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US takes another look at recycling nuclear fuel

David Kramer

As the Biden administration seeks to triple the nation's nuclear energy capacity in response to climate change, it is edging closer to lifting a more than four-decade-long moratorium that the US has observed on the recovery of plutonium from spent nuclear fuel. Ending the prohibition is critical to the plans of some advanced reactor developers, but it would be a major change in US nonproliferation policy, which opposes separating plutonium that could potentially be stolen or diverted to construct a nuclear explosive device. Current policy also recognizes that reprocessing by the US could encourage other nations with nuclear power to follow suit.

Department of Energy officials say the moratorium on commercial reprocessing will remain in place for now. But the Biden administration has shown a receptiveness to reprocessing that contrasts sharply with his Democratic predecessors, dating to Jimmy Carter. "The Biden–Harris administration and DOE recognize the importance of developing practical uses for America's used nuclear fuel," energy secretary Jennifer Granholm stated in October 2022. "Recycling nuclear waste for clean energy generation can significantly reduce the amount of spent fuel at nuclear sites and increase economic stability for the communities leading this important work."

"With many advanced reactor designs that could use spent nuclear fuel coming closer to reality, DOE is assessing reprocessing and recycling technologies with more urgency," stated Kathryn Huff, DOE assistant secretary for nuclear energy. In written responses to questions, Huff said the agency will continue R&D on reprocessing approaches "to assess options as technologies and economics evolve."

A spokesperson for the National Nuclear Security Administration, the semiautonomous agency that monitors DOE's nonproliferation policy, said it supports "limited, responsible" R&D on reprocessing to evaluate options. "We also recognize that US industry and other countries are pushing forward on nuclear fuel recycling concepts whether we like it or not, and not always with the same commitment to nonproliferation that we have." The spokesperson added that "the jury is still out" on whether reprocessing technologies can be developed that will adequately address proliferation concerns.

A 2023 report by the National Academies of Sciences, Engineering, and Medicine recommends that the once-through nuclear fuel cycle be continued "for the foreseeable future." It also calls for "fundamental studies" on reprocessing to be maintained.

The US and 21 other nations pledged to triple their nuclear energy outputs by 2050 during December's United Nations Conference of the Parties climate change conference in Dubai. DOE is placing its bets on advanced nuclear technologies, which it says promise to be cheaper, quicker to build, and safer than today's hulking light-water reactors (LWRs). Many of those advanced technologies would benefit from reprocessing, and several companies include reprocessing as integral to their business plans.

La Hague, France, is the site of one of two operational commercial reprocessing plants in the world. Russia's state-owned Rosatom also offers commercial reprocessing services. The UK's Sellafield reprocessing plant closed in 2022.

Plutonium stockpiles

The International Atomic Energy Agency says that as little as 8 kg of plutonium could produce a crude explosive device; more sophisticated actors, it says, might require just 3.5 kg.

Reprocessing by other nations has produced commercial stockpiles of plutonium totaling 410 metric tons (t) in storage at locations in Russia, France, Japan, and the UK, most of which has no clear disposition path, according to the International Panel on Fissile Materials. The UK alone has accumulated 116 t of civilian plutonium. Russia and France continue commercial reprocessing today. In 1997 Japan began construction of a reprocessing plant that has yet to operate.

To be suitable for LWRs, the separated plutonium must be mixed with depleted uranium to form mixed-oxide (MOX) fuel. MOX fuels are used for roughly 10% of France's nuclear energy production, says Frank von Hippel, an emeritus professor of physics at Princeton University whose research focuses on nonproliferation issues. But Électricité de France, which operates all five of the UK's power reactors and is building another there, declined to buy MOX fuel from Britain's Sellafield reprocessing facility, opting for the once-through fuel cycle instead, he notes. Previous Sellafield customers in Belgium, the Netherlands, and Switzerland all abandoned MOX fuel. Lacking any customers, Sellafield was shut down in 2022.

"Reprocessing as it exists today is certainly not competitive with a once-through cycle," says Ross Matzkin-Bridger, senior director for nuclear materials security at the Nuclear Threat Initiative. "I have not seen any kind of analysis that would indicate that reprocessing becomes cost-competitive or cost-advantageous for advanced reactor technologies."

