Companies not listed | Enrichment at Urenco and use in German nuclear power facilities | 445,000 |
| XSOU8802 | 3/19/2004 | Ore | China, Estonia, Kazakhstan, Thailand | Companies not listed | Recovery of tantalum for nonnuclear end use | 350** |
| XSOU8803 | 3/31/2004 | Ore | Kazakhstan | Companies not listed | Commercial, nonnuclear end use at Ulba | 286 |
| XSOU8804 | Unable to verify | UO2 | Japan | Companies not listed | Manufacturing tests at Nuclear Fuel Industries, Ltd. | 180 |
| XSOU8805 | 12/29/2004 | UO2 | Japan | 1. Nuclear Fuel Industries, LTD. Tokai Works (JPN)<br>2. Nuclear Fuel Industries, LTD. Kumatori Works (JPN) | Power evaluation tests at nuclear facilities | 1,000 |
| XSOU8807 | 3/29/2006 | Ore | China, Germany | 1. PROPRIETARY<br>2. Xiamen Tungsten Co. Ltd. (CHN)<br>3. H.C. Starck GmbH & Co. (DEU) | Tungsten ores and concentrates for nonnuclear end use | 74 |
| XSOU8808 | 6/22/2006 | Ore | Estonia, Brazil, China, Japan, Kazakhstan | 1. AS Silmet (EST)<br>2. Companhia Industrial Fluminense (BRA)<br>3. Conghua Tantalum & Niobium Smeltery (CHN)<br>4. Duoloshan Sapphire Rare Metal Co Ltd. of Zhaoqing (CHN)<br>5. F&X Electro-Materials Ltd. (CHN)<br>6. Fogang Jiata Metals Co., Ltd (CHN)<br>7. Gui-Family Tantal-Niobium LTD. (CHN)<br>8. Hengyang Kingxing-Lifeng New Materials Co., Ltd. (CHN)<br>9. Jiujiang Tanbre's Smeltery (CHN)<br>10. Mitsui Mining & Smelting Co., Ltd. (JPN)<br>11. Ningxia Non-Ferrous Metals Import and Export Corp. (CHN) | | |

*(continues)*

| *License Number* | *Date* | *Commodity* | *Country* | *Ultimate Consignee(s)* | *End Use* | *Quantity (kg)* |
|---|---|---|---|---|---|---|
| | | | | 12. Ulba Metallurgical Plant (KAZ)<br>13. Zhuzhou Cemented Carbide Works (CHN) | Recovery of tantalum and niobium for nonnuclear end use | 12,000 |
| XSOU8810 | 1/5/2007 | UF6 | UK, Germany, Netherlands | 1. Urenco (Capenhurst) Ltd. (GBR)<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NLD) | Enrichment and use in reactors in EURATOM or the US | 350,650 |
| XSOU8811 | 3/13/2008 | UF6 | UK, Germany, Netherlands | 1. Urenco (Capenhurst) Ltd. (GBR)<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NLD) | Enrichment and use in reactors in EURATOM or the US | 490,000 |
| XSOU8812 | 4/18/2008 | UF6 | UK, Germany, Netherlands | 1. Urenco (Capenhurst) Ltd. (GBR)<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NLD) | Enrichment and use in reactors in EURATOM | 262,000 |
| XSOU8813 | 7/25/2008 | UF6 | UK, Germany, Netherlands | 1. Urenco (Capenhurst) Ltd. (GBR)<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NLD) | Enrichment and use in reactors in EURATOM | 1,000,000 |
| XSOU8814 | 10/2/2008 | Yellowcake | Canada | Cameco Corporation (CAN) | Conversion | 3,500,000 |
| XSOU8816 | 1/23/2009 | Ore | Canada | SGS Lakefield Research, Limited (CAN) | Processing of tantalum ores and return to Cabot Supermetals for nonnuclear end use | 25 |
| XSOU8817 | 5/4/2009 | UF6 | UK, Germany, Netherlands, France | 1. Urenco UK Limited (GBR)<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NDL) | | |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  |  |  |  | 4. Eurodif Production (FRA) | Enrichment and use in non-US reactors | 130,000 |
| XSOU8818 | 5/18/2009 | UF6 | UK, Germany, Netherlands, France | 1. Urenco UK Limited (GBR)<br>2. Urenco Deutschland GmbH (DEU)<br>3. Urenco Nederland BV (NDL) |  |  |
|  |  |  |  | 4. Eurodif Production (FRA) | Enrichment and use in non-US reactors | 1,000,000 |
| XSOU8823 | 12/17/2010 | Yellowcake | France | Comurhex (FRA) | Conversion, enrichment, and return to US for fabrication and use in a US reactor | 1,500,000 |
| XSOU8824 | 2/8/2011 | UO2 | Canada | 1. Cameco Corporation Fuel Services (CAN) |  |  |
|  |  |  |  | 2. Port Hope Conversion Facility (CAN) | Conversion and fuel fabrication | 10,000 |
| XSOU8826 | 7/7/2011 | Yellowcake | Canada and UF4 | 1. Cameco Corporation Fuel Services (CAN) |  |  |
|  |  |  |  | 2. Cameco Corporation Fuel Services Port Hope Conversion Facility (CAN) | Reload fuel for US and/or EURATOM reactors | 35,550 |
| XSOU8827 | 11/17/2011 | Ore | Brazil, Japan, Mexico, Vietnam and the EU | Companies not listed | Commercial, nonnuclear end use | 9,500** |
| XSOU8828 | 6/11/2012 | Yellowcake and ThO2 | Estonia, Brazil, China, Japan, Kazakhstan, Canada, Thailand, Germany | 1. AS Silmet (EST)<br>2. Companhia Industrial Fluminense (BRA)<br>3. Conghua Tantalum & Niobium Smeltery (CHN)<br>4. Duoloshan Sapphire Rare Metal Co. Ltd. of Zhaoqing (CHN)<br>5. F & X Electro-Materials Ltd. (CHN)<br>6. Fogang Jiata Metals Co., Ltd. (CHN)<br>7. Gui-Family Tantal-Niobium Ltd. (CHN)<br>8. Hengyang Kingxing-Lifeng New Materials Co., Ltd. (CHN)<br>9. Jiujiang Tanbre's Smeltery (CHN) |  |  |

*(continues)*

| License Number | Date | Commodity | Country | Ultimate Consignee(s) | End Use | Quantity (kg) |
|---|---|---|---|---|---|---|
| | | | | 10. Mitsui Mining & Smelting Co., Ltd. (JPN) | | |
| | | | | 11. Ningxia Non-Ferrous Metals Import and Export Corp. (CHN) | | |
| | | | | 12. Ulba Metallurgical Plant (KAZ) | | |
| | | | | 13. Zhuzhou Cemented Carbide Works (CHN) | | |
| | | | | 14. SGS Lakefield Research Ltd. (CAN) | | |
| | | | | 15. H.C. Starck Co., Ltd. (THA) | | |
| | | | | 16. H.C. Starck Ltd. (JPN) | | |
| | | | | 17. H.C. Starck GmbH 1M Schleeke 78-91 (DEU) | | |
| | | | | 18. H.C. Starck GmbH (DEU) | Recovery of tantalum and niobium for nonnuclear end use | 30,000 |

Note: BWXT, Babcock and Wilcox Technologies; EURATOM, European Atomic Energy Community; kg, kilogram; ThO2, thorium dioxide; UF4, uranium tetrafluoride; UF6, uranium hexafluoride; UK, United Kingdom; UNH, uranium nitrate hexahydrate; UO2, uranium dioxide, UO3, uranium trioxide; US, United States.

*Parenthetical information denotes location of the ultimate consignee. BRA, Brazil; CAN, Canada; CHN, China; DEU, Germany; EST, Estonia; FRA, France; GBR, United Kingdom; JPN, Japan; KAZ, Kazakhstan; NLD, Netherlands; THA, Thailand.

**Quantity includes thorium in addition to natural uranium.

Source: Licenses were compiled via the online Agencywide Documents Access and Management System (ADAMS) database of the Nuclear Regulatory Agency (NRC) from May 31, 2013–June 14, 2013. http://adams.nrc.gov/wba/.

# Appendix 4. Glossary of Terms

**Direct Use Material**: nuclear material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment. Please refer to International Atomic Energy Agency (IAEA) Safeguards Glossary #4.25 (http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf).