Huff said reprocessing can conserve uranium, lessen the environmental impacts of mining, and lower US dependence on uranium imports. Reprocessing all the nation's spent fuel could reduce the need for mined uranium by a factor of 100 or greater, she said.

Opponents of reprocessing say that uranium will remain plentiful for the foreseeable future. "Reprocessing started because of a belief that uranium was relatively scarce and expensive and that as nuclear power grew, uranium would become more expensive and it would pay to breed new fissile fuel," says Steve Fetter, dean of

the graduate school at the University of Maryland, who is active in nonproliferation issues. “That hasn’t been the case.” Even at today’s relatively high uranium price, he says, “we are far below the level that would make reprocessing economically attractive.”

Fast reactors

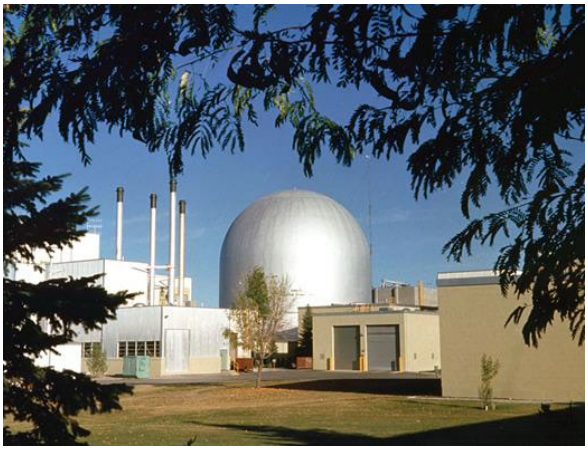
Driving DOE’s support for reprocessing R&D is the hope that many of the advanced reactor types, so-called fast reactors, will catch on commercially. Of the 60 or so advanced reactor designs under development globally, 25 are fast reactors, according to the International Atomic Energy Agency. The Bill Gates–backed Natrium reactor, which is to receive a $2 billion subsidy from DOE, is a liquid-sodium-cooled fast reactor. (See Physics Today, November 2021, page 25. https://doi.org/10.1063/PT.3.4878)

Unlike LWRs, which slow neutrons to make them more likely to be captured by the fissile 235U isotope, fast reactors produce high-energy neutrons. Fast reactors breed plutonium from 238U, which accounts for about 95% of the content of spent LWR fuel. Some fast reactors can produce more plutonium than they fission. They also can transmute the other actinides in spent fuel, such as neptunium and americium, into short-lived fission products.

Fast reactors require fuel that’s more enriched in 235U than the 3–5% typical for LWRs. That so-called high-assay low-enriched uranium (HALEU) is enriched up to 19.75% in 235U. (See “DOE plans bomb-grade uranium fuel for Idaho reactor,” Physics Today online, 17 May 2023. https://doi.org/10.1063/PT.6.2.20230517a)

DOE plans to provide fast-reactor developers with initial loadings of HALEU fuel. It will accomplish that by diluting some of the department’s surplus highly enriched uranium, which is mostly 93% 235U. On 9 January the agency issued a solicitation for industry to supply HALEU, but it will take many years to gear up commercial enrichment providers. Apart from small amounts produced by Centrus in Ohio, Russia has the only commercial provider of HALEU. Since fast reactors can fission and breed reprocessed plutonium, they could cut the need for HALEU in half, says Huff.

Fast reactors and reprocessing could reduce by 90% the volume of nuclear waste that will need to be stored in a geological repository for tens of thousands of years, according to Huff. It could cut by a similar fraction the amount of long-term radiation from the spent fuel by transmuting the actinides. But a 1996 report from the National Research Council concluded that the rate at which actinides can be fissioned is so slow that it could take hundreds or even thousands of years of continuous reprocessing and recycling to make a meaningful reduction in the total amount of waste.



The Experimental Breeder Reactor-II at Idaho National Laboratory operated from 1964 to 1994. The sodium-cooled fast test reactor inspired Oklo's planned Aurora fast reactor, which the company plans to commission at the Idaho laboratory by 2027. Aurora will get its initial fuel load from the reprocessed spent fuel of the now-decommissioned reactor.

"DOE is in the difficult position of trying to justify its call for a huge expansion of nuclear power when the US is unable to move forward with a program to dispose of the nuclear waste that has already been generated," says Edwin Lyman, director of nuclear power safety at the Union of Concerned Scientists.

Matzkin-Bridger notes that reprocessing also produces a much larger volume of low-level waste—items that are contaminated with radioactive material or that become radioactive through exposure to neutron radiation—and creates several new waste streams. "Reprocessing is not an answer to the spent-fuel challenge," he says.

A closed fuel cycle

Since the initial 1977 ban, US reprocessing policy has seesawed through successive administrations. Republican administrations have been mostly supportive of reprocessing, while Democratic presidents have favored continuation of the prohibition. Ronald Reagan removed the ban, but without government subsidies, there was no commercial interest, and US nuclear utilities opted for a spent-fuel repository that remains to be built. Bill Clinton reinstituted the moratorium, and George W. Bush proposed the Global Nuclear Energy Partnership, a multinational program that included building fast reactors and reprocessing plants in the US, Russia, and other nuclear weapons states. Congress declined to fund the program, and Barack Obama reinstituted the reprocessing ban shortly after entering office.

Reprocessing is integral to the business plans of some advanced-reactor developers. One, Oklo, plans to build a liquid-metal-cooled fast reactor it calls Aurora at the Idaho National Laboratory site by 2027. The lab has agreed to provide the Santa Clara, California–based company with Aurora's initial fuel load, supplied from the reprocessed waste from a decommissioned experimental fast reactor at the lab site. Oklo is preparing to reapply for a license to build and operate Aurora after the Nuclear Regulatory Commission turned down its initial application in January 2022.

"Our business model involves setting up our own fuel cycle to supply reactors," an Oklo spokesperson said in written responses to questions. "By efficiently utilizing recycled fuel, our advanced fuel recycling process contributes to reducing and ultimately eliminating plutonium." The spokesperson added that the use of recycled fuel for Aurora can be done safely and economically within the existing US policy framework.

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Oklo has received at least $15 million from DOE to develop its reprocessing technology. That includes an October 2022 award of $4 million from one of two programs of DOE's Advanced Research Projects Agency–Energy (ARPA–E) that support reprocessing R&D and other spent-fuel management technologies. Initiated during the current administration, the ARPA–E programs have dispensed a total of $74 million to 19 companies, universities, and national laboratories to date.

The technology used in existing commercial reprocessing plants is an aqueous method known as plutonium–uranium extraction (PUREX). The US developed PUREX during the Cold War nuclear weapons buildup. Even proponents of reprocessing acknowledge that PUREX presents an unacceptable proliferation risk. India's first atomic test in 1974 was with plutonium clandestinely extracted using the PUREX process. The US provided technical assistance to build that supposedly civilian facility.

Most alternative reprocessing technologies in development today are based on electrometallurgical separation techniques, which aim to increase proliferation resistance by keeping other waste elements mixed with plutonium. That's the approach being followed by Oklo. But other technologies are also being explored. TerraPower, developer of the Natrium fast reactor, has received $8.6 million, the largest grant from one of the ARPA–E programs, to mature a process that exploits the volatility of chloride salts at high temperatures to recover uranium from spent fuel.

Shine Technologies, a Wisconsin company, proposes to build a standalone commercial reprocessing facility in the state to treat spent fuel from nuclear utilities. CEO Greg Piefer says the plant will likely incorporate an aqueous separation process. "It's not just about recycling plutonium because there's a tremendous amount of other valuable isotopes in the waste stream that are beneficial to humans," he says. Separating those, he continues, "is much more easily done with an aqueous stream."

Ross Radel, Shine's chief technology officer, says its separated product will be a 5:1 uranium–plutonium mixture, similar to MOX fuel.

Opponents of reprocessing argue that alternative separation processes would only delay the time required to render the plutonium usable for a weapon. A nation aspiring to produce nuclear weapons could further purify plutonium by tweaking the newly developed technologies, notes Fetter.

One 2009 evaluation of alternative reprocessing technologies by researchers from six national laboratories found only a modest improvement in reducing proliferation risk over existing PUREX technologies, and those modest improvements applied primarily to subnational groups, such as terrorists.

Two attempts at commercial reprocessing in the US failed. A plant in West Valley, New York, reprocessed spent fuel for six years before closing in 1972. Looking to expand the plant, the owners balked at the costs required for upgrades needed to meet new regulatory standards. Construction of a reprocessing plant in Barnwell, South Carolina, was halted in 1977 following the Carter administration's ban.

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