**High Enriched Uranium**: Uranium containing 20 percent or more of the isotope uranium-235.

**Indirect Use Material**: all nuclear material except direct use material. It includes: depleted, natural and low enriched uranium, and thorium, all of which must be further processed in order to produce direct use material. Please refer to IAEA Safeguards Glossary #4.26 (http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf).

**Low Enriched Uranium**: Uranium containing less than 20 percent of the isotope uranium-235.

**Natural Uranium**: Uranium containing the relative concentrations of isotopes found in nature (0.7 percent uranium-235, 99.3 percent uranium-238, and a trace amount of uranium-234 by mass).

**$P_2O_5$**: Diphosphorous pentoxide. A phosphate oxide that is a powerful desiccant and dehydrating agent. It is commonly used for fertilizer and other industrial purposes. Uranium can also be recovered as a byproduct of phosphate mining.

**Pu**: Plutonium. A radioactive element which occurs only in trace amounts in nature, with atomic number 94. As produced by irradiating uranium fuels, plutonium contains varying percentages of the isotopes 238, 239, 240, 241 and 242.

**Significant Quantity**: the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. Significant quantities take into account unavoidable losses due to conversion and manufacturing processes and should not be confused with critical masses. Significant quantities are used in establishing the quantity component of the IAEA inspection goal. Please refer to IAEA Safeguards Glossary #3.14 (http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf).

**Source Material**: Uranium in any physical or chemical form, provided that the uranium has not been enriched in the isotope uranium-235, or ores that contain, by weight, one-twentieth of one percent (0.05 percent) or more of uranium. Source material does not include special nuclear material. For the purposes of this paper, “source material” does not include thorium.

**Special Nuclear Material**: Plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235.

**U**: Uranium. A naturally occurring radioactive element with atomic number 92. Natural uranium contains isotopes 234, 235 and 238; uranium isotopes 232, 233 and 236 are produced by transmutation.

**U-235**: Uranium-235. The fissile isotope of uranium found in nature. Approximately 0.7% of natural uranium is of the isotope U-235.

**U-238**: Uranium-238. The most common isotope of uranium found in nature. It is not fissile. Approximately 99.3% of natural uranium is of the isotope U-238.

**$U_3O_8$**: Triuranium octoxide. The primary form of uranium oxide present in yellowcake. It is generally considered to be the most stable form of uranium oxides. Measurements of ore concentrates are often described in terms of $U_3O_8$ or $U_3O_8$ equivalent.

**$UF_4$**: Uranium tetrafluoride. An intermediary compound of uranium and fluorine in the conversion process of uranium oxides to uranium hexafluoride ($UF_6$).

**$UF_6$**: Uranium hexafluoride. A compound of uranium and fluorine that is used in uranium enrichment process. Conversion facilities convert uranium oxides into uranium hexafluoride.

**Uranium Concentrate**: Also called “Yellowcake.” Produced in the uranium recovery process and contains a mixed oxide usually referred to as $U_3O_8$ (UO2 • 2 UO3). Due to a number of impurities contained, it needs further refining before it can be used for nuclear fuel production.

**Uranium Ore**: For the purposes of this paper, “uranium ore” refers to ore containing at least 0.05 percent of uranium, thus qualifying as source material.

**Uranium Oxides**: Forms of uranium oxide include $U_3O_8$, $UO_2$, $UO_3$, $UO_2O_2$ or $UO_4$. Yellowcake tends to be finalized in the form of $U_3O_8$ since it is the most stable form of uranium oxide under normal environmental conditions.

**Uranium Recovery Facility**: For the purposes of this paper, “uranium recovery facility” is defined as a facility producing uranium concentrate; specifically an in-situ leach plant, conventional mill, or byproduct operations (i.e. phosphates), but does not include conventional uranium mines.

**Yellowcake.** The solid form of mixed uranium oxide, which is produced from uranium ore in the uranium recovery process. The material is a mixture of uranium oxides, which can vary in proportion and color depending on the temperature at which the material is dried. Yellowcake is commonly referred to as $U_3O_8$ because that chemical compound comprises approximately 85 percent of the yellowcake produced by uranium recovery facilities. That product is then transported to a uranium conversion facility, where it is transformed into uranium hexafluoride ($UF_6$), in preparation for fabricating fuel for nuclear reactors.

